28th INTERNATIONAL CONFERENCE ON
PRINTING, DESIGN AND GRAPHIC COMMUNICATION

BLAŽ BAROMIĆ

Proceedings

8th – 9th May 2025, Zagreb, Croatia

2025

8th-9th May 2025, Zagreb, Croatia

28th International Conference on Printing, Design and Graphic Communication

PUBLISHER

University of Zagreb Faculty of Graphic Arts, Zagreb, Croatia

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ISSN: 3102-2324 (Online)

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FOREWORD

Dear readers,

Welcome to the Proceedings of the 28th International Conference on Printing, Design and Graphic Communication BLAŽ BAROMIĆ 2025 (PDC BLAŽ BAROMIĆ 2025), organized by the University of Zagreb Faculty of Graphic Arts, taking place on May 8 and 9, 2025. The Conference highlights the latest scientific and professional achievements in graphic engineering, design, and visual communications, with a special emphasis on interdisciplinary research and the application of contemporary technologies.

This conference gathered together experts, researchers, and practitioners from graphic technology, packaging, multimedia, and visual communication to exchange the latest scientific findings and professional experiences.

Contributions from authors across multiple countries demonstrate the Conference's international scope and foster the development of future collaborations and partnerships. In an era of rapid technological change and increasingly complex media landscapes, an interdisciplinary approach is essential for understanding and shaping the future of visual culture and industry. Participants explore innovative technologies, research projects, and initiatives that are shaping our daily lives—from digital media and virtual reality to artificial intelligence, sustainable materials, circular design, and education.

The Conference also supports young researchers through activities in the Doctoral school, encourages the exchange of ideas, and enables the formation of collaborations that strengthen the global professional community. In addition, the program includes an International Student Exhibition and the Graphic Product Contest, celebrating emerging talent and creativity.

May these Proceedings serve as a lasting record of the presented research, as well as a source of inspiration for further exploration, innovation, and responsible action in the fields of design and communication. We proudly emphasise the importance of collective effort, knowledge sharing, and creativity in shaping a sustainable and innovative future.

We extend our sincere thanks to all authors, reviewers, and participants whose contributions have made this Conference possible.

Editor

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INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

INVITED LECTURE

INOVATIONS YOU CAN FEEL: THE IMPACT OF MULTISENSORY PRINTING DESIGN

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ABSTRACT

In the broad field of communication, the role of multisensory printing technologies is becoming a central element in the design of interactions that transcend traditional visual boundaries. The paper shows how extensive knowledge of graphic prepress and printing techniques can revolutionise the way we interact with printed materials.
Through the detailed exploration of different printing techniques and the innovative integration of sensory elements such as scent and sound, this approach expands the communicative possibilities of print media. These technologies are carefully utilised to create printed materials that not only appeal to multiple senses but also ensure accessibility and enhanced interaction for a wide audience, including people with sensory impairments.
The focus is on the rigorous prepress processes that are essential to the accurate and effective reproduction of graphic content, preparing materials to convey information in new and meaningful ways. This preparation includes sophisticated design and layout adjustments, precise colour management and the careful selection of materials and inks to create tactile, auditory and olfactory elements that complement the visual aspects.
By presenting successful applications and technological advances, we emphasise the transformative impact of integrating multisensory elements into printing. These innovations not only cater to the needs of different users but also enrich the sensory experience for all by redefining the boundaries of printed communication and setting new standards for inclusion and engagement.

Keywords: printing, design, printing form, optical methods.

1. INTRODUCTION

In today's rapidly changing graphic communication landscape, advances in print technology are not only refining traditional techniques but also changing the way we interact with media in a multisensory world. This paper explores how cutting-edge print processes are incorporating tactile, auditory and even olfactory dimensions, extending the communicative power of print beyond the visual. This development reflects a broader shift in communication practise where dynamic, multimodal experiences such as image-audio combinations and interactive touch elements are becoming the norm.
Modern communication is characterised by its depth and diversity. It goes far beyond simple, text-based exchange and includes multisensory interactions with images, sounds and physical engagement. These diverse forms of expression are designed to appeal to a global audience with a variety of sensory needs and preferences. Recognising this diversity, the European Union [1–3] has introduced strict regulations to ensure that everyone – regardless of their sensory abilities – has access to comparable experiences. These regulations require communication materials to include features tailored to the needs of vulnerable groups such as the blind, visually impaired, dyslexic or colour-blind.
Through advanced graphic prepress techniques and the latest technological innovations, our approach to multisensory printing not only fulfils the new communication standards

but also contributes to their design. Features such as fragrances, sounds and enhanced tactile textures are now seamlessly woven into everyday print materials. These sensory elements are designed to provide an experience that goes beyond the visual, engaging multiple senses and opening new levels of interaction and expression in print media.

1.1. Multisensory design principles

Designing multisensory experiences goes far beyond combining image and sound – it requires a holistic approach that integrates a wide range of materials, methods and technologies. These strategies are carefully crafted to achieve specific goals, such as increasing user engagement in educational settings through interactive learning environments, creating emotional connections in marketing campaigns by evoking nostalgia or excitement through sensory elements, improving accessibility for people with sensory impairments by designing experiences tailored to different needs, or perhaps even promoting relaxation and well-being in therapeutic contexts through soothing soundscapes and visual stimuli. They are based on a deep understanding of how people perceive, process and respond emotionally to sensory input.
Multisensory experiences also go beyond the basic, physical senses – seeing with the eyes, tasting with the tongue, hearing with the ears, touching with the skin and smelling with the nose. Contemporary phenomenological research suggests that "seeing" is not limited to visual input but also includes contextual awareness and deeper cognitive processes such as intuition and mental imagery (Figure 1). This broader understanding applies to all senses, with the thoughtful integration of visual, auditory and interactive elements playing a key role in designing immersive and meaningful user experiences. [4, 5]

Figure 1: Multisensory design principles

The surface level – where users interact directly with a product – marks the pinnacle of experience design. It reflects the outcome of the previous phases, including strategic planning, structural organisation and the basic framework. For the experience to be effective, this layer must integrate seamlessly with the underlying components and ensure that the message is clearly communicated, and the user is fully engaged. [6–8]

2. ADVANCEMENTS IN GRAPHIC PREPRESS AND PRINTING TECHNOLOGY

2.1. Novelties in graphic prepress

Graphic prepress has evolved rapidly in recent years. The evolution was driven by the integration of digital automation, colour science, artificial intelligence (AI) and the growing demands for accessibility and personalisation. These innovations have redefined prepress – not just as a technical step in production, but as a strategic, creative and highly adaptable process.

One of the most important advances in recent years has been the integration of AI and machine learning into prepress workflows. AI-driven tools can now automatically detect image errors, correct colour imbalances, adjust resolution, optimise layouts for different formats and even detect accessibility issues such as low colour contrast. These intelligent systems significantly reduce human error and production time, allowing large print runs to be customised and personalised with greater efficiency.

Cloud platforms such as Adobe Creative Cloud, Enfocus Switch, callas pdfToolbox and Kodak PRINERGY On Demand enable the seamless integration of prepress tasks – such as file preflighting, proofing, imposition and design versioning – across teams in different locations. This not only improves collaboration, but also ensures consistent and accurate file preparation, especially for hybrid projects that include both print and digital formats.

The growth of data-driven print marketing has led to major advances in variable data printing (VDP) and content versioning tools. Today's prepress systems can automatically generate thousands of personalised outputs – from multilingual documents to custom names, images and dynamic layouts – while ensuring consistent colour fidelity and print quality across all versions.

Modern prepress workflows use spectral colour measurement and advanced gamut profiling – such as 7-colour extended gamut systems – to achieve greater colour accuracy and consistency across different substrates and printing technologies. Tools such as GMG OpenColor and EFI Fiery provide precise control over spot colour reproduction and ensure reliable colour consistency, especially in packaging applications.

As inclusive design continues to grow in importance, prepress systems are increasingly equipped with tools that evaluate and improve the accessibility of content. These tools can assess the legibility of fonts, ensure appropriate contrast ratios, check font selection for readers with dyslexia and optimise file structures for compatibility with screen readers or tactile formats.

Today, a modern graphic prepress software offers support for 3D modelling and visualisation, especially for printed packaging, labels and tactile graphics. These features allow designers to preview textures, depths, embossing and finishing effects – such as varnish, foil or raised ink – before production begins. Such tools are particularly valuable for multisensory printing, which supports applications such as tactile maps, Braille publications and interactive packaging.

Prepress also plays a leading role in promoting sustainable design. Modern tools help to optimise ink consumption, minimise waste through intelligent nesting and imposition algorithms and enable soft proofing to reduce reliance on physical materials. File preparation today typically includes the creation of eco-profiles tailored to the different printing systems, supporting efforts to reduce the carbon footprint throughout the print production lifecycle.

These advances in graphic prepress not only streamline production and improve output quality, but also redefine the possibilities of print as a multisensory, inclusive and environmentally conscious medium. As print technologies continue to evolve, prepress remains an important bridge between creative vision and precise technical execution, shaping the future of print communication.

2.2. Novelties in graphic printing technology

Recent advances in graphic technology have significantly expanded the capabilities of modern printing systems. Today's technologies are no longer limited to putting ink on paper, but enable the creation of multisensory, interactive, sustainable and highly personalised outputs – that meet changing design, communication and accessibility requirements. State-of-the-art digital printing systems deliver high-resolution output, reliable colour consistency and fast turnaround times. With features such as VDP, the ability to print with white ink and compatibility with a wide range of substrates, they are perfect for short run, personalised and on-demand production across all graphic arts industries – from publishing to packaging.
UV and LED UV curing have transformed both sheetfed and web printing by enabling instant ink curing, lower energy consumption and better compatibility with different materials. These technologies can also be used to achieve high gloss, raised and textured effects – ideal for tactile designs, luxury packaging and multisensory printing applications.
3D printing goes beyond traditional print formats and enables the production of tactile and structural elements used in education, museums and accessible design. Emerging 4D printing technologies – where printed materials change shape or properties in response to environmental factors such as heat, humidity or light – are opening new doors for dynamic, interactive communication tools and sensory experiences.
Innovations in ink formulation have paved the way for functional inks, including thermochromic, photochromic, conductive and microencapsulated fragrance inks. These advanced materials are increasingly being used for packaging, branding and tactile printing to introduce interactive and informative elements. Coatings based on microcapsules, for example, release fragrances when touched and add a rich, sensory dimension to the print. Today, modern technologies enable the precise digital application of foils, varnishes and embossing effects – so you no longer need conventional cutting dies. These embellishments can be customised in each run and offer significant benefits for brand identity, accessibility (e.g. raised tactile elements) and visually appealing design.

Hybrid printing systems combine digital and conventional technologies – such as offset and flexo printing - in a single production line and enable print service providers to utilise the strengths of both processes. This integration makes it possible to switch between static and dynamic content in real time, maintain efficient production over long periods of time and process a variety of materials with greater flexibility.
Sustainability focussed innovations in graphic technology promote the use of biodegradable or recyclable substrates, low VOC inks and energy-efficient production methods. Techniques such as waterless offset printing, bio-based UV inks and environmentally friendly paper alternatives – such as stone or grass paper are becoming increasingly popular to meet environmental standards without compromising print quality.
Machine vision (image processing) systems and AI-driven quality control systems are increasingly being integrated into modern presses to detect defects, ensure colour accuracy and fine-tune print parameters in real time. These technologies increase reliability, minimise waste and support zero-defect environments – crucial for high-precision areas such as packaging and security printing.
Today's advances in graphic technology are transforming print into a medium that is not only visually sophisticated, but also interactive, inclusive and environmentally conscious. As the boundaries between physical and digital media continue to blur, graphic technology is redefining the way we experience printed communication – engaging the senses of sight, touch, hearing and even smell in entirely new ways.
In today's digitised and automated world, graphic technology has evolved into a cutting-edge, interdisciplinary field driven by advanced software, AI driven systems and

precision engineering. The industry is no longer considered "dirty work"," but combines creativity with innovation, sustainability and smart manufacturing. This shift emphasises the need to promote technological literacy and spark the interest of current and future students. It is important to inspire curiosity and appreciation for this dynamic field – not only to ensure its continued relevance, but also to empower the next generation of professionals to shape the future of visual communication with smart tools and forward-thinking processes.

3. FROM THEORY TO PRACTICE

Building on the technological and conceptual developments explored in this paper, we have moved from theory to practise through a series of application projects. These initiatives were not only educational, but also research-led design experiments. They utilised advanced graphic prepress techniques and cutting-edge print technologies to create meaningful, multisensory experiences tailored to specific user groups.

One of the first project was a tactile picture book for children entitled Kiki the Mouse Fell into the Pantry, which is suitable for blind and visually impaired readers as well as sighted readers. To bring this inclusive vision to life, flexo and screen printing techniques were purposefully combined, resulting in vibrant, touch-responsive illustrations and text. In addition to braille and large print formats, specially developed screen printing inks were used – that contained expanding microcapsules with different fragrances to appeal to children's sense of smell and enhance the content. This innovative blend of techniques resulted in a rich, multisensory reading experience that allowed children to connect with the story not only visually or through the text, but also through touch and scent – making the book even more engaging, intense and memorable.

The second project, entitled The Tactile Wall Story – The Magical Journey of Girl Ada and Dog Beni, was a large-scale, multisensory installation for the staircase of the Centre IRIS – Centre for Education, Rehabilitation, Inclusion and Counselling for the Blind and Partially Sighted in Ljubljana. The installation was designed to transform a typically overlooked transitional space into a vibrant, interactive learning environment.

By combining printed visual backgrounds, tactile elements, soundscapes and educational games, the project provided a unified narrative experience. A sophisticated prepress workflow allowed for the inclusion of braille, large Latin letters and tactile graphics created from high-resolution vector illustrations and overlaid file formats. Production used both UV inkjet and screen printing techniques on a variety of materials including wood, textiles and thermoformed surfaces. Additional sensory layers – such as fragranced microcapsules and inbuilt audio components – added depth and richness to the experience. This immersive installation is an example of how graphic technologies can be used to create inclusive educational environments. Here, children are not just passive observers, but active participants in a multisensory journey that makes learning both accessible and engaging.

The third project focussed on the redesign of the Museum of Post and Telecommunications – the first fully inclusive museum renovation in Slovenia designed specifically for blind and visually impaired visitors. The initiative, which focussed on accessibility, showed how cultural institutions can effectively integrate the principles of equal opportunities. A practical guide for museum professionals, designers and technicians was developed, including detailed documentation on tactile graphic design, material selection, substrate preparation and specialised printing techniques. Using screen printing, UV curable inks and relief printing, selected exhibits were transformed into tactile models, raised maps and Braille displays. This project emphasised the important role of graphic technology in promoting the cultural participation and social inclusion that the museum strives for.

The fourth project extended this approach by adapting various works of art, animals (such

as the fauna of Postojna Cave) and everyday objects. These adaptations were created both as tactile 2D graphics and as 3D printed models developed jointly by students and researchers. Each model was carefully adapted in shape, size and level of abstraction to meet the perceptual needs of blind and visually impaired people. The aim was to translate the invisible into tangible, accessible forms so that users can explore the cultural and natural heritage through direct tactile interaction. The production process combined modern techniques such as 3D printing, digital sculpting, thermoforming and screen printing, demonstrating the diverse possibilities of modern graphic and material technologies.
Taken together, these projects show how graphic technology, when considered from an inclusive perspective, can go beyond the needs of underrepresented groups. They also enhance the expressive and communicative potential of print products for everyone. They are impressive examples of interdisciplinary collaboration and demonstrate the importance of integrating accessibility, sensory design and technological innovation for the future of design education and practise.

4. CONCLUSION

Graphic communication today has evolved into a sophisticated, multisensory and interdisciplinary field that seamlessly combines creativity and cutting-edge technology. With the advent of intelligent prepress systems, advanced materials and innovative printing techniques, modern print media appeals not only to the eyes, but also to the sense of touch, sound and even smell.
In our increasingly digital and automated world, graphic technology is being enhanced by AI, precision engineering and smart manufacturing. Far from being the "dirty job" of the past, it has evolved into a clean, modern and forward-thinking profession that is essential to delivering rich, meaningful and engaging communications.
For this dynamic field to continue to grow, it is crucial to promote technological literacy and inspire both current and future generations of students. By addressing diverse needs and promoting accessibility, we are paving the way for more inclusive, engaging and impactful communication experiences.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

INVITED LECTURE

ÉCRAN-PAPIER-ÉDITER : WEB-TO-PRINT TECHNOLOGIES

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ABSTRACT

Digital technologies have been transforming professions in the graphic design chain since they emerged: production of documents for printing, support for book design, typographic design, illustration... all these professions have been affected by the development of new tools, generally inspired by older manual techniques. Through these new digital tools, a new way of thinking has also been introduced: computing and programming are not simply the means of mimicry, but rather a new way of designing and organizing editorial and graphic workflows. Today, as a relative technical maturity is reached in graphic engineering and the industry it has made possible, a latent development that has been going on for several decades is coming to completion: the profound cross-over of editorial objects between screen and paper. Web-to-print, understood as a set of web-based technologies that enable the content of a web page to be printed on paper, is at the heart of this evolution. We would like to take a look at the challenges and effects of web-to-print through the work carried out as European cooperation project EPE (Ecran-Papier-Editer), which brings together art and design schools and engineering schools to consider the impact of web-to-print in the future professions of the graphical chain, but also to produce tools chains for graphic designers. Between screen and paper, what new opportunities and techniques are opening up at a time when the web browser has become a virtual machine?

Keywords: web-to-print, graphic design research, computed layout, open source, computer programming.

1. ABOUT GRAPHIC DESIGN ACCEPTIONS

Ecran-Papier-Editer[1] is a European cooperation project initiated by the École Supérieure d'Art et Design in Valence[2], France. Its origins lie in the recent evolution of web-to-print technologies, a term we use to describe the possibility of producing printed editorial objects from a web browser. We see web-to-print in the context of graphic design practices and the impact this technology could have on the profession of graphic designer in the near future. It seems important, in the framework of this scientific and technical conference, to first situate the type of graphic design that is considered in the Graphic Design department of Esad•Valence.

1.1. Design in art schools

Like design in general, graphic design has its origins in the industrial revolution and the assembly-line reproduction techniques it introduced, making it possible to manufacture objects in large numbers at low cost. Modernity and its impact on the environment and daily life, particularly in urban environments, have led to a significant increase in the need for visual organization of information: newspapers, magazines, advertisements, public announcements, posters for commercial or political propaganda, books and urban signage are just some of the graphic productions that involve a more global design dimension than that of the objects themselves. Consideration of the environment of visual artifacts has become an issue, in addition to their aesthetic characteristics.
This implies a certain understanding of the sociopolitical mechanisms at work in society

at the time a given graphic object is conceived, in addition to the constraints defined by the commissioner. For graphic design, therefore, it's not simply a matter of giving shape to information so that it transmits a message. It's also a matter of knowing how to organize the equivalent of a sub-text, a second possible interpretation layer. This distancing, done in articulation with the assignment, enables graphic objects to carry a certain critical dimension, to produce a discourse. In this respect, graphic design does have a certain aesthetic quality in what it produces, in a similar way to the work of artists (who produce "artworks").
This approach to graphic design as part of the practice of art, and as a means of questioning the world, is quite common among art and design schools in France and, to a certain extent, more widely in Europe. However, this critical dimension also means not forgetting the strong relationship that design has always had with technology and, by extension, with industry. It is here that the EPE project intends to position itself: the technical fact is part of design practice, and we maintain that it participates in the construction of the critical discourse that design can deliver. If we insist on this way of looking at graphic design practices, it's because one of its consequences is that we keep a certain distance from other practices, such as those of graphic design more directly attached to a certain effectiveness of the communication objects it shapes (advertising, adherence to ideas, marketing, industrial design). The aim of this article is to offer some insights, drawn from the EPE project, into the role that graphic design can assume in challenging professions in the graphic design chain, at the intersection of the arts, engineering and technology.

1.2. Graphic design and digital technics

Graphic design works in many fields and on many scales. Typeface design defines the fundamental elements of text formatting, making it possible to register discourse. These texts, which are organized within inscription spaces, are accompanied, or sometimes replaced, by images. Just as texts can be of very different natures (poetic, scientific, novelistic, descriptive, administrative, etc.), images have different origins and purposes (illustration, photography, technical diagrams, etc.). Organizing this information into coherent units is one of the missions of graphic design, and the resulting objects are designed in relation to the nature of the "content" assembled together: a long text might be presented in the form of a book, shorter and more ephemeral factual information in a poster or flyer, a regularly changing set of information in a digital medium such as a website, and so on in a wide variety of formats and techniques that we won't list here.
The "media" thereby produced are intended both to respond to an assignment and to be distributed to their target audience. This means that there are other professions involved in graphic design, both in the production of content and in the manufacturing of the objects: writer, photographer, scientist, journalist, artist, papermaker, printer, web developer, interaction designer, publisher... or perhaps we should say that graphic design is at the crossroads of all these professions. For graphic designers, it's a crucial task to know how to relate to these professions, to understand their practices, and to design their projects according to their inherent constraints. An obvious example concerns the choice of paper, ink and printing technique for a printed product: everything that makes up the physical object must be taken into account in the graphic design of the object, each technique having its own limitations.
The case of digital media is of particular interest to us here, as the design of on-screen objects, most often interactive, has become one of the skills expected of graphic designers by their clients. Recent history has shown us that computer technology and its tools have already greatly disrupted the more traditional practices of graphic design: typography, page layout, image creation and editing have been based entirely on the use of computer software dedicated to media production for several decades. What interests us here

is not the use of software to replace and enhance earlier analog, mechanical or manual techniques. It's the possibility offered by digital technologies to conceive new modes of production that we place at the heart of our research: the creation of tools for design and by design. In our view, the challenge of graphic design working with digital technologies is not to reproduce already familiar media production contexts (text, images, animations, videos) using dedicated editing tools (InDesign, Photoshop, AfterEffect or Première in the Adobe suite), but rather to invent new media enabled by the flexibility allowed by digital technology.

2. WEB-TO-PRINT?

2.1. Designing programs

In computer science, the creation of software tools requires the writing of programs. The computational potential of digital machines can only be exploited on one condition: that you write down in advance what you want these machines to do. This is an engineering skill, because computer programming is a branch of mathematics with a strong technical dimension. But as computer science evolves rapidly, programming languages have become closer to natural languages, while remaining firmly rooted in their mathematics-logic origins: the syntax of the languages must be scrupulously respected for the program to be executed, and ingenuity is required to design a program that will produce the expected results (and not something else). Today, web technologies are a little more technically accessible because they are based on interpreted languages (as opposed to compiled languages), and because of their ubiquity on screens of all sizes (computers, smartphones, smartTVs), they have also become one of the major fields of experimentation for graphic design. This has led to the emergence of several design categories: Web Design, User Interface and User Experience Design (UI/UX), and interaction design. A form of convergence between design and engineering is at work here.

2.2. The web universal machine

The Web browser is a software program designed to interpret documents made available by another software program, the server. These documents are described in specific languages and are stored on disk spaces made accessible using data transfer protocols. Using an address representing the location of the documents (URL), the browser downloads a main document described in HTML, which it interprets fragment by fragment to produce a graphic representation. HTML is a tag-based language that defines the organization of the elements making up the document (header, body, titles, sections, divisions, etc.). It can also be used to call up other files using complementary languages, such as CSS, which defines the graphic style of page elements (colors, fonts, spatial organization, animated transition effects, etc.), and JavaScript, a scripting programming language that defines the behavior of the page itself and its elements (elements, styles, external resources). This software stack was originally designed to display information within an operating system window, i.e. on a screen. However, many of the notions used in HTML specifications originate from the world of print, starting with the very notion of document. One might then see a kind of contradiction if web documents can't be printed, or at least not properly.
In practice, it has always been possible to print a web page, but what is then produced is merely an automatic and often clumsy migration to paper of the document in the same format as it appears in the browser window. In other words, there is no adaptation of content to the destination printing format. However, this concept of adaptation to the target medium does exist on the web, the most obvious use case being the transition from one screen size to another, for example between a computer screen and that of a smartphone.

So-called responsive design has been implemented in the CSS language through media queries[3]. Initially designed primarily for layout variations between screens of different dimensions, media queries enable the application of certain style rules only if the chosen media meets certain specified characteristics (e.g.: if the screen is less than 320 pixels wide, then a particular group of elements will be arranged vertically rather than horizontally). The ability to define rules for a particular type of print media was then introduced, to separate styles intended for screens from those intended for print, with its associated rule, @page, which defines the behavior of elements on the current page when printed.

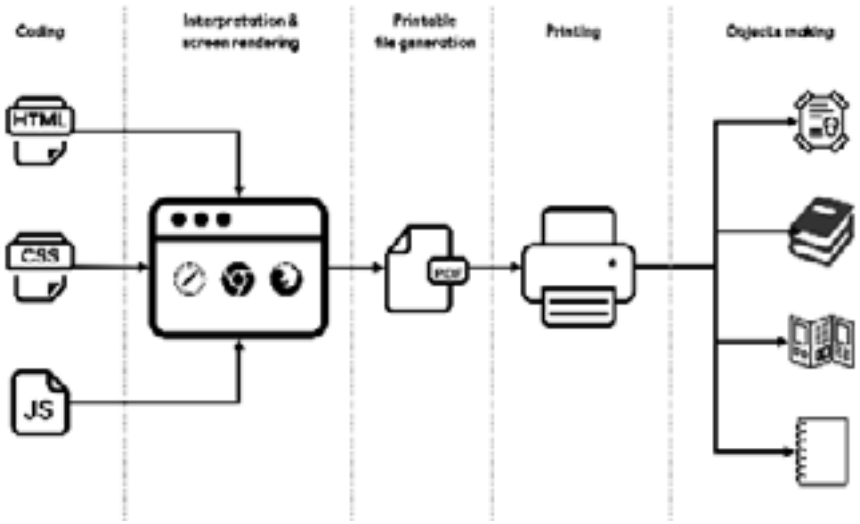

Figure 1: Web-to-print scheme: from web browser to printed object

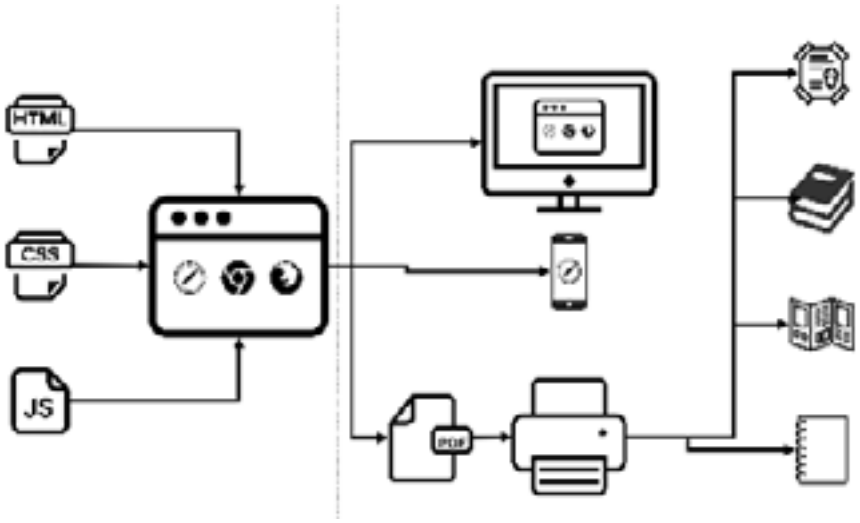

Figure 2: Web-to-print scheme: from web browser to multiple output format, printed objects and digital displays

This apparently straightforward possibility is of major interest to graphic design, as it presupposes that it is possible to use the entire range of web technologies to design printed works directly from the browser. This opens the door to a vast amount of experimentation that has the potential to profoundly transform the methodologies currently used in the graphics chain.

3. EPE PROJECT MAIN FOCUSES

3.1. Specifications versus implementation

One of the cruel realities of software development is the speed at which software technologies appear and disappear, and the difference in pace between the definition of specifications for certain functionalities and their actual implementation. Specifications make it possible to define with great precision the principles of a technique and the results it should produce. In the case of the @page rule and its derivatives, the specifications have been in draft form since 2013 under the title "CSS Paged Media"[4]. At the time we were writing the EPE project for submission to Europe Creative, in 2023, the first specifications were already 10 years old, and yet almost none of them had been implemented in the major web browsers on the market (Chrome and all Chromium derivatives, Safari and Firefox). Despite a degree of evolution in the specifications, the absence of actual implementation in browsers meant that any experimentation under real conditions was postponed to a hypothetical future, making the great potential opened up by Paged Media a dream as distant as it was uncertain.

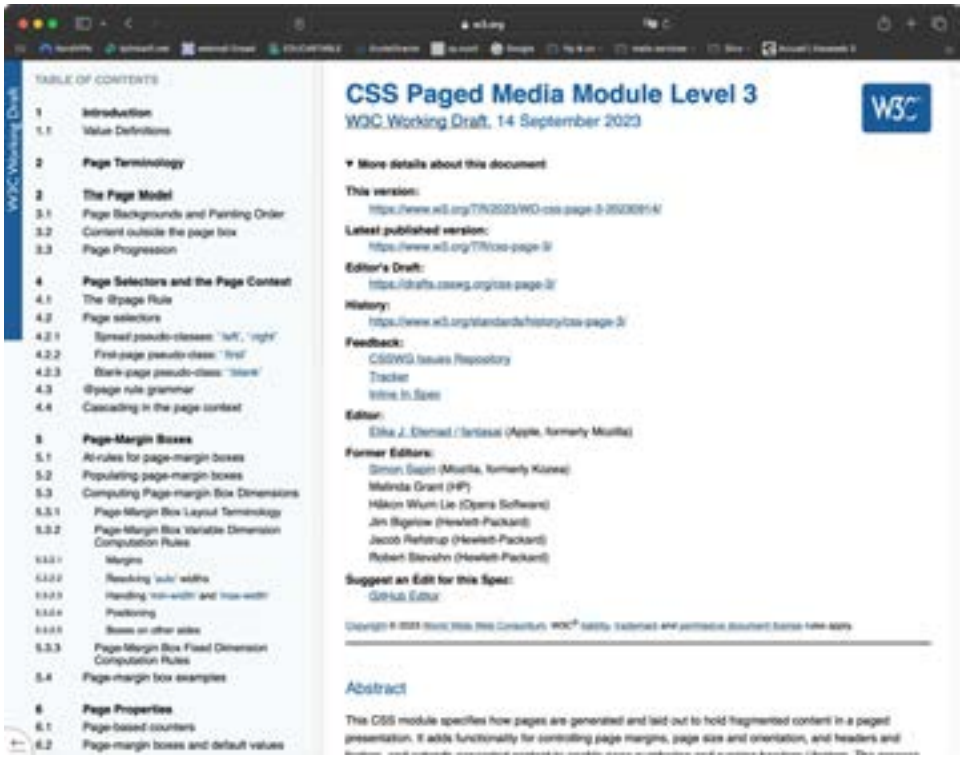

Figure 3: CSS Paged Media Module Level 3 [https://www.w3.org/TR/css-page-3]

A group of enthusiasts (the Coko Foundation[5]) then decided to implement a polyfill of the Paged Media specification, i.e. a software library that enables "replication of an API using JavaScript when the browser doesn't have it natively". Named Paged.js[6], and released under an open-source license, this library paved the way for numerous experiments, from which we were able to build the EPE project. As a small-scale cooperation project under the scientific responsibility of Esad-Valence for a period of 2 years (2023-2025), Ecran-Papier-Editer brings together institutions of higher education, Faculty of Graphic Arts of Zagreb (the very location of this conference), Izmir University of Economics Visual Communication Department (Turkey), Sfax University – Institut Supérieur des Arts

et Métiers, center 4C (Tunisia), INP-Pagora International school of paper, print media and biomaterials (Grenoble), as well as a national theater, the Hexagone theater. The project has three main pillars: education, technology and research.

3.2. Education

We are convinced that the profession of graphic designer is constantly evolving, and that web-to-print is going to disrupt publishing practices. It is therefore essential to ensure a certain transmission of the knowledge that future professionals will need to be actively involved in designing the new editorial chains that web-to-print makes possible. EPE offers workshops bringing together professors and students from the consortium's member schools and universities. Three phases have been designed. Propagation, to introduce web-to-print technologies and collectively explore their potential; Prototyping, to implement these technologies in the design of new tool chains and new editorial principles; Production, which proposes that Théâtre Hexagone set up a specific editorial chain to promote the artist residencies organized by its team, in other words, an experimental production on a scale of 1 in a real context.

3.3. Technology

Web-to-print tools are still fragile. Paged.js is one of the major technical elements we've used to design editorial chains requiring automatic pagination. Distributed under a free and open-source license, Paged.js, like all software tools based on a similar development model, needs support to be maintained and evolve. EPE therefore contributes to its development. But we're also looking at the entire editorial object production chain. We are particularly interested in the current limits of web-to-print chains for industrial printing: if professionals are still unable to move away from hegemonic tools such as InDesign, it's because printing standards are not currently respected by web-to-print, such as conversion between RGB and CMYK of PDFs produced by browsers, but also the ability to easily and precisely manage the separation of color layers in direct tones or the screening to be used. We propose concrete software solutions to resolve these difficulties.

3.4. Recherche

The fundamentally interdisciplinary nature of EPE's work naturally drives us to structure the project according to research methods. In this case, the development of certain tools requires close collaboration between expertise in graphic design, computer science and printing systems engineering. But more general issues also came to the surface, concerning the content management methods used to produce hybrid publications, and their possible forms on screen and on paper.

4. SOME EXEMPLES

To illustrate a part of our approach in the EPE project, we would like to present a few projects realized during the series of workshops that were organized. The first was produced at the Faculty of Graphic Arts in Zagreb during the second workshop, in March 2024. A group of 5 students from Esad-Valence travelled to Zagreb for this occasion, each forming a duo with one of the 5 FGA students. The aim of this workshop, part of the Propagation phase, was to create a booklet using Paged.js, based on text and image content prepared before the workshop, and for some of the groups to develop an original screen proposal based on the same content. One of the groups, formed by Maïssane Escur (Esad-V) and Ema Lovrić (FGA), worked on content dealing with the history of packaging in Croatia. The texts and images, collected from various online sources and compiled into a docx

document, were first reformatted in Markdown (md), a popular lightweight markup language that can be seen as a highly simplified form of HTML. Using markdown-it[7], an open-source JavaScript library, md files are converted on the fly into valid HTML elements, generating two distinct objects.
The first is a 38-page A5 booklet, entirely layouted using CSS and Paged.js. The meticulous work carried out revealed certain difficulties linked to the management of document sections and the management of certain object positioning properties (chapter heading pages, page breaks, etc.), as well as the many advantages of such a technique: when technical knowledge is sufficient, a booklet showing good graphic quality can be produced with these technologies, avoiding the need to use software such as InDesign.

Figure 4: Booklet PDF screenshot made by Maïssane Escur (Esad•V) and Ema Lovrić (FGA) during the second EPE workshop (2024) in the Faculty of Graphic Arts of Zagreb, about packaging design in Croatia

The second is a website organizing the four chapters in a grid of four zones, each displaying a chapter title and summary. By clicking on one of the zones, the opposite half of the window changes to show the corresponding text, but in a different layout to that of the printed booklet, navigable by scrolling. Clicking on any part of this text populates a table of contents displayed in the remaining area: the user selects the paragraphs to be added to the table of contents in the background. Clicking on the "preview for print" button displays a preview of a booklet composed of all the elements selected by the user during consultation, respecting the graphic choices of the 38-page booklet produced separately. The aim here was to prototype an interactive booklet composition system, to be printed out by the user and composed of the elements chosen voluntarily, in order to avoid printing a complete document in which only a few parts would be of interest. So, to a certain extent, it's an eco-responsible approach: if reading is more pleasant on printed media, it's possible to limit the amount of paper we use when only a few parts of a potentially very large set of online contents seem relevant to us.

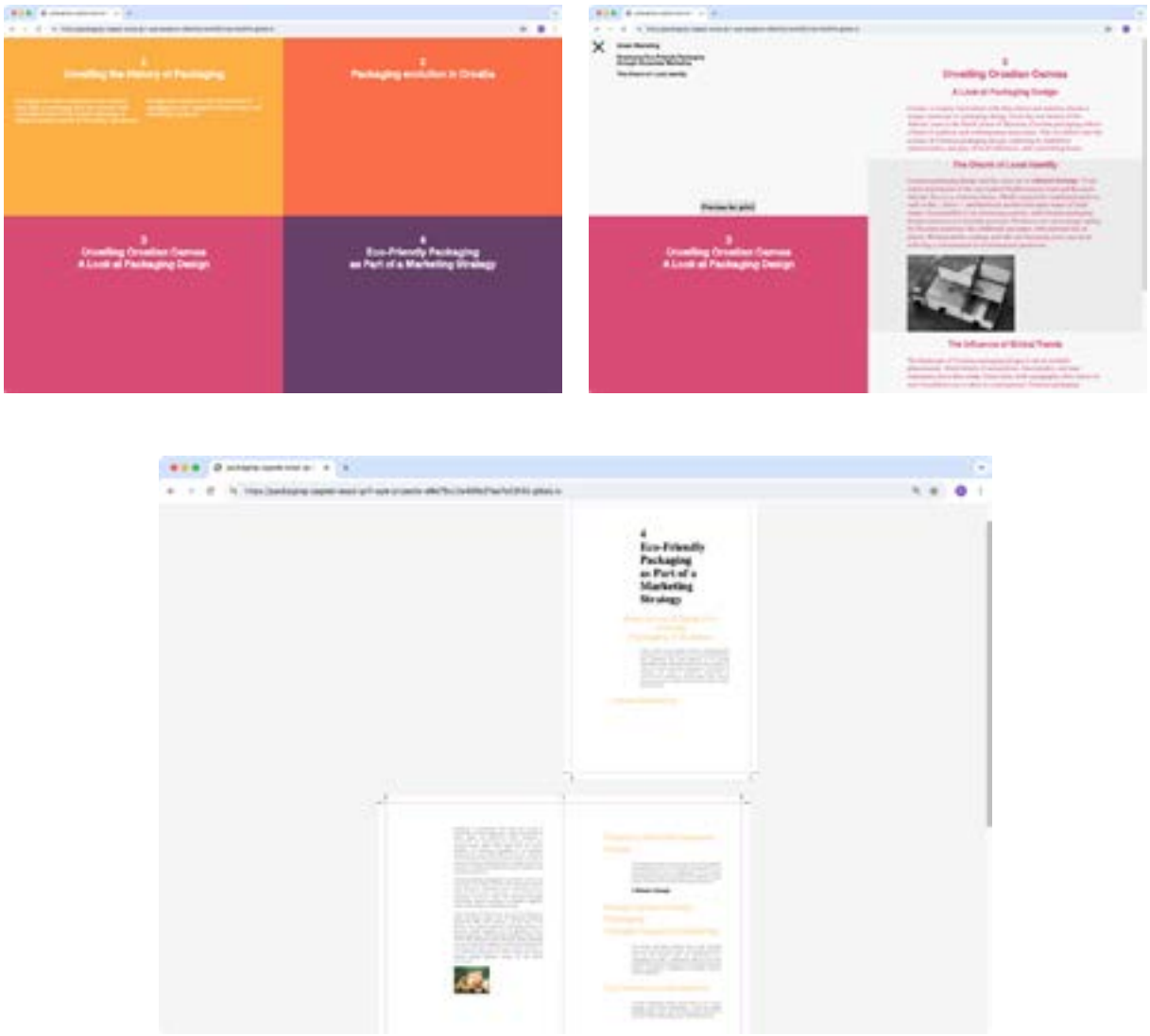

Figure 5: Screenshots of the website version made for the project of Maïssane Escur (Esad•V) and Ema Lovrić (FGA). The last screenshot shows the result after the user selection of the paragraph to be printed. [https://packaging-zagreb-esad-gv1-epe-projects-d9e75cc3e40fb37aa7e02f43.gitlab.io/. 2024.]

This process was followed up by a workshop at Izmir University of Economics in May 2024. For this third and final workshop in the Propagation phase, all five student duos were asked to produce printable website projects. Maïssane Escur and Dilara Sirkeci (Izmir) worked on a prototype presenting a scientific text dealing with semiotics in relation to drawing and design (Drawing, Design and Semiotics, Clive Ashwin,Design Issues, Autumn, 1984, Vol. 1, No. 2 Autumn, 1984, pp. 42-52, MIT Press). The web page presents text in paragraphs that are obviously independent of each other on the page, as they appear in an animation starting from the outer areas of the page, as the reader scrolls down. Here again, paragraphs can be selected, but this time it's not the paragraphs themselves that are stored in memory to form a printable publication, but content linked to these paragraphs: images from the original article or other proposals selected by the students, as well as fragments of another scientific text written in Turkish and offering an echo to the article written in English.

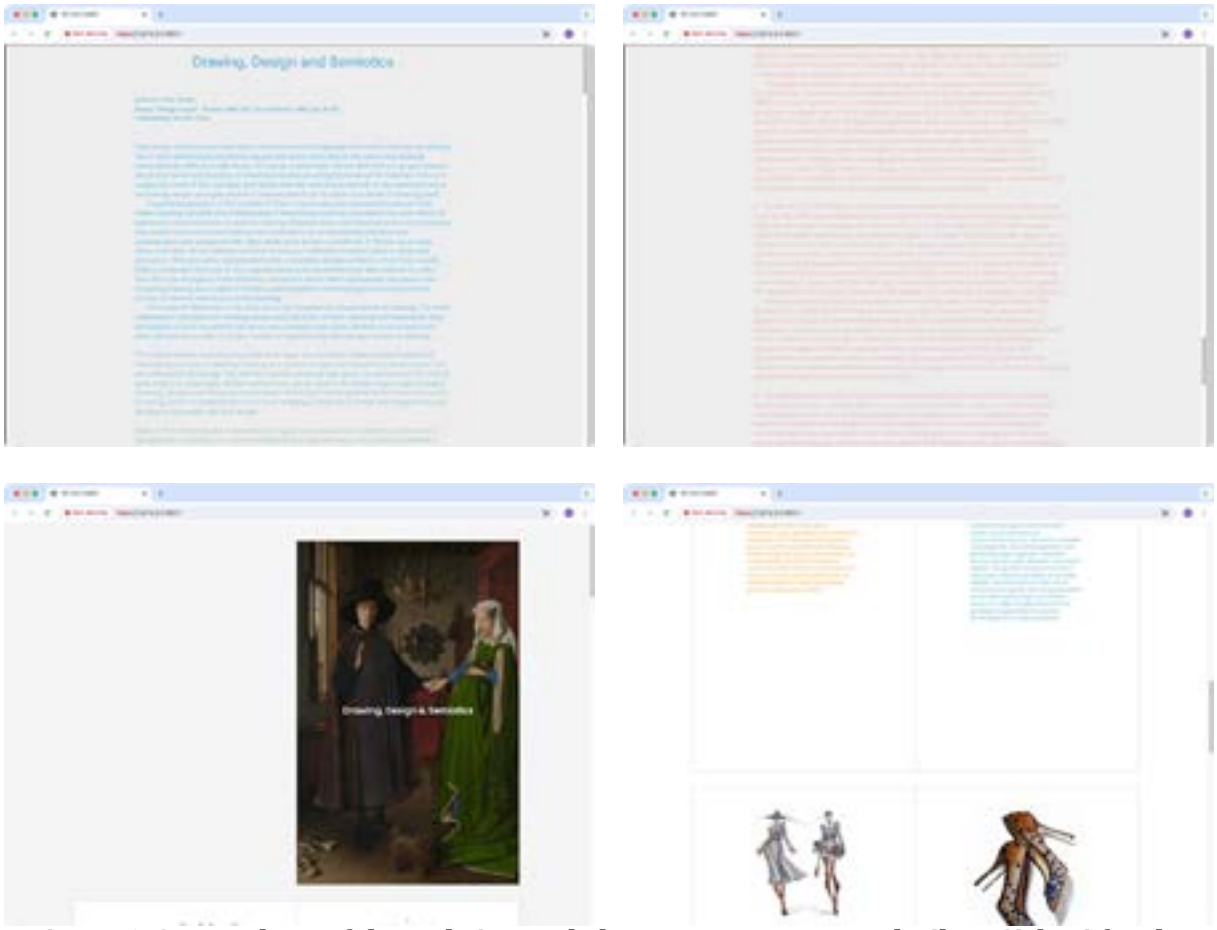

Figure 6: Screenshots of the website made by Maïssane Escur and Dilara Sirkeci for the EPE workshop in Izmir University of Economy, VDC. [https://dds-izmir-esad-gv1-epe-projects-15b21b32d9330ca9cbc7d04d5e9676a.gitlab.io/. 2024]

About 25 projects were completed over the course of the 5 workshops covering the Propagation and Prototyping phases of the EPE project (at the time of writing, the last workshop, covering the Production phase, is in active preparation). Entering into the details of these projects would reveal numerous directions for research, ranging from writing environments for authors to image screening systems before printing, as well as hypotheses for workflows and various methodologies between all the parties involved in the graphics chain. Such a study cannot be proposed within the limits of this article, so we prefer to formulate a number of observations and open the debate on the basis of our experience for the last part that concludes this text.

5. SOME STATEMENTS TO TAKE FROM EPE

By bringing together professionals and students from the fields of graphic design, visual communications, software engineering, papermaking and printing systems, the EPE project and the experiments it has enabled in the exploration of new tool chains for the publishing industry demonstrate the interdisciplinary nature of graphic chain professions. The diagram below provides a non-exhaustive overview of the special role played by graphic design in the web-to-print era.

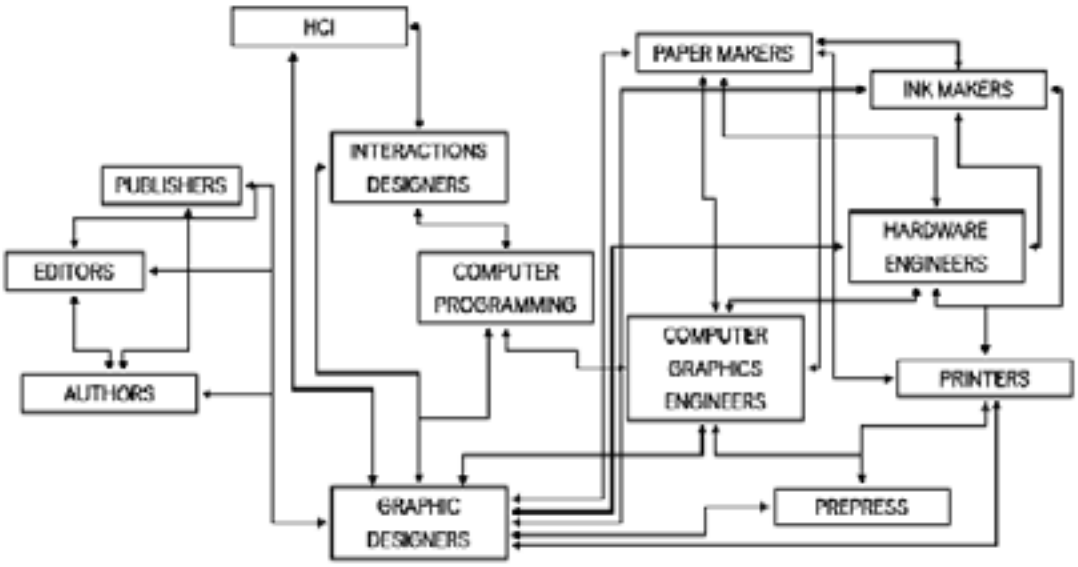

Figure 7: Relationship graph of professions in the graphics chain we deduce from the EPE projects

Based on this evidence, which we have been able to confirm in the fields of pedagogy, technology engineering and research, we would like to outline a few general positioning statements that the EPE project enables us to make.

5.1. New media art & design

As we briefly pointed out in the introduction, digital technologies make it possible to reproduce existing media. Most production software (DTP) clearly demonstrates this. The simple example of digital images confirms this: they are made up of a set of data discretized into fundamental units, colored dots, organized in a regular two-dimensional grid. This organization of digital data responds to a pre-existing model that originated in the history of images, from painting to photography, and which postulates the idea that an image is a two-dimensional object that we observe frontally. Digital videos, sounds and documents share this genesis, linked to the history and form of pre-digital media. However, a different attitude is possible: that of inventing new media thanks to the potential of the digital. This is what new media art does, proposing new media forms and, in the process, redefining the very functions of digital technologies. That's the attitude we claim to represent.

We should not forget that the word technology, in its etymology, refers to the science of technique. Technique can be seen as a set of gestures and manipulations of materials that make it possible to produce artifacts. Technique is therefore essential to the practice of art, since it enables us to give form to objects that will incorporate artistic intentions. The arts, of which design is also a part, as we explained in the introduction, aim to release what we call aesthetic artefacts, capable of producing a critical perception of the world. The aim of an aesthetic artefact is to reach out to the senses of its recipient, and thus touch their emotions and intellect. In other words, works of art are intended to stimulate reflection by formulating questions through objects. In this context, design can be understood as a set of tools for designing and producing aesthetic objects in a methodical way, in response to needs identified in projects or assignments. In a similar way, engineering enables the design and production of technical artifacts, such as tools or machines, which provide

solutions to identified problems. It's clear, then, that design lies at the intersection of the arts, engineering and technology.

5.2. Designing tools, tools for design

Our research thus always comes back to the same statement: the tools of design are correlated with the design of tools. It is through the activity of creation that we are brought to think about the tools of creation. Because contemporary creation, in the broadest sense, is increasingly based on digital technologies, it's by designing the tools of creation with technologies that we fully embrace our epoch. In other words, we support the idea that it is only through technique that we can (re)take power over technologies and create with them in a state of awareness of their potential. This mindset is at the origin of the EPE project and underpins its interdisciplinary approach. A similar mindset can be found in the STEAM (Science, Technology, Engineering, Art & Mathematics) educational method.
This method is an evolution of a previous one, STEM (Science, Technology, Engineering & Mathematics), which promotes the linking of scientific disciplines very early on in the school curriculum (elementary school), emphasizing the importance of their interaction. The motivation behind this link-up is essentially the expectation that it will produce more open-minded and agile individuals, able to cope with the growing complexity of our contemporary societies, governed by digital technologies and largely organized around often opaque algorithmic systems. But there was another essential skill: critical thinking, which enables us to reconsider the reality we live in, and to imagine alternative forms, possibly breaking with what already exists. The arts were then introduced into these educational models to fill this gap. These educational models, that were modeled by research, are making their way into higher education, because it's an increasingly asserted necessity: our future cannot rely on individuals who reproduce a siloed system of thinking, separating knowledge from each other in non-porous (and therefore, non-curious) disciplines.
Today, at a time when AI technologies are casting doubt on entire sectors of our society, this interdisciplinarity, which focuses on the development of critical thinking and its articulation with the exact sciences and engineering, needs to be joined by design to arrive at a STEAM+D model.

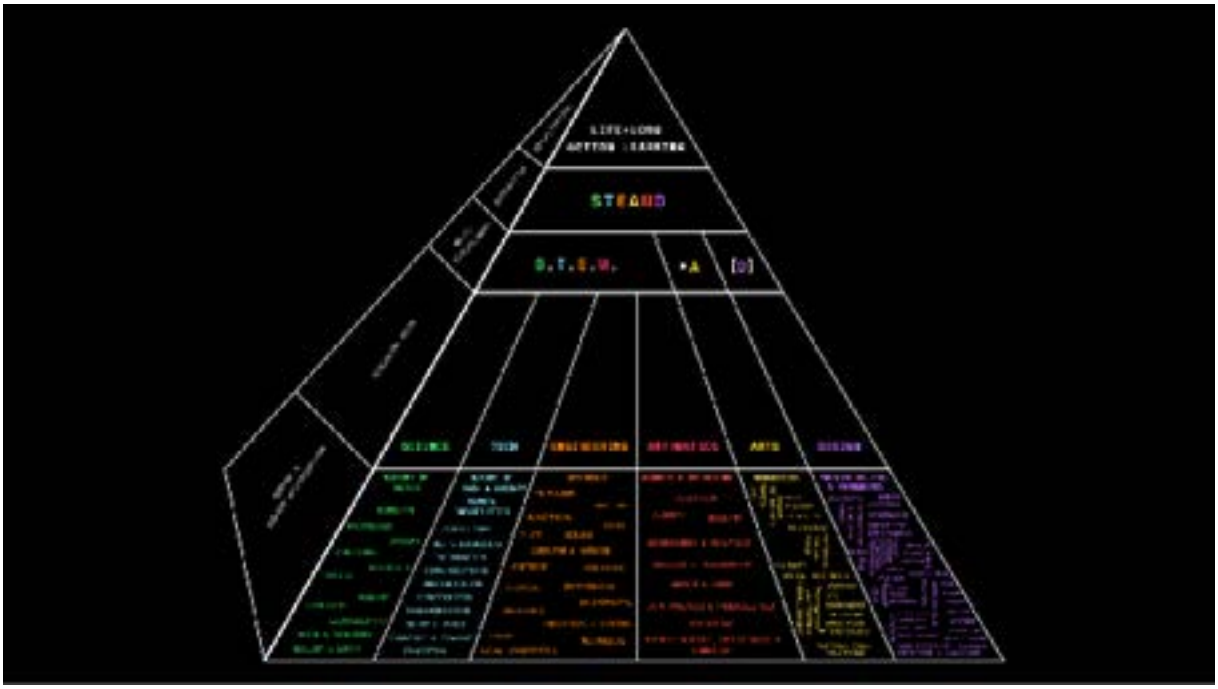

Figure 8: S.T.E.A.M.D. - A modern framework for education - Ai Design Corps™ [Available from: https://aidesigncorps.org/steamd]

The challenges currently being faced by our societies, and indeed by humankind as a whole, require an accurate yet critical perception of the world we have built up over the ages. Climate change is forcing us to make an energy transition, as our way of inhabiting the planet must evolve to guarantee future generations some hope of a future. The economic system, essentially capitalist and based on productivity, has been showing its limits for several decades now, and should be transformed too. The means of communication we have at our disposal have never been so fast or so complete, but they also generate behavioral drifts. The cocktail produced by smartphones and social networks is a form of poison whose only antidote seems to lie in a significant strengthening of the world's education systems. With the advent of AI, these problems will accelerate even further, bringing back old ones that are reminiscent of previous industrial revolutions: professions will disappear to make way for new ones, the daily lives of certain countries will be disrupted for better or worse, and the economy will change its balance.
All of this is based on the same basic technologies and our relationship to them: the digital. In the end, it all boils down to the same problem: what kind of policy do we need to produce and get people to act on? Perhaps the STEAM+D education model, still in its infancy, doesn't represent the solution to all our problems, but it does at least seem to enable an unprecedented alliance between the exact sciences, the natural sciences and the humanities and social sciences. Unprecedented in that it involves one of the fields that is most propitious to invention: creation in art and design.

Acknowledgement(s):

Ecran-Papier-Editer is financed by the European Union in the framework of the Europe Creative program: " CREA-CULT-2023-COOP-101131949".

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

REVIEW

DIGITAL PRINTING IN PUBLISHING

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ABSTRACT

Digital printing has revolutionized the publishing industry by enabling cost-effective, high-quality, and flexible production processes that cater to the dynamic demands of modern consumers. Unlike traditional offset printing, digital printing does not require extensive setup, allowing for economically viable short-run and print-on-demand (POD) services. This technological advancement has significantly reduced inventory costs, minimized waste and expedited time-to-market for books, magazines and other printed materials.

Moreover, digital printing supports variable data printing (VDP), which facilitates personalized content delivery a growing demand in today's publishing landscape. Innovations in inkjet and electrophotographic technologies have further enhanced print quality and substrate compatibility, expanding the scope of applications in both commercial and niche markets.

This paper explores the transformative impact of digital printing in publishing, emphasizing its influence on production workflows, cost structures, and market accessibility. It also examines the integration of digital printing with emerging technologies such as artificial intelligence and cloud-based platforms, which are reshaping the future of the publishing industry. Through a review of current trends and challenges, this study underscores the pivotal role of digital printing as a driver of innovation in the publishing sector.

Keywords: digital printing, design, print-on-demand, variable data printing, publishing

1. INTRODUCTION

Printed products can be systematically classified into three principal categories: publications, commercial printing and packaging [1]. The category of publications includes newspapers, magazines, books, directories and catalogues. Commercial printing encompasses photographic products, advertising materials, business forms, identification documents, promotional items, security documents, transactional documents and general commercial print products. The packaging segment comprises labels, cartons, corrugated materials, flexible packaging, rigid plastics and metal printing.

Published materials are generally divided into two fundamental types: periodical and non-periodical publications [2]. Periodical publications are characterized by regular publication intervals and are part of an ongoing series, whereas non-periodical publications are issued as single editions, except in cases of reissues of substantially unchanged content.

Among non-periodical publications, books represent the most substantial and historically significant category. Books have played a crucial role in preserving human intellectual achievements and cultural heritage, dating back to the earliest civilizations. While not every book holds enduring value, a nation's literary corpus, evaluated over time, serves as an essential repository of cultural knowledge. For statistical classification, the United Nations Educational, Social and Cultural Organization (UNESCO) defines a book as "a

non-periodical printed publication comprising at least 49 pages, excluding covers." [3].
Periodical publications can be further divided into two primary subcategories: newspapers and magazines. Although the distinction between these forms is not always rigid—given that some magazines focus on current events and newspapers often include magazine-style content—differences in format, publication frequency, and functional objectives remain distinct. Newspapers, which are typically published daily or weekly, feature large, unbound pages, emphasize immediate information dissemination, and contain a broad spectrum of content. Magazines, on the other hand, are generally published weekly, monthly, or quarterly, feature smaller pages that are usually bound, and tend to focus on specialized content with a less urgent tone [2].
Both newspapers and magazines emerged following the advent of printing technology and have experienced exponential growth to fulfil the demand for timely information and periodic entertainment. Historically, newspapers have held the highest readership among printed media, playing a pivotal role in the democratization processes of the 19th and 20th centuries. Magazines, closely following newspapers in both historical development and readership, have diversified extensively from their origins in scholarly discourse to encompass a vast range of topics. In contemporary media landscapes, magazines cater to virtually every human interest, whether trivial or profound, across diverse demographic groups.
Printing processes can be broadly categorized into two principal types: conventional and digital. Conventional printing methods, despite their inherent differences, share a fundamental characteristic—the use of a "printing plate" as an intermediary for transferring ink onto a printing substrate. Within conventional printing, four primary techniques are distinguished: Letterpress, Gravure, Planographic and Screen Printing [4].
Conversely, digital printing methods eliminate the requirement for a permanent master. These techniques can be classified into multiple groups based on the underlying physical or chemical mechanisms governing their operation [4]. These categories encompass Electrophotography, Inkjet, Ionography, Magnetography, Thermography, Photography, and X-graphy.
Among digital printing technologies, Electrophotography and Inkjet are the most widely adopted for producing a diverse range of printed materials.
Electrophotography is characterized by a sequence of six essential steps [4, 5, 6, 7]:
1. Charging,
2. Imaging,
3. Inking,
4. Toner transfer (printing),
5. Toner fixing,
6. Cleaning (conditioning).

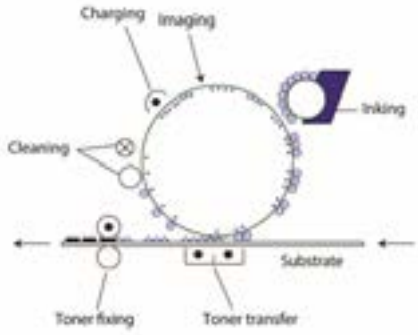

Figure 1: Electrophotography [5]

The inkjet printing process represents a computer-to-print technology in which ink is

ejected through nozzles, eliminating the necessity for a printing master and enabling direct imaging onto the substrate [4]. This efficiency renders it the fastest method for imprinting information onto a substrate. Inkjet printing is categorized into two principal types: Continuous Inkjet (CIJ) and Drop-on-Demand Inkjet.

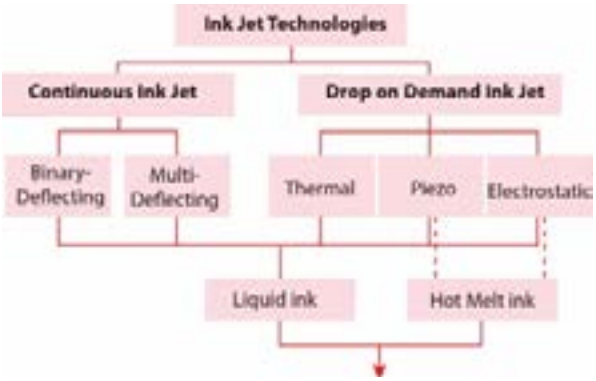

Figure 2: Inkjet technologies [5]

The primary distinction between these two processes lies in the method of ink droplet formation. In Drop-on-Demand Inkjet printing, ink droplets are generated only when required for image reproduction. Conversely, Continuous Inkjet systems produce a constant stream of minute ink droplets, of which only a fraction is selectively directed onto the substrate according to the image signal. The remaining droplets are collected and recirculated for reuse [8].

2. PUBLISHING INDUSTRY

The number of books deposited in national repositories exhibited an upward trend, increasing from 2.4 million in 2018 to a peak of 2.8 million in 2019, primarily driven by the expansion of digital deposits. However, during the period 2020–2021, the number of deposited books experienced a significant decline due to the restrictions imposed by the COVID-19 pandemic, with a 12% reduction in 2020 compared to 2019. The most recent data indicate a recovery, with a 5% increase in 2022, reaching 2.7 million deposits, although this figure remains slightly below the 2019 peak. The global estimate is derived from data reported by 91 national repositories [9].

In 2022, Europe accounted for the largest share of global book deposits, representing 52.1% of the total 2.7 million books, followed by Asia (34.0%) and North America (10.5%). Africa, Latin America and the Caribbean (LAC) and Oceania collectively accounted for only 3.3%, partly due to limited survey responses, with only 26 national repositories from these regions providing data to WIPO. Germany recorded the highest number of books deposited at a national repository in 2022, with 401,197 titles, followed by the United States (264,722), the United Kingdom (167,000), Japan (113,296), and Spain (98,289). Although data from China for 2022 are unavailable, the National Library of China received 467,417 books in 2021, surpassing all other national repositories [9].

Among the top 10 national repositories, the United States exhibited the most substantial increase in book deposits, rising from 197,931 in 2021 to 264,722 in 2022. Denmark (+49,700), Spain (+7,239), and the United Kingdom (+14,645) also reported significant growth in deposits compared to the previous year. In contrast, Germany (-11,961) and the Republic of Korea (-11,132) reported the most pronounced declines in book deposits during the same period [9].

A substantial proportion of deposited books in Denmark (82.4%), Germany (71.4%), and

the United States (91.7%) in 2022 were in digital format. Conversely, print books constituted most deposits in Romania (93.4%), Sweden (96%) and Vietnam (90.4%). The high proportion of print format books in certain countries may be attributed, at least in part, to incomplete data coverage for digital formats [9].
In Croatia, 7,354 books were deposited at recognized repositories, whereas in Serbia, the number of deposited books reached 11,850 [9].
In terms of constant value, the global publishing market—including books, magazines, newspapers, directories and catalogues—has experienced a decline since 2012, decreasing from $179.2 billion to $135.5 billion. Additionally, the overall print volume has diminished, dropping from the equivalent of 29,131 billion A4 prints in 2012 to 25,135 billion A4 prints in 2022 [10].
The publishing industry faces several critical challenges, which can be classified into six primary categories [11]:

1. Technological Disruptions: The proliferation of e-books and digital platforms, the rise of audiobooks and podcasts, advancements in artificial intelligence and machine learning, and challenges in content discoverability.
2. Market Dynamics: Evolving consumer preferences, the impact of self-publishing, the emergence of subscription models, fluctuating revenue streams and challenges in retaining readership.
3. Economic Issues: Pricing pressures, declining print sales and revenue, the influence of major retailers and distributors and complexities in royalty management.
4. Legal and Ethical Concerns: Intellectual property rights and copyright management, issues related to censorship and freedom of expression and the protection of privacy and data.
5. Sustainability: The environmental impact of print publishing and the need for sustainable practices in digital publishing.
6. Diversity and Representation: The inclusion of diverse voices in published content and efforts to enhance diversity within the publishing workforce.

3. DIGITAL PRINTING

In table 1 and 2 are presented digital printing processes used in global publishing market [10].

Table 1: Digital print processes in global book publishing market, 2012–22 ($ million, constant 2016 prices and exchange rates)

Product	Digital technique	2012	2022	CAGR (%) 2017-2022
Books	Electrophotography	5,433.7	3,854.6	-7.1
	Inkjet	1,147.1	9,168.4	25.7
Magazines	Electrophotography	1,244.2	1,914.5	3.8
	Inkjet	0.4	408.7	36.9
Newspapers	Electrophotography	18.4	5.9	-9.3
	Inkjet	940.6	2,656.6	10.1
Catalogues	Electrophotography	396.0	497.9	-1.5
	Inkjet	2.2	142.1	17.3
Directories	Electrophotography	595.2	891.3	4.0
	Inkjet	0.0	0.0	n/a

Table 2: Digital print processes in global book publishing market, 2012–22 (billion A4 prints)

Product	Digital technique	2012	2022	CAGR (%) 2017-2022
Books	Electrophotography	22,866	11,860	-7.8
	Inkjet	13,339	152,744	26.8
Magazines	Electrophotography	9,139	16,145	4.7
	Inkjet	1	2,084	28.1
Newspapers	Electrophotography	489	270	-4.0
	Inkjet	12,174	20,979	5.2
Catalogues	Electrophotography	2,230	4,495	6.1
	Inkjet	8	1,295	31.0
Directories	Electrophotography	1,596	3,229	7.1
	Inkjet	0.0	0.0	n/a

In Table 1, the utilization of digital printing processes within the global publishing market output is presented for the period 2012 to 2022, measured in millions of dollars (adjusted for constant 2016 prices and exchange rates). The data indicate a substantial increase in digital printing processes during this timeframe [10].
Specifically, within electrophotography, the market value declined from $7,687.50 million in 2012 to $7,164.20 million in 2022. Conversely, inkjet technology exhibited significant growth, expanding from $2,090.30 million in 2012 to $12,375.80 million in 2022.
Throughout the 2012–2022 period, print volumes also demonstrated notable variations. Electrophotography did not contribute to this increase, as print volumes decreased from 36.2 billion A4-sized sheets to 35.99 billion A4-sized sheets. In contrast, inkjet technology experienced substantial growth, with print volumes increasing from 25.5 billion A4-sized sheets in 2012 to an impressive 177.1 billion A4-sized sheets in 2022.
The impact of digital printing on the publishing industry has been substantial, offering several advantages:

- Lower production costs: Digital printing enables cost-effective small print runs, allowing publishers to print books on demand and reduce costs associated with traditional offset printing.
- Faster production times: Digital printing eliminates the need for plates and other time-consuming prepress processes, allowing for quicker turnaround times.
- Increased efficiency: Publishers can efficiently manage inventory, printing additional copies as needed rather than relying on large initial print runs that risk overstocking.
- Expanded market opportunities: Digital printing has facilitated self-publishing and print-on-demand services, enabling authors to independently publish and distribute books more affordably.
- Improved accessibility: Digital printing supports the production of books in various formats, such as large print, audio, and e-books, enhancing accessibility for diverse reader needs.

4. CONCLUSION

The evolution of printing technologies, particularly the advent and expansion of digital printing, has significantly influenced the publishing industry. Traditional print processes, while still relevant, have faced increasing competition from digital alternatives, which offer advantages in cost efficiency, production speed and market adaptability. The glob-

al publishing landscape has witnessed fluctuations in book deposits and market values, with digital formats gaining prominence, particularly in developed markets. Despite these changes, print remains a crucial medium for information dissemination, preserving cultural heritage and fulfilling diverse consumer needs.
The publishing sector has also encountered numerous challenges, including technological disruptions, shifting market dynamics, economic pressures and legal concerns. The transition towards digital publishing has reshaped industry strategies, compelling publishers to adopt new business models and embrace technological advancements. Digital printing, particularly inkjet technology, has demonstrated remarkable growth, facilitating smaller print runs, reducing waste and enabling on-demand publishing. This shift has opened new opportunities for self-publishing, enhanced accessibility for diverse audiences and contributed to the sustainability of publishing practices.
Looking ahead, the continued advancement of digital printing technologies is expected to further transform the industry, promoting efficiency, customization and environmental sustainability. While print publishing may continue to decline in certain segments, its adaptability through digital integration ensures its ongoing relevance. As publishers navigate these changes, balancing tradition with innovation will be key to sustaining the industry's growth and meeting the evolving demands of readers worldwide.

Acknowledgement:

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-137/2025-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project "Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad 2025" (No. 01-50/295).

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

ENERGY EFFICIENCY IN PHOTOGRAMMETRY: A COMPARATIVE ANALYSIS OF DATASET, HARDWARE, AND RESOLUTION EFFECTS IN AGISOFT METASHAPE

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ABSTRACT

Photogrammetry enables detailed 3D reconstruction from images but often involves computationally intensive workflows. While processing time is frequently analysed, energy consumption is a critical but less quantified factor, particularly concerning variations in datasets, hardware, and processing parameters. This study quantitatively evaluates the impact of dataset type (uniform Single-Source vs. heterogeneous Multi-Source), hardware platform (energy-efficient Apple Mac Mini M4 vs. high-performance Windows/NVIDIA RTX 4090), and input image resolution (4000px, 6000px, Native) on processing time and total energy consumption using Agisoft Metashape Professional. Experiments involved processing two 335-image datasets across the hardware and resolution configurations using a standard workflow with consistent 'Medium' quality settings, while monitoring time and energy usage. Results indicate the high-performance system was significantly faster (average 1.74x) but consumed substantially more energy (average 4.65x) than the energy-efficient platform. Energy consumption scaled approximately linearly with the total number of aligned pixels processed under constant settings. The Single-Source dataset demonstrated greater robustness, succeeding where the Multi-Source dataset failed in one low-resource scenario, although the Multi-Source dataset showed competitive or better efficiency in some successful tests on the energy-efficient hardware. These findings highlight crucial trade-offs between speed, energy efficiency, and robustness, providing empirical data to inform workflow optimisation based on specific project constraints.

Keywords: photogrammetry, Agisoft Metashape, energy consumption, processing time, hardware comparison, dataset quality, image resolution, Structure from Motion (SfM), energy efficiency.

1. INTRODUCTION

Image-based 3D reconstruction, commonly known through Structure from Motion (SfM) and Multi-View Stereo (MVS) techniques collectively referred to as photogrammetry, has become an indispensable tool across diverse fields such includes cultural heritage documentation, topographic surveying, infrastructure inspection, visual effects, and game development (1). Software solutions like Agisoft Metashape Professional have emerged as industry standards, enabling users to generate detailed 3D models, orthomosaics, and digital elevation models (DEMs) from sets of overlapping photographs (2).
While these photogrammetric workflows offer powerful capabilities, they are often computationally intensive, demanding significant processing time and hardware resources (3). Traditionally, research and end-user focus have centred on optimising processing speed and geometric accuracy. However, with the growing emphasis on sustainable computing practices, rising energy costs, and the potential expansion of photogrammetry to resource-constrained or battery-powered platforms, understanding and quantifying the

energy consumption of these workflows is becoming increasingly critical (4). Factors such as the characteristics of the input dataset, the choice of processing hardware, and the selected input image resolution are known to influence processing time, but their specific impact on total energy usage within a defined workflow is less comprehensively documented.

Previous studies have often benchmarked photogrammetry performance primarily in terms of speed, particularly highlighting the advantages of utilising Graphics Processing Units (GPUs) for specific calculation stages (3,4). The influence of dataset characteristics, such as image count or overlap, on processing time and accuracy has also been investigated (5). However, a gap exists in quantitative, comparative data regarding the energy expenditure associated with varying fundamental aspects of the workflow: the inherent complexity and consistency of the input dataset (e.g., imagery from a single, uniform source versus imagery from multiple, mixed sources), the hardware profile (e.g., energy-efficient System-on-Chip vs. high-power discrete CPU/GPU combinations), and the resolution of the input images processed.

This study aims to address this gap by quantitatively evaluating the processing time and, crucially, the total energy consumption of a standard photogrammetric workflow in Agisoft Metashape Professional (Version 2.2.0 build 19890) under varying conditions. Specifically, the objectives are:

1. To compare the processing time and energy consumption required for a Single-Source Dataset (SSD), captured with uniform camera settings, versus a Multi-Source Dataset (MSD), composed of images from multiple cameras, lenses, and resolutions.
2. To compare the processing time and energy consumption between an energy-efficient hardware platform (Apple Mac Mini M4 with integrated GPU) and a high-performance workstation (Windows PC with Intel i9 CPU and NVIDIA RTX 4090 GPU).
3. To evaluate the effect of input image resolution (downscaled to approx. 4000px and 6000px wide, and native camera resolution) on processing time and energy consumption for both datasets and hardware platforms.
4. To analyse the interplay between these factors (dataset type, hardware, resolution) and their combined effect on the overall time and energy budget.

The contribution of this paper lies in providing empirical data on energy consumption for these common photogrammetry scenarios. These findings offer practical insights for users and researchers seeking to optimise workflows not only for speed and accuracy but also for energy efficiency, enabling more informed decisions regarding data acquisition strategies, hardware selection, and processing parameter choices.

2. METHODOLOGY

This study employed an experimental approach to compare processing time and energy consumption across different dataset types, hardware platforms, and input resolutions within a standardized photogrammetric workflow using Agisoft Metashape Professional.

2.1. Datasets

Two distinct datasets, each comprising 335 images of the same physical object but captured under different conditions, were used for this analysis.

- Single-Source Dataset (SSD): This dataset represents a controlled capture scenario. It consists of 335 images acquired using a single camera body (Sony ILCE-7RM3) equipped with a single prime lens (FE 35mm F2.8 ZA). All images share the same native resolution of 7952 x 5304 pixels (~42 MPix) and intrinsic camera parameters, simplifying the calibration process within Metashape. This dataset corresponds to the reports prefixed with "SSD-".
- Multi-Source Dataset (MSD): This dataset simulates a less controlled or more op-

portunistic capture scenario, incorporating heterogeneity in the source data. It also consists of 335 images but utilizes a combination of two camera bodies (Sony ILCE-7RM3 and Canon EOS RP) and multiple lenses (Sony FE 24-105mm F4 G OSS zoom, Sony FE 35mm F2.8 ZA prime, and Canon RF 24-70mm range). Images within this dataset were captured at various focal lengths using the zoom lenses and possess different native resolutions, primarily 7952 x 5304 pixels (~42 MPix) and 6240 x 4160 pixels (~26 MPix), including both landscape and portrait orientations. This inherent variability necessitates the estimation of multiple distinct camera calibration groups by Metashape during processing. This dataset corresponds to the reports prefixed with "MSD-".

2.2. Hardware Platforms

Two distinct computing systems were utilized to represent different hardware profiles:

- System 1 (Energy-Efficient): An Apple Mac Mini featuring an Apple M4 SoC (System on Chip) with integrated graphics and 16 GB of unified RAM, running Mac OS Sequoia 15.3.2 64 bit.
- System 2 (High-Performance): A custom-built Windows 11 PC equipped with an Intel Core(TM) i9-14900K CPU, 64 GB of DDR5 RAM, and utilizing an NVIDIA GeForce RTX 4090 discrete GPU alongside integrated Intel(R) UHD Graphics 770, though primary acceleration relies on the NVIDIA GPU, running Windows 64 bit.

2.3. Software

All processing was conducted using Agisoft Metashape Professional, version 2.2.0 (build 19890). GPU acceleration was enabled in Metashape preferences for all tests, utilizing the available capabilities of each hardware platform (Metal on Mac M4, CUDA on NVIDIA RTX 4090).

2.4. Experimental Design

A full factorial experimental design was implemented, crossing the two dataset types (SSD, MSD), the two hardware platforms (Mac M4, Win/RTX4090), and three input resolution levels:

- 4000px: Images downscaled prior to processing so the longer dimension was approximately 4000 pixels (e.g., 4000x2668 or 4000x2666).
- 6000px: Images downscaled prior to processing so the longer dimension was approximately 6000 pixels (e.g., 6000x4002 or 6000x4000).
- Native: Images processed at their original captured resolution. For the SSD, this was 7952 x 5304 pixels. For the MSD, this involved the mix of native resolutions (primarily 7952 x 5304 and 6240 x 4160 pixels) present in that dataset.

—> Datasets: https://e.pcloud.link/publink/show?code=kZhqudZCjKAksIqMmkS6dMTiJyxsBIWiLYV
This resulted in 12 distinct test runs, corresponding to the reports analysed: MSD-MAC-4000PX, MSD-MAC-6000PX, MSD-MAC-NATIVE, MSD-RTX4090-4000PX, MSD-RTX4090-6000PX, MSD-RTX4090-NATIVE, SSD-MAC-4000PX, SSD-MAC-6000PX, SSD-MAC-NATIVE, SSD-RTX4090-4000PX, SSD-RTX4090-6000PX, SSD-RTX4090-NATIVE.
—> Reports: https://e.pcloud.link/publink/show?code=kZnqudZkunLlcRlQ1pNLlVcWW9ajjLTzi0X
It is noted that the MSD-MAC MINI M4-4000PX run failed to produce a usable 3D model and is therefore excluded from comparative performance analysis where applicable. The circumstances of the failure are considered in the Discussion section.

2.5. Processing Workflow and Parameters

A standard photogrammetric workflow was executed in batch (all steps are run one after the other automatically, without interaction of the user.) for each test run within Metashape, consisting of the following steps:

1. Load Images
2. Align Photos
3. Build Depth Maps
4. Build Dense Cloud
5. Build Mesh (from Depth Maps)
6. Build Texture

Key processing parameters were consistent across all runs:

- Align Photos: Accuracy set to Medium. Generic Preselection: Yes. Key point limit: 40,000. Tie point limit: 4,000.
- Build Depth Maps: Quality set to Medium. Filtering mode: Moderate.
- Build Dense Cloud: Derived directly from Depth Maps (Source data: Depth maps).
- Build Mesh: Source data: Depth Maps. Surface type: Arbitrary. Interpolation: Enabled.
- Build Texture: Mapping mode: Generic. Blending mode: Mosaic. Texture size: 8,192 x 8,192.

2.6 Data Acquisition

- Processing Time: Timestamps for the completion of major processing stages (Matching, Alignment, Depth Maps, Dense Cloud, Mesh Reconstruction, UV Mapping, Texturing) were extracted directly from the "Processing Parameters" section of the generated Metashape PDF reports. Total processing time was calculated by summing the durations of these key stages.
- Energy Consumption: Total energy consumed for the entire Metashape processing workflow (from the start of Align Photos to the end of Build Texture) was measured using an external Commel digital power meter, recording cumulative Watt-hours (Wh).
- Quality Metrics: Geometric accuracy indicators (RMS Reprojection Error in pixels) and output model complexity metrics (Dense Cloud points, Mesh faces) were extracted from the reports for comparative analysis.
- Input Data Size: Total input pixels for each dataset at each resolution level were calculated based on the image dimensions and the number of aligned images reported for each specific run.

3. RESULTS

The processing time, total energy consumption, and key quality metrics were recorded for each test run. The MSD-MAC MINI M4-4000PX configuration, utilizing the Multi-Source Dataset (MSD) on the Mac M4 at the lowest resolution, failed during the alignment stage and did not produce a usable 3D model; its energy consumption up to the point of failure (14 Wh) is noted, but it is excluded from time-based performance comparisons. The primary results for the 11 successful test configurations, plus the energy data for the failed run, are summarised in Table 1. Total processing time represents the sum of durations for Alignment (Matching + Alignment), Depth Maps, Dense Cloud, Mesh (from Depth Maps), and Texture (UV Mapping + Blending) stages as reported by Metashape. Total Aligned Pixels were calculated based on the resolution and number of successfully aligned images for each run. Energy consumption was measured using a Commel digital power meter logger.

Table 1: Summary of Processing Time, Energy Consumption, and Output Metrics

Test ID	Aligned Images	Total Aligned Pixels (Gpix)	RMS Error (pix)	Dense Points (Millions)	Mesh Faces (Millions)	Total Time (H:M:S)	Total Energy (Wh)
SSD-MAC-4000PX	335	3.58	2.09	2.75	0.12	0:16:36	12
SSD-MAC-6000PX	335	8.04	2.58	5.17	0.28	0:36:20	28
SSD-MAC-NATIVE	335	14.11	3.17	9.74	0.45	1:01:24	47
SSD-RTX4090-4000PX	335	3.58	2.10	2.81	0.12	0:10:19	63
SSD-RTX4090-6000PX	335	8.04	2.59	5.26	0.26	0:19:28	123
SSD-RTX4090-NATIVE	335	14.11	3.19	9.12	0.40	0:30:42	194
MSD-MAC MINI M4-4000PX*	329*	3.52*	1.70*	19.62*	0.52*	0:18:02*	14*
MSD-MAC-6000PX	331	7.96	1.95	10.36	0.67	0:33:17	26
MSD-MAC-NATIVE	330	12.81	2.35	14.79	0.82	0:54:46	43
MSD-RTX4090-4000PX	330	3.54	1.79	4.71	0.27	0:11:52	76
MSD-RTX4090-6000PX	330	7.96	1.95	9.61	0.61	0:20:33	130
MSD-RTX4090-NATIVE	330	12.81	2.35	18.24	0.80	0:29:44	193

*Processing completed according to report, but the resulting 3D model was unusable/broken as per experimental observation (Figure 8.).

3.1. Impact of Hardware Platform on Speed and Energy Consumption

Significant differences in processing speed and energy usage were observed between the energy-efficient Mac M4 and the high-performance Win/RTX4090 systems. The Win/RTX4090 platform consistently completed the photogrammetric workflow faster than the Mac M4 across all comparable successful runs (Figure 1). The average speedup was substantial, with the Win/RTX4090 system being approximately 1.74 times faster on average. The largest speedup (2.15x) was observed for the SSD at Native resolution, while the

smallest (1.20x) occurred for the MSD at 6000px resolution.

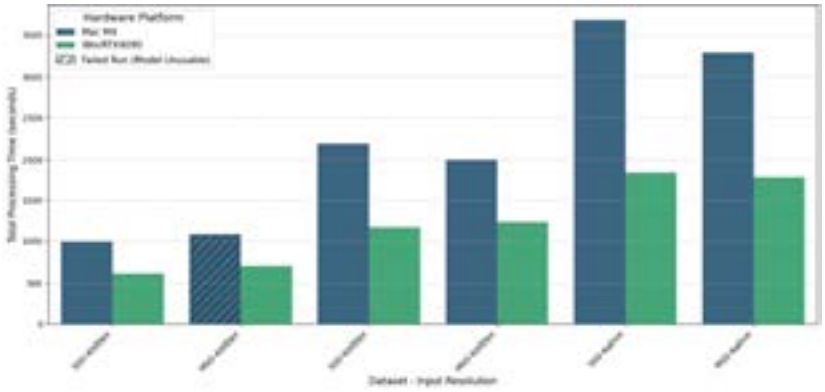

Figure 1: Processing Time Comparison by Hardware. This figure shows the total processing time for each configuration, grouped by Dataset/Resolution, with bars colored by Hardware, includes the failed run (marked with hatching).

Conversely, the enhanced speed of the Win/RTX4090 system demanded significantly higher energy consumption (Figure 2). Across all comparable successful runs, the high-performance system used, on average, 4.65 times more energy (Wh) than the Mac M4. The energy increase factor ranged from 4.13x for the SSD-Native configuration to 5.25x for the SSD-4000px configuration. Figure 2 also highlights the energy consumed (14 Wh) by the MSD-MAC MINI M4-4000PX run before it failed to produce a usable model, indicated by the hatched bar.

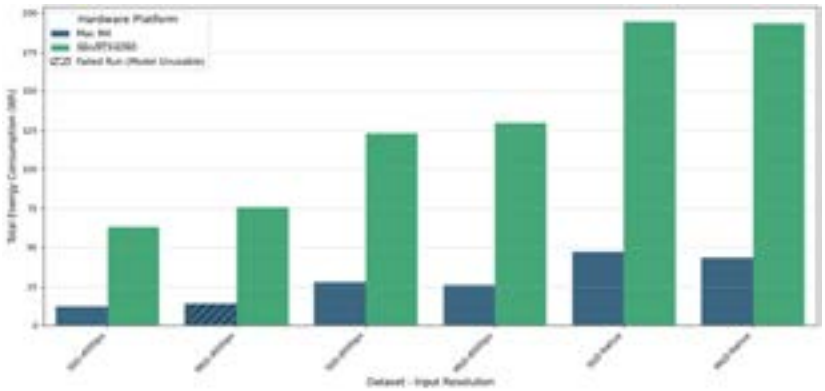

Figure 2: Energy Consumption Comparison by Hardware. This figure shows total energy consumption, similar to Figure 1, includes the failed run (marked with hatching).

3.2. Impact of Input Resolution on Efficiency

Processing time and energy consumption generally increased with higher input image resolution for both hardware platforms and dataset types, as illustrated in Figure 3 and Figure 4. On the Mac M4 with the SSD, increasing the resolution from 4000px to 6000px resulted in a ~50% time increase and a ~133% energy increase. The subsequent step from 6000px to Native resolution led to a further ~120% increase in time and ~68% increase in energy. Similar upward trends were observed for the Win/RTX4090 system and the MSD, although the specific scaling factors varied. Figure 4 includes the energy data point for the failed MSD-MAC MINI M4-4000PX run, marked with a red 'x', showing the energy consumed despite the lack of a corresponding completion time in Figure 3. Higher resolutions consistently yielded denser point clouds and meshes (Table 1).

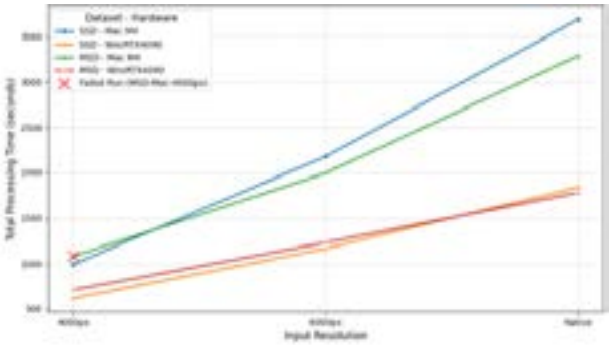

Figure 3: Processing Time vs. Input Resolution. This figure uses line plots to show how processing time changes with resolution for each Dataset/Hardware combination and includes a marker for the failed run's energy usage.

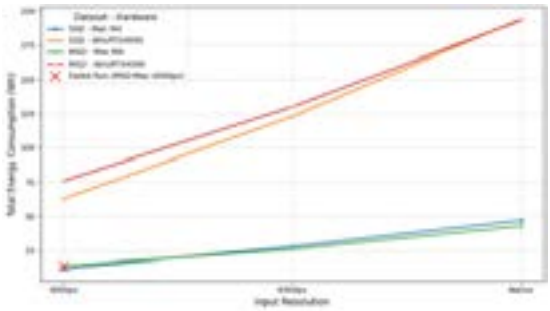

Figure 4: Energy Consumption vs. Input Resolution. Similar to Figure 3, but for energy consumption, and includes a marker for the failed run's energy usage.

3.3. Impact of Dataset Type (SSD vs. MSD) on Processing Efficiency

The comparison between the Single-Source Dataset (SSD) and the Multi-Source Dataset (MSD) revealed differences in robustness, processing time, energy use, and output quality, often interacting with the hardware platform.

As noted previously, the MSD failed to process at 4000px on the Mac M4, whereas the SSD succeeded, demonstrating superior robustness for the simpler dataset under these conditions (Figure 5, annotation on Mac M4 subplot).

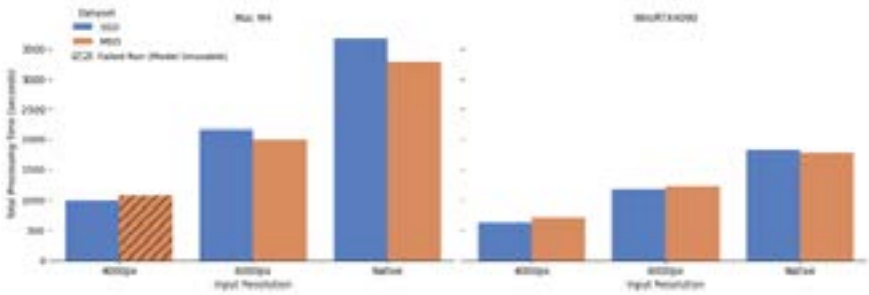

Figure 5: Processing Time: SSD vs. MSD Comparison. Uses facets (subplots) to compare SSD and MSD processing times side-by-side for each hardware platform and including the bar for the failed run (with hatching).

For successful runs on the Mac M4 (6000px and Native), the MSD processed faster than the SSD (Figure 5). At 6000px, MSD was ~15% faster, and at Native, ~9% faster. This time advantage translated to lower energy consumption for the MSD on the Mac M4 (Figure 6), using ~7% less energy at 6000px and ~9% less at Native resolution.
On the Win/RTX4090 platform, the trend reversed slightly. The SSD processed marginally faster than the MSD at all resolutions (Figure 5). Correspondingly, the SSD consumed less energy at 4000px (~17% less) and 6000px (~5% less), while energy consumption was nearly identical at Native resolution (Figure 6).

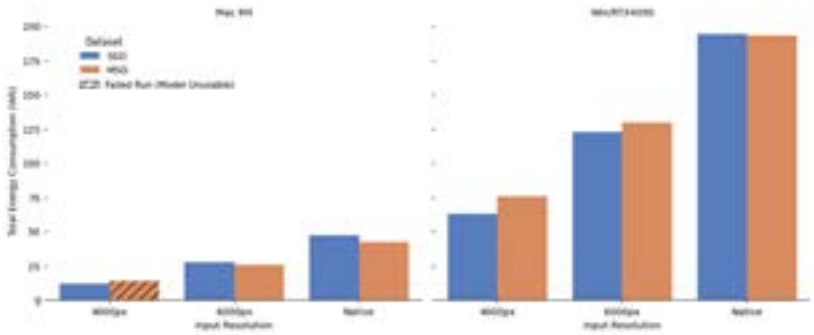

Figure 6: Energy Consumption: SSD vs. MSD Comparison. Similar faceted plot as Figure 5, but showing energy consumption and including the bar for the failed run (with hatching).

Despite sometimes being less efficient in terms of time and energy (especially on the Win/RTX4090), the MSD consistently produced lower RMS reprojection errors (Table 1), indicating a better geometric alignment relative to the image data. It also generated significantly denser point clouds and meshes compared to the SSD at equivalent settings (Table 1).

3.4. Relationship Between Processing Time and Energy Consumption

A strong positive correlation exists between total processing time and total energy consumption across all successful runs, as depicted in the scatter plot (Figure 7). The runs are clustered primarily by hardware platform, with the Win/RTX4090 runs occupying the upper-left region (shorter time, much higher energy) and the Mac M4 runs occupying the lower and lower right region (longer time, much lower energy). Within each hardware cluster, increasing resolution generally moves points diagonally up and to the right, indi-

cating increases in both energy and time.

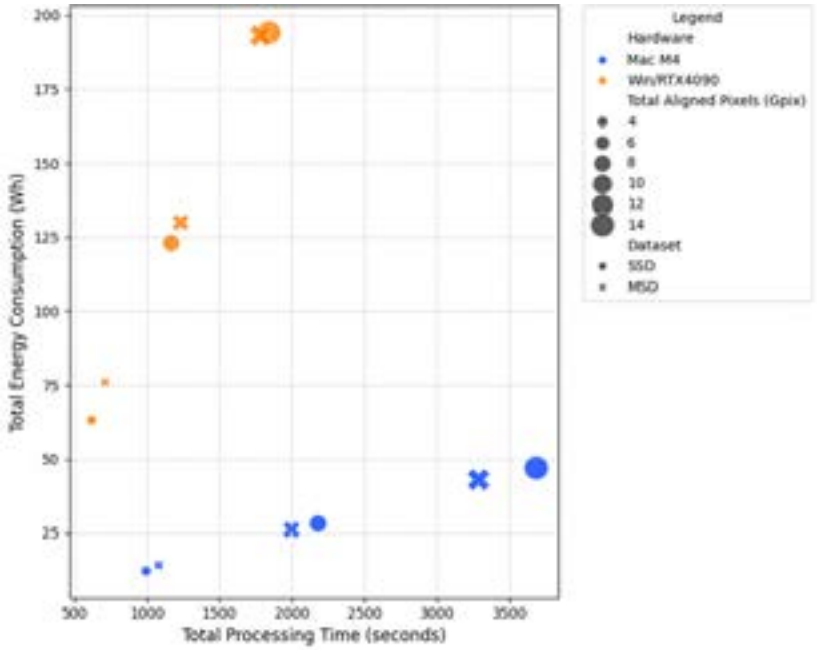

Figure 7: Processing Time vs. Energy Consumption. A scatter plot showing the relationship between time and energy, with points colored by hardware and potentially styled by dataset or resolution.

4. DISCUSSION

This study aimed to quantitatively evaluate the impact of dataset type (Single-Source vs. Multi-Source), hardware platform (energy-efficient vs. high-performance), and input image resolution (4000px, 6000px, Native) on the processing time and total energy consumption of a standard photogrammetric workflow in Agisoft Metashape Professional. The results presented provide several key insights into the complex interplay between these factors.

4.1. Dataset Type: Robustness vs. Nuanced Efficiency

The comparison between the Single-Source Dataset (SSD) and the Multi-Source Dataset (MSD) yielded perhaps the most nuanced findings. As hypothesized, the structural simplicity of the SSD translated into greater robustness, particularly under challenging conditions. The complete failure of the MSD alignment on the Mac M4 at 4000px resolution (Figure 8), while the SSD succeeded, underscores this point (Table 1). This failure likely stems from the combination of lower feature distinctiveness at reduced resolution and the increased complexity of simultaneously optimizing multiple, potentially poorly constrained, camera calibration groups inherent to the MSD (6). From an efficiency standpoint, successful completion is paramount; thus, the SSD proved more efficient in this

specific scenario.

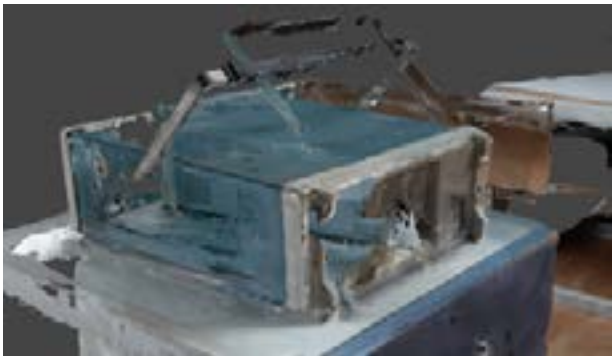

Figure 8: The complete failure of the MSD alignment on the Mac M4 at 4000px resolution

Figure 9: Successfully processed model from MSD on the Mac M4 at Native resolution

Counter-intuitively, however, when both datasets were processed successfully on the Mac M4 (at 6000px and Native resolutions), the MSD demonstrated slightly better efficiency, completing faster and consuming less energy than the SSD (Figure 5, Figure 6). This suggests that factors beyond mere structural complexity influence overall efficiency. The consistently lower RMS reprojection error achieved with the MSD (Table 1) implies a better geometric solution was found, potentially due to the richer geometric information provided by the varied focal lengths and camera positions. This superior geometric fit might enable more efficient processing in subsequent stages like depth map calculation or texturing, potentially outweighing the increased overhead during the initial alignment phase on the M4 platform, where computational bottlenecks may differ from the high-performance system. Furthermore, the slightly fewer aligned images for MSD at Native resolution (330 vs 335) contributed to processing less pixel data, directly impacting energy and time (Table 1).

On the high-performance Win/RTX4090 system, the results aligned more closely with initial expectations. The SSD consistently held a slight advantage in processing time and consumed notably less energy at 4000px and 6000px resolutions (Figure 5, Figure 6). This suggests that when computational power is abundant, the overhead associated with managing the MSD's multiple calibration groups becomes a more dominant factor relative to any potential benefits from its geometric diversity, making the simpler SSD structure more efficient overall. The near-identical energy consumption at Native resolution on this platform indicates that at very high data volumes, the sheer pixel processing load might overshadow the subtle differences in dataset structural overhead.

4.2. Hardware Platform: The Speed vs. Energy Trade-off

The comparison between the Mac M4 and the Win/RTX4090 platform starkly illustrates the well-established trade-off between processing speed and energy consumption in high-performance workstation (7). The Win/RTX4090 system, leveraging its powerful CPU and particularly its high-end discrete GPU, achieved significant reductions in processing time, averaging a 1.74x speedup over the Mac M4 (Figure 1). As indicated by stage-specific timings in the reports, this advantage is primarily driven by the massive processing capabilities of the RTX 4090, accelerating GPU-dependent tasks within Metashape, such as depth map calculation and texture blending (8). Stages less amenable to GPU scaling or potentially more CPU-bound, like mesh reconstruction from depth maps in this workflow, showed less dramatic or even negligible speed differences.

However, this performance gain came at a steep energy cost. The Win/RTX4090 system consumed, on average, 4.65 times more energy than the Mac M4 to complete the same tasks (Figure 2). This disproportionate increase highlights that the higher clock speeds, larger core counts, and especially the power-hungry discrete GPU, while reducing wall-clock time, operate at a much lower energy efficiency (Joules per calculation) compared to the integrated SoC design of the Apple M4. This finding is crucial for users operating under energy constraints, such as those using battery power, facing high electricity costs, or aiming for more sustainable processing practices. The choice of hardware presents a clear decision point between optimizing for time or for energy efficiency.

4.3. Input Resolution and Data Size: A Near-Linear Cost

The results demonstrate a strong, near-linear positive correlation between the amount of processed pixel data (Total Aligned Pixels in Gpix) and both total processing time and total energy consumption, particularly when viewed within a specific hardware/dataset configuration (Figure 3, Figure 4, Figure 7). The energy consumption, in particular, showed remarkable linearity with the GigaPixel workload for each hardware platform, irrespective of the dataset type (SSD vs MSD), suggesting an approximate energy cost per GigaPixel processed (roughly 3.4 Wh/Gpix for Mac M4, 12.5 Wh/Gpix for Win/RTX4090 under these 'Medium' settings). Processing time also scaled positively with data size, though with slightly more variability, potentially influenced by factors like alignment convergence or variations in feature density across resolutions.

It is critical to note that this observed linearity is contingent on the consistent use of "Medium" quality settings for alignment and depth map generation across all runs. These settings involve internal image downscaling by Metashape[2]. Therefore, while the relationship between aligned input pixels and resource use appears linear here, changing the quality settings (e.g., to High or Ultra High, which use less or no downscaling) would alter the number of effectively processed pixels and likely result in a non-linear increase in time and energy relative to the raw input pixel count. Nonetheless, for consistent processing parameters, the total aligned pixel count serves as a strong predictor of the computational workload and associated resource consumption.

4.4. Limitations

This study provides valuable quantitative data but has several limitations. The findings are based on two specific datasets representing particular types of object geometry and capture strategies; results may differ for scenes with significantly different characteristics (e.g., highly complex geometry, poor texture, aerial vs. terrestrial). Only two hardware platforms were compared, representing specific points on the performance/efficiency spectrum. All processing was performed using a single version of Agisoft Metashape with predominantly "Medium" quality settings; different software or settings (e.g., High/Ultra High quality, different filtering modes) would likely yield different absolute and

relative results. The energy measurement method captured total system energy during the workflow, potentially including minor background OS activity, rather than isolating Metashape's consumption perfectly. Finally, the single failure of the MSD on the Mac M4 at 4000px limits direct comparison for that specific configuration.

4.5. Implications and Future Work

The results offer practical guidance for optimizing photogrammetry workflows based on specific constraints. For maximum robustness, especially on lower-power hardware or with lower-resolution imagery, using a consistent Single-Source Dataset is advisable. When processing speed is paramount and energy costs are secondary, a high-performance system with a powerful discrete GPU offers significant time savings, albeit at a high energy premium. Conversely, platforms like the Apple Silicon Macs provide remarkable energy efficiency, completing tasks with substantially less power, making them suitable for energy-constrained environments. The near-linear scaling of energy with processed pixels (under constant settings) allows for rough estimation of energy budgets based on dataset size.

Future work could expand this analysis across a wider range of hardware (including different GPUs, CPUs, and mobile platforms), investigate the impact of different Metashape quality settings (Low, High, Ultra High) on the time/energy/quality trade-offs, and measure energy consumption on a per-stage basis to better understand bottlenecks. Comparing energy profiles across different photogrammetry software packages for the same tasks would also provide valuable context. Further investigation into the factors causing the MSD to outperform the SSD on the Mac M4 platform could also yield interesting insights into software-hardware interactions.

5. CONCLUSION

This study provided a quantitative comparative analysis of processing time and energy consumption in Agisoft Metashape Professional, evaluating the effects of dataset type (Single-Source vs. Multi-Source), hardware platform (energy-efficient Mac M4 vs. high-performance Win/RTX4090), and input image resolution (4000px, 6000px, Native).

The results demonstrate the significant impact of hardware choice on photogrammetric processing efficiency. While the high-performance Win/RTX4090 system offered substantial speed improvements, roughly halving processing time compared to the Mac M4, this came at the cost of consuming over four times the energy. This highlights a critical trade-off for users selecting hardware based on priorities for speed versus energy conservation or cost.

Input data size, measured as total aligned pixels processed, showed a strong, near-linear relationship with both time and energy consumption when processing settings were held constant. This suggests that the volume of pixel data is a primary driver of resource usage within a given hardware and software configuration.

The comparison between dataset types yielded nuanced results. The Single-Source Dataset (SSD) proved more robust, successfully processing under conditions where the Multi-Source Dataset (MSD) failed. On the high-performance system, the SSD generally offered slightly better time and energy efficiency. However, on the energy-efficient Mac M4, the MSD unexpectedly demonstrated superior efficiency in successful runs, potentially due to achieving better geometric alignment, indicating that dataset complexity interacts significantly with hardware capabilities and requires further investigation across more diverse scenarios to draw fully coherent conclusions.

Overall, this research underscores the importance of considering dataset characteristics, hardware selection, and processing resolution not only for optimizing processing speed and output quality but also for managing energy consumption in photogrammetric work-

flows. While high-performance systems offer speed, energy-efficient platforms present a preferd alternative when power usage is a primary concern, and simpler, consistent datasets generally offer greater processing reliability.

Acknowledgements:
This research was supported by the project EUROCC2 funded by the European High-Performance Computing Joint Undertaking (JU) under grant agreement No 101101903 and the HybridScale project of the Croatian Science Foundation under grant agreement number HRZZ-UIP-2020-02-4559.

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ORIGINAL SCIENTIFIC PAPER

ERGONOMIC PACKAGING: JAR LID SHAPE DESIGN

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ABSTRACT

Jars are a popular packaging option for preserving and storing food products. Whether made of glass, plastic, or metal, they are a popular solution for packaging products. They offer benefits in the preservation and storage of food products, as well as versatile aesthetics and durability as containers. One of the components of a jar is the lid, which plays a significant role in protecting the jar's content, often requiring multiple openings and closings. Screw Top lids are often used as they offer a tight seal of the jars, but they often require significant torque to do so. This could pose a problem for populations with lesser grip strength. The primary factors influencing the ergonomic performance of the jar are the material, shape, and surface texture of the lid. This study aims to investigate the impact of lid shape on the maximum torque achieved, as well as participants' subjective assessments of the lid's performance. Results show that maximum torque and participants' subjective judgments are dependent on the lid shape, which packaging designers can use to improve jar lid usability.

Keywords: ergonomics, jar lid, design, shape, packaging.

1. INTRODUCTION

Packaging can be considered a tool for distribution, storage, and sales, and it can be an integral part of the product itself or an external container. It is essential both for the seller as a tool to distribute, store, and promote the product and for the customer as a means of identification and usage. As there is a huge variety of products that need packaging, there is an even wider variety of packaging solutions that can fulfil that assignment.

1.1. Jars

One of the most commonly used types of packaging is jars. Jars are a popular packaging option for preserving and storing food products, and they are applicable to a wide range of products. Whether the jar body and lid are made of glass, plastic, or metal, they are a popular solution for packaging products, offering versatile aesthetics and durability as containers. The jar lid plays a significant role in protecting the packaged content, often requiring multiple openings and closings. There are numerous types of lids differing in the principle of ensuring closing and sealing the jar safely and reliably; some of them are: twist-off lids or screw lids, Le Parfait Familia Wiss lids, clop-top lids, etc.
This article will deal with the screw top type lids, which are often used as they offer a tight seal of the jars. During processing or packaging, especially of food products, the heat forces air out of the jar. As the jar cools, a vacuum forms, pulling the lid tight. Therefore, opening the jar often requires significant torque. This could pose a problem for all users, especially for populations with weaker grip strength, such as the elderly with age-related conditions and chronic diseases or children [1, 2, 3]. Considering this problem, the ergonomic characteristics of the lid shape design become essential for the comfortable usage

of the jar.

1.2. Ergonomics of jar and lid design

Ergonomics, as an applied science, is concerned with designing and arranging things so humans interact with them most efficiently and safely. To understand the interaction between humans and others, elements of system ergonomics employ an interdisciplinary approach, applying knowledge to workspace design, product design, packaging design, and other related disciplines. [4, 5, 6, 7]
The primary factors influencing the ergonomic performance of the jar are the material, shape, and surface texture of the lid. Of all influencing factors, the shape of the jar lid will be of special interest to the study presented in this paper. Studies on packaging that requires a twisting motion or the application of torque for opening jars emphasize the importance of coordination between the user's two hands as a crucial factor [8, 9, 10]. Difficulties in judging participants' coordination led the majority of researchers to focus on achieved torque as the primary objective measurement for evaluating the performance of jar designs for tamper-evident bottle closures [11] and jars [12, 13, 14, 15, 16]. Alongside research based on objective torque measurements, some studies rely on consumer reports of their satisfaction with the performance of food and beverage packaging, primarily based on questions and consumer feedback [17]. There is a lack of research connecting the quantitative evaluation of torque with the qualitative analysis of user experience.
This study aims to investigate the impact of lid shape on the maximum torque achieved, as well as participants' subjective assessments of the lid's performance.

2. EXPERIMENTAL METHOD

To gain a detailed insight into the influence of the jar lid shape on the opening and closing torque achieved by the participants, an experiment was conducted, followed by a questionnaire that recorded participants' subjective judgments of each lid variation. In this experiment, the lid shape, the lid side angle and the number of ridges on the lid sides were varied.

2.1. Participants and experimental conditions

Participants were chosen from age group 25 to 30 years of age, five male and five female. A precondition for participation was having healthy hands, free from any chronic or acute injuries, including the smallest cuts or skin irritations. Also, participants practicing professional or frequent sports activities were eliminated.
The ambient temperature was maintained at 23 °C ± 2°, and the relative air humidity was kept at 50% ± 2% to prevent palm sweating.

2.2. Experimental setup

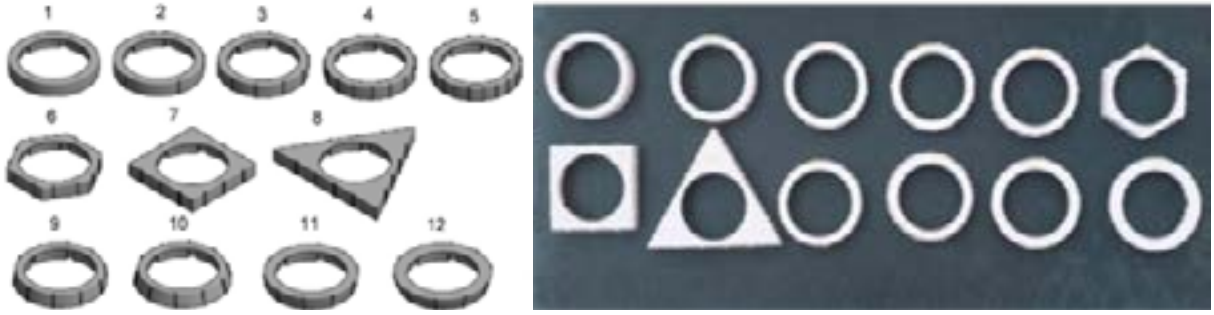
In order to measure opening and closing torque Shimadzu Compact Tabletop Testing EZ-LX was used equipped with additional equipment for jar model fixation and torque measurement. Shimadzu force measuring head 1-500N was mounted 0.1 m from the pivot point (lid centre) in order to measure force applied, from witch torque applied was calculated. Trapezium software was used for results recording. Samples were set to average comfortable height for all participants. Figure 1 shows the experimental setup and partiCipants' position.

Figure 1: Experimental setup, Shimadzu Compact Tabletop Testing EZ-LX

Participants were asked to apply maximal opening (counter-clockwise) and closing (clockwise) torque for 3 seconds in each direction without experiencing discomfort or pain. The type of hold applied was left to the participants preference. They were offered a break and rest to prepare for the next specimen, although no one requested a rest due to discomfort or fatigue.
Additionally, participants were asked to complete a questionnaire regarding their subjective comfort experience for each specimen, rating it on a scale of 1 to 10, with 1 being the lowest grade and 10 the highest grade.

2.3. Experimental specimens (lid models)

Lid models used as specimens in this experiment were modelled using Autodesk Inventor software and produced using an FDM 3D printer. The variations of specimens were categorized into three groups, comprising a total of 12 specimens. Figure 2a shows an image of the 3D models, and Figure 2b is a Photograph of the produced specimens.



a) b)

Figure 2: a) Image of numbered 3D models, b) Photograph of produced specimens

There are four shape variations of the lid: No.3: circular, No.6: hexagonal, No.7: square, and No.8: triangle). Five variations in number of ridges, increasing by 5 ridges, were applied to a circular shape with a diameter of 85 mm, No.1: without ridges, up to No.5: with 20 ridges. Five variations of lid side angle (No.3: 0°, No.9: 7.5°, No.10: 15°, No.11: -7.5°, No.12: -15°) were applied to a circular shape with a diameter of 85 mm. The height of all specimens was 15 mm.

3. RESULTS AND DISCUSION

Results shown in Figure 3 represent the opening and closing torque [Nm] achieved by each participant for all of the lid shapes.

Figure 3: Torque achieved by each participant for all of the lid shapes in both directions

Results for the torque achieved show similar trends in opening and closing directions, with some individual preferences; however, overall there is no clear pattern. Noticeable and repeatable differences in torque achieved are present for the lid models, No. 7 (square shape) and No. 8 (triangular shape), compared to the other lids. This could be explained by the angle of the force vector and the contact surface of the lid. In the case of square and triangular shapes, the force vector is more perpendicular to the surface and thus offers greater impact. Additionally, due to the shape of specimens No. 7 and No. 8, the force can be applied at a greater distance from the pivot point of the lid, thereby producing greater torque if held in this manner. Figure 4 illustrates the torque [Nm] comparison among different shapes: No. 3, circular; No. 6, hexagonal; No. 7, square; and No. 8, triangular, further emphasizing the differences in results caused by the lid shape.

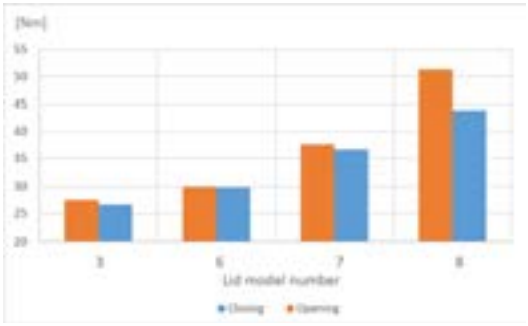


Figure 4: Torque achieved on the specimens with different shapes

Figure 5 shows the different torque values [Nm] achieved by opening and closing lid models with varying numbers of ridges on the lid side, increasing from No. 1 to No. 5. Torque is inversely correlated with the number of ridges, indicating that the ridges may have been irritating to the participant's hand. It is worth noting that the ridges in this experiment were pronounced and not so delicate that they could be considered as textured surfaces. This conclusion is supported by the results of comfort judgment shown in Figure 7.

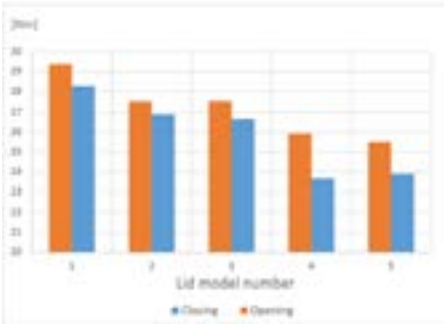


Figure 5: Torque achieved on the specimens with different number of ridges

Differences in torque [Nm] caused by the angle of the sides are minor, as shown in Figure 6, indicating that this factor has no significant impact. Although there is no impact on the torque value, it is important to notice a significant impact on the reported comfort, as shown in Figure 7.

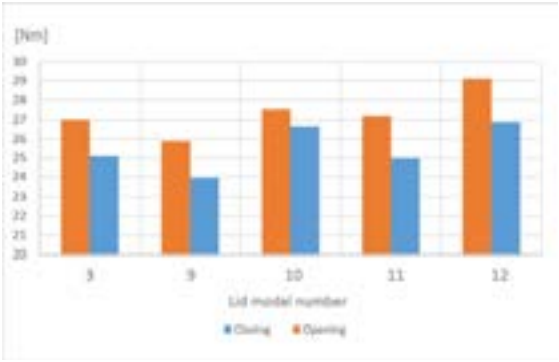


Figure 6: shows the average subjective judgment of all lid models.

Figure 7 shows reported subjective comfort judgments by the participants on the scale 1 to 10, 10 being most comfortable. As mentioned earlier, comfort is decreasing with an

increased number of ridges on the side of the lid. Specimens No. 6, No. 7, and No. 8 offer good contact through their angular shape, thereby providing a firm grip that is perceived as comfortable by the participants. Notably, the "downward" angle of the lid side, present in specimens No. 11 and No. 12, provided comfort without a significant increase in torque.

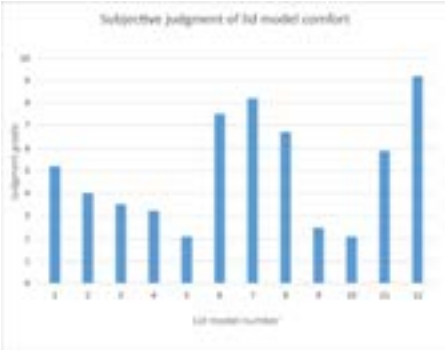


Figure 7: Reported subjective comfort judgments by the participants

4. CONCLUSION

Importance of the good ergonomic design practices is well known and applied across numerous industries. Packaging industry is no exception, ergonomically designed packaging can offer greater comfort and ease of use to the consumers. This research investigated three factors in the jar lid design and their relation to the performance measured through torque achieved and subjective comfort judgment. Shape of the lid proven to have greatest impact on both the performance and the comfort. Number of ridges proven to have negative impact on both the performance and the comfort. Greater number of ridges decreased the torque and the comfort. It must be emphasized that this result could be attributed to the shape and size of the ridges in this study. Angle of the lid side proven to have little or no effect on the performance torque wise, but have shown great impact on the reported comfort this should be further examined by specially constructed study.

Acknowledgement(s):

This research has been supported by the Ministry of Science, Technological Development and Innovation through Contract No. 451-03-136/2025- 03/200156.

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ORIGINAL SCIENTIFIC PAPER

PHOTO ANALYSIS OF TECHNIQUES IN ITF TAEKWON-DO: FIGHTS AND MANDATORY PATTERNS

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ABSTRACT

The combined study explores the optimization of techniques in ITF Taekwon-do, focusing on sparring and mandatory patterns through photo analysis. The first part investigates how the photographer's viewing angle can highlight the effectiveness of kick techniques during competitions and training, identifying the optimal angles for showcasing and improving technical performance. The second part examines the correlation between technical performance in mandatory patterns and the quality of photographs. Through objective and subjective analysis of captured images, the study evaluates how visual representation can identify technical inconsistencies and enhance skill development. Both approaches emphasize the role of photographic analysis as a crucial tool for athletes and coaches to understand and refine techniques in ITF Taekwon-do. The findings provide a framework for integrating photographic feedback into training programs and competitions, contributing to the advancement of this martial art.

Keywords: photo analysis, ITF Taekwon-do, sparring, patterns, skill enhancement.

1. INTRODUCTION

Sports photography captures key moments in athletic events, preserving emotion, motion, and intensity [1,2]. At the same time photo analysis in sports helps improve athletes' performance by identifying strengths and weaknesses through detailed visual feedback [3]. Coaches use it to study techniques, strategies, and opponent behavior. It also aids in injury prevention by detecting improper movements or posture [4]. In modern martial arts practice, technology plays a vital role in performance development. This study combines insights from visual documentation of ITF Taekwon-do sparring and patterns, exploring how photo quality and angle influence the interpretation of technique. With the growing presence of visual content in training and coaching, the ability to analyse static images for real-time performance insights offers coaches and athletes a powerful improvement strategy.

This paper investigates not only technical feedback in sparring but also how analysis of form execution in patterns can highlight minor faults and encourage precision. Through photographic capture and analysis of movement in action [5], athletes are empowered to refine their form, rhythm, and balance, while coaches are provided with a repeatable visual database for feedback and evaluation.

1.1. Theoretical framework and background

ITF Taekwon-do, founded by General Choi Hong Hi in 1966, is a dynamic martial art focusing on power, control, and precision [6]. It includes both combat (sparring) and choreographed sequences (patterns). While sparring emphasizes strategy and reaction, patterns demand strict adherence to technique and timing.

In recent years, photo and video analysis have gained attention in martial arts as tools for identifying form inconsistency, injury risks, and performance progression [7,8]. Viewing

angle significantly affects the observer's ability to analyse movement. A technique may appear correct from one perspective and flawed from another. This is especially relevant in Taekwon-do where line work [9], symmetry and rhythm [10] are evaluated.
Visual analysis methods enable coaches to slow down moments that happen too quickly to critique during live action. A single photo can freeze and preserve a position, enabling a detailed breakdown of body posture, stance accuracy, and attack execution. By repeating this process across a variety of techniques and scenarios, patterns emerge that can be used to construct corrective training interventions [11,12].

2. MATERIALS AND METHODS

Photographs were taken during the 2022 European Championship (Poreč), the 2023 European Championship (Jesolo), and national team training sessions. A Canon EOS 80D [13] with a 50mm f/1.8 lens was used with shutter speeds between 1/500 and 1/1250 s and aperture settings from f/1.8 to f/2.0, allowing for fast, sharp captures of movement.
The methodology included:

- Side and frontal camera positioning
- Comparative analysis between training and competition images
- Subjective and objective evaluation of image quality and technical accuracy
- Evaluation of patterns and sparring sequences to determine angle-dependent visibility of execution
- Use of close-up shots to detect wrist misalignment, foot positioning errors, and lack of hip rotation
- Categorisation of technical elements based on visibility: stance, strike form, timing, and balance
- Statistical cross-reference of angles with success rate in judges' scoring for sparring
- Comparison of camera settings to determine optimal configuration for various environments

3. ADVANCED APPLICATIONS OF PHOTOGRAPHIC ANALYSIS IN TECHNIQUE DEVELOPMENT

While photo analysis provides a foundation for assessing technique, its full potential lies in nuanced application for performance optimization. The integration of visual feedback must go beyond identification of errors and evolve into a continuous loop of correction, reinforcement, and improvement. To achieve this, training programs must embed photographic checkpoints into each macrocycle and mesocycle of the athlete's development. These checkpoints can take the form of designated evaluation sessions where athletes perform set sequences—either sparring drills or patterns—under controlled photographic observation.
This method allows the coach to gather a timeline of visual data for each athlete. Over time, such visual timelines can uncover hidden patterns in skill evolution or stagnation. For example, a young black belt competitor might exhibit excellent leg extension during turning kicks at age 16, but gradual reduction in flexibility and elevation by age 18 due to overuse or injury compensation. Such changes are often imperceptible in live action but evident when comparing two photos taken a year apart.
Additionally, this type of long-term visual dataset allows for the establishment of individual performance baselines. Once a baseline is documented, any deviations in stance depth, hand position symmetry, or body lean during execution can be objectively tracked, rather than relying on subjective memory [6]. Coaches benefit from a growing database of athlete-specific biomechanical behavior, while athletes learn to identify their own fluctuations in form.

4. PHOTOGRAPHY IN PATTERN ANALYSIS: FINE-TUNING FORMS THROUGH STILL FRAMES

Mandatory patterns (tul) in ITF Taekwon-do [13, 14] require exact replication of techniques with proper timing, rhythm, and energy distribution. The execution is judged not only on correctness but also on expression of power, breathing control, and synchronization with imaginary opponents. For this reason, photographic analysis of patterns is uniquely valuable—it allows the frozen visualization of sequences where movement intention, posture, and extension must harmonize.

When viewed in still images, errors in stance width, misaligned angles of the rear foot, or over-rotation of the torso are more noticeable. Take for example the walking stance middle punch (Gunnun Sogi Kaunde Jirugi)[13, 14]. When captured from the side, one can analyze whether the athlete's front knee is properly bent at 90°, whether the back leg is straight and extended, whether the hips are square, and if the punch aligns with the solar plexus level (Figure 1). Frontal photography, though less revealing of depth and rotation, becomes useful in assessing symmetry—especially in double forearm blocks or twin vertical punches.

In addition, rhythm and energy flow—two subjective but judgeable criteria—can be dissected through burst-mode photography. A sequence of four to five frames can visually represent whether a motion was continuous or segmented, dynamic or rushed. Coaches and evaluators can even mark "moment of pause" zones to track energy release points and transitions. This has particular value in high-difficulty patterns like Ge-Baek or Choi-Yong, where precision of dynamic tension and continuity is paramount.

A further benefit of pattern photography lies in its use for pre-competition visualization. Athletes can study optimal photos of their own forms to mentally rehearse not only techniques but angles of performance most likely to be visible to the panel of judges. In this way, photographic analysis also becomes a mental preparation tool.

Figure 1: International Youth Open, Donja Stubica 2022.

5. OPTIMIZATION OF EQUIPMENT AND SETUPS FOR PHOTOGRAPHIC EFFICIENCY

The effectiveness of visual analysis is directly influenced by the quality of the photographic capture. As described in previous sections, the use of a Canon EOS 80D with a 50mm f/1.8 lens, combined with fast shutter speeds, provides sharp imagery of high-speed movement. However, additional layers of optimization can elevate the clarity and utility of images:

- Lighting: Especially in pattern photography, lighting consistency is essential. Side lighting (with softboxes or LED panels) can highlight muscle tension and body contour during movements, allowing for better evaluation of physical expression. In sparring photography, high-intensity ceiling lights reduce blur and increase contrast.

- Tripod-Free Mobility: For sparring, hand-held shooting remains preferable due to the

dynamic, unpredictable nature of movement. However, for patterns performed in designated spaces, tripods with pan-tilt heads or gimbal stabilizers can be used for cinematic movement tracking, especially if filming is combined with photography.

• Multiple Angles: Using two to three cameras simultaneously—side, frontal, and elevated diagonally—provides a composite visual understanding of each motion. Modern DSLR or mirrorless systems allow for wireless sync and remote shutter control, enabling a single operator to manage multiple perspectives.

• Lens Variety: While a 50mm lens is ideal for tight indoor captures, a secondary 85mm or even 24-70mm zoom lens offers flexibility in large spaces, such as national competition halls. The latter enables mid-movement reframing without compromising aperture settings.

Combining these equipment recommendations with a planned shot list—designed based on common errors observed per athlete—results in targeted, efficient photography that serves both real-time feedback and long-term documentation.

6. PSYCHOMOTOR LEARNING THROUGH IMAGE-BASED CORRECTION

The process of skill acquisition in martial arts is deeply rooted in kinaesthetic learning—learning by doing. However, coupling this with visual comparative feedback enhances psychomotor development by providing external validation of internal sensations. This is particularly true for younger practitioners who may not yet possess developed proprioception or body awareness.

For instance, a green belt student may "feel" that their side kick (Yop Chagi) is high and aligned, but only upon reviewing a photograph may they realize that the foot is angled downward, the hip is not fully rotated, and the head is tilted sideways, compromising balance. This realization leads to cognitive restructuring of how the kick should feel versus how it actually appears—an important step in psychomotor alignment.

To maximize this learning method, a side-by-side visual comparison can be utilized. Athletes can view their execution next to an ideal model, preferably of a world-class performer or high-DAN level master. Such comparisons bring immediate insight and foster self-correction. Moreover, coaches can draw directly on the image with digital annotation tools, highlighting lines of motion, points of misalignment, and labelling key anatomical deviations.

This mode of feedback has shown strong efficacy in other sports, such as gymnastics and figure skating, where form and body angles determine scoring. In ITF Taekwon-do, the opportunity is ripe to adopt these methods more systematically.

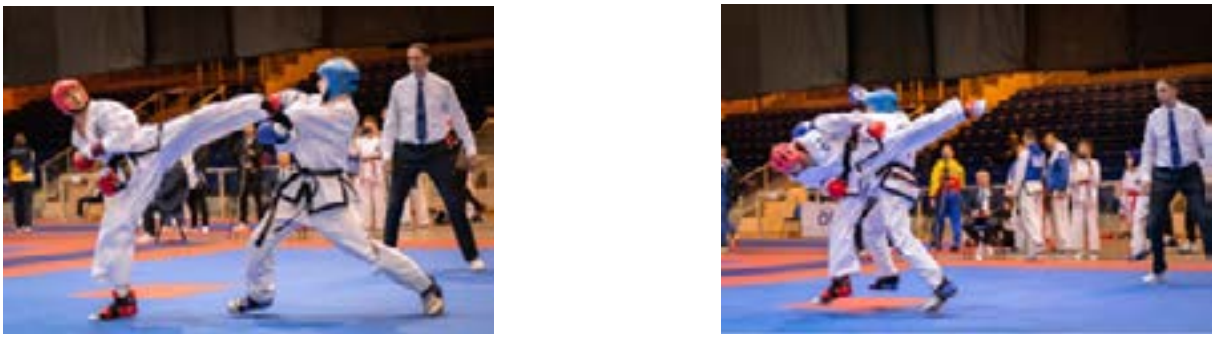

Figure 2: Side angle

7. PATTERN-SPECIFIC STRATEGIES FOR ANGLE-BASED EVALUATION

Each ITF Taekwon-do pattern [13,14] contains unique structural elements that benefit from specific photographic angles. Developing a guide or protocol for camera positioning based on the pattern performed can greatly enhance evaluation efficiency. Below are some examples:

- Chon-Ji & Dan-Gun: Use frontal angles for early postural discipline; side angles for knife-hand blocks and low stances.
- Toi-Gye: Elevated diagonal angles reveal stance transitions and twin vertical punches.
- Ge-Baek: Requires high-resolution side photography during slow motion segments to assess timing and strength modulation.
- Choi-Yong & Yoo-Sin: Benefit from high-angle overviews to observe complex footwork and body axis changes during spinning movements.

For each pattern, photography should also aim to capture breath control moments, which are often overlooked in video but visible in photos via abdominal contraction or posture shifts. A moment where an athlete visibly tightens the core while performing a punch speaks volumes about inner discipline and energy management.

8. RESULTS

Side-view photography consistently provided superior insight into body positioning, kick trajectory, and rotational movement. For example, Dollyo Chagi (roundhouse kick) and Bandae Chagi (reverse turning kick) were best captured from a side angle, revealing hip rotation and impact point. In patterns, side angles helped evaluate stance stability and arm extension.

Frontal angles occasionally offered better emotional context and opponent reactions, but often obscured limb positioning. In competitive sparring, a frontal angle may catch the intensity of engagement, but side angles are more useful for confirming point-scoring contact. In patterns, frontal shots helped observe transitions between techniques and judge symmetry.

Training photos taken at close range provided high-resolution views of technical detail, enabling detection of minor faults such as bent wrists during punches or misaligned stances. It was found that exposure control (shutter speed and aperture) was crucial to capturing dynamic movements sharply without blur.

Statistical comparison of photo clarity and evaluative usefulness showed that over 70% of side-angle photos contributed more effectively to performance analysis than frontal angles. Coaches also reported greater success using these images in post-training feedback. In patterns analysis, it was evident that certain stances, such as Gunnun Sogi (walking stance), were misaligned due to uneven knee positioning—only visible when viewed from the side.

The study also observed consistent technical regression under competitive stress. Athletes whose technique was near flawless during training were prone to drop shoulders or execute less fluid movements under pressure, a discrepancy clearly observable through time-stamped photo series.

9. DISCUSION

Image-based feedback proved particularly valuable in assessing differences between training and competition execution. Athletes under pressure showed reduced form consistency. Adjusting camera angles dynamically during performance enabled better tracking of movement nuances. Both sparring and pattern photography revealed that consistent camera positioning is essential for valid comparative analysis.

One major insight was the correlation between the photographer's understanding of Taek-

won-do and the quality of usable images. Familiarity with sequence timing and technique flow enabled the capture of critical moments—especially in patterns, where anticipation of movement is key.
Additionally, camera distance and lens choice had a measurable effect. While a 50mm prime lens was ideal for medium-distance action, there were occasional limitations when athletes moved too far from the expected path. However, maintaining a shallow depth of field with f/1.8 helped isolate subjects from busy backgrounds.
Photographic angles also affect how judges and coaches interpret contact and execution quality. For example, a reverse turning kick may appear effective from a frontal view, but the actual contact point, hip rotation, and recoil motion are better assessed from the side.
The study also identified differences between photo quality in training versus competition. In training, controlled lighting and movement predictability led to better photo quality. In competitions, lighting variance and unpredictability of sparring action introduced challenges for clarity and timing.
Moreover, photo series shot in burst mode revealed transitional movements that often go unnoticed in real-time. These micro-adjustments between techniques are crucial for overall flow and were especially valuable for identifying rhythm and timing errors in patterns.

10. CONCLUSION

Photographic analysis in ITF Taekwon-do is an effective tool for visualising and correcting technical flaws. Side angles offer the best results for kick and punch evaluation. Coaches and athletes can benefit from integrating image-based reviews into their regular training cycles. This method bridges the gap between visual representation and practical performance enhancement.
To maximise effectiveness, future work should explore multi-camera setups, real-time feedback tools, and AI-assisted tagging of errors. Merging artistic photography with performance science opens new directions for both sports documentation and skill development.
The integration of image analysis into Taekwon-do coaching paradigms not only elevates training effectiveness but also contributes to a new standard of visual literacy in martial arts. By combining photographic artistry with biomechanical insight, the field moves toward a more analytical and holistic understanding of martial performance.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

PROFESSIONAL PAPER

A DYSTOPIAN GUIDEBOOK TO A FUTURE VILNIUS: AI + HISTORY AS TOURISM

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ABSTRACT

Tourism and its artifacts will reinforce the reigning political hierarchy, and that phenomenon is documented in the way guidebooks consolidate history into easy consumption for foreign visitors. An examination of guidebooks to Vilnius from the preceding 170 years demonstrates how every reigning hegemony has reified their power through the description of tourist attractions. This work extrapolates current trends in technology, politics, culture, and religion to create a terrifying vision of Vilnius in 2054. The peril of dystopian tendencies underlies the landmarks and monuments that populate the city 30 years in the future. The guidebook "A Guide to Pilgrimage Sites of Vilna and Northwest Krai," presents a world where newly conscious plants have been wired into artificial intelligence to enslave humanity in a mélange of their own obsessions and addictions. A resurgent variant of Soviet Imperialism has merged Orthodoxy and Catholicism and formed a revived hybrid of theocratic communism with a state cult of the grape and the wheat. The sites that a visitor would see serve as validation to this regime where history is rewritten and the present status quo glorified.

Keywords: Dystopian, Artificial Intelligence, Guidebook, Tourism, Totalitarianism

1. INTRODUCTION – GUIDEBOOKS AS POLITICAL REIFIERS

Tourism inherently interprets topographies in ways that will manifest the biases of the interpreter. The phenomenon of tourism takes its origins in the practice of pilgrimage, which imbues travel with a religious intention, and the need to guide those pilgrims serves as justification for the earliest guidebooks. Guidebooks also provide us with a written record of how the religious, social, and political perspective of their authors and the power structure they represent can be reified through the way tourist attractions are contextualized. An examination of guidebooks to the Lithuanian capital, Vilnius, from the preceding 170 years demonstrates how every reigning hegemony has reified their power through the description of tourist attractions. The exhibited guidebook emerged from the project to write a screenplay about the discovery of a guidebook from thirty years in the future. The text and accompanying artworks extrapolate current trends in technology, politics, culture, and religion to create a terrifying vision of Vilnius in 2054. The sites included in the guidebook serve as validation to this regime where the history of Lithuania is rewritten and the present dystopian reality glorified.

2. PILGRIMAGE AS THE ORIGIN OF TOURISM

The concept of pilgrimage remains at the center of the phenomenon of tourism from its origins to the present day. The guidebook for this project is titled a "Guide to the Pilgrimage Sites of Vilna and the Northwest Krai" because many of the earliest guidebooks we know of were in fact just that, an itinerary for pilgrims. Using the term pilgrimage also roots the text within this future society's techno-theocratic autocracy. In terms of cultural practice,

the act of pilgrimage serves as the predecessor to our modern industry of tourism. It also may be as old as civilization itself, and in many ways played a crucial role in its genesis. The oldest religious site in the world, Göbekli Tepe, had no apparent permanent dwellings, but seemed to serve as a gathering place for communal sacred rituals with peoples travelling there to partake in them [1]. Even though not the political center of the Kingdom of Ur, the temple of Ekur at Nippur dedicated to the god Enlil, attracted visitors from across ancient Mesopotamia and served as a religious center distinct from the political center of early dynastic Ur [2]. The sanctuary of Delphi attracted pilgrims from throughout Greece for nearly 1,200 years who would come to hear the prophesies of its oracle, the Pythia [3]. By connecting larger populations through a common religious practice, pilgrimage sites served to forge common identities out of a common belief structure.

With the rise of Abrahamic religions, their core scriptural locations would similarly shape these much more geographically disbursed peoples by binding them to a common sacred topography. Jews would travel to the ruins of their Temple Mount when Christian prohibitions were not in place, under Persian and Muslim rule [4]. Christians also began traveling to Jerusalem and Palestine to visit the core sites of Jesus' life and passion following the Edict of Milan and his mother St. Helena's founding of many churches at what were believed to be those holy locations [5]. Mecca and its Ka'ba (cube-shaped structure) had already been a place of pilgrimage when the city was known as a center for many different pagan religions, but following the establishment of Islam, Mohammed codified a new set of practices around the same artifacts and topos [6].

The use of the Ka'ba and its core object, the (possibly) meteoritic black stone (al-Ḥajar al-Aswad) [7], already sacred from pre-Islamic times, would take on new roles as key objects of the Haj. The Qur'an describes the Ka'ba as the first religious structure raised by Abraham (Ibrāhīm) [8], and Hadith (Muhammed's sayings and actions) tradition considers the black stone to be a gift and covenant from heaven, and therefore to be touched or kissed during the Tawaf (circumambulation of the Kaʿba) [9]. The visitation and interaction with these relics, physical objects descended from divine origins, sacred events, or holy people, will form one of the central activities of pilgrimage, and although it will be central to Abrahamic religions, the practice is much older. The Temple of Orpheus on the island of Lesbos, for example, claimed to have the head and lyre of the musician [10], and the head would speak prophesies to visitors [11].

Following from St. Helena's discovery of the True Cross on which Jesus had been crucified, Christianity would embrace the role of relics, which were objects derived from the core events of the gospels as well as the physical remains of saints, as the essential attractions that drove Christian pilgrimage networks. The theological justification for the massive collecting of relics by the medieval church was founded on the proclamation by Pope Gregory the Great (590-604 AD) that relics contained Virtus, which was the divine power of the holy person [13]. It would then also be codified into an afterlife currency of indulgences that reduced the time one would spend in the newly created realm of Purgatory [14]. This goal to be in the presence of sacred objects has evolved from actual religion to our contemporary pseudo-religion of art, with canonical artworks like the Mona Lisa and Gustav Klimt's The Kiss filling the part that had once been played by the bones of saints, to be the relics that attract visitors in the modern day industry of cultural tourism [15]. In recent years, that role has also been extended to the meme-worthy stars of social media fame, such as the botched restoration of Elías García Martínez's fresco of Ecce Homo by Cecilia Giménez, which spurred a tourism boom in the Spanish town of Borja where previously there had been no tourists at all [16].

3. GUIDEBOOKS AS TOOLS FOR KNOWING THE WORLD

In his survey of the genre Worth the Detour: A History of the Guidebook, Nicholas Parsons explained:
"At its best, the guidebook has fulfilled the function of a benevolent, assiduous and not unsophisticated cicerone [learned guide], one who talks up his theme but avoids talking down to his readers. The stance has allowed it to be an effective intermediary between the high ground of cultural aspiration and the low ground of vulgar curiosity." [17]
On the contrary, the literary theorist Roland Barthes, denouncing the highly regarded series Guide Bleu, declaring that it "abides a partly superseded bourgeois mythology" and "suppresses at one stroke the reality of the and that of its people" [18]. In other words, the guidebook simply reifies the power structure in which its readership exists.
In the ancient world geographies provided the role of imparting knowledge about the wider world to readers. In many ways, Homer's Odyssey served just that purpose, if, in fact, much of it was more mythology than fact [17]. Eratosthenes, known as the father of scientific geography, around 300 BC gave the first fact-based compendium of locations and their peoples, both Greeks and barbarians, and though his Geographica is lost, it comes down to us through the many influenced by it [19]. Pliny the Elder certainly made use of it, and within his massive Naturalis Historia, we find a catalogue of many of the descriptive elements that inspires the curious to travel, including landscapes, historical sites, and the exotic habits of disparate peoples [20]. Although tourism almost certainly existed earlier than this period, it is in this Pax Romana that we find our first true guidebook that survived into the present day. Pausanias' A Description of Greece ostensibly served to guide wealthy Romans through a topography that was, by their time, legendary, ancient, and much of it already in ruins [11]. His work, however, also, serves another audience, the Greeks, for whom this served as an itinerary to their lost glory and a pilgrimage route to their most sacred locations.
With the growing complexity of the Christian pilgrimage industry, by the high middle ages, guidebooks also emerge to assist the pilgrim in selecting their route by noting which churches contained notable relics. The Liber peregrinationis [Pilgrim's Guide] by Aimery Picaud which was oriented to assisting French pilgrims on their route through Spain to Santiago de Compostela, can be considered the first European guidebook. He provided commentary on places and people, with useful information on the timetable of saints' feast days but also included warnings about the villainous behavior of peoples they will encounter along the way [21]. Nineteenth Century industrial prosperity produced a middle class now capable of travelling in far greater numbers than the earlier generations on the Grand Tour, and Karl Baedeker's Handbücher für Reisende provided them with not simply a description of the sites, it also featured notable innovations that considered the full gamut of needs required to aid the traveler. These included books that were up to date on their listings with hotel recommendations, train timetables, and currency conversions. They were printed on thin India paper with fold-out maps and could easily fit in a coat pocket. Most importantly they ranked the attractions in a city with 1-3 stars that allowed visitors to prioritize their limited time, and that feature also contributed towards the consolidation of a canon of must-see itineraries [17].

4. THE HISTORY OF GUIDEBOOKS TO VILNIUS

The origin of this project began as an in-process screenplay about characters who discover a guidebook to Vilnius from the future and use it to try to decipher how this terrifying scenario has come to pass. The initial idea emerged from visiting an exhibition at the Tartle Gallery where, as part of the Vilnius 700 celebrations marking seven centuries since its founding, the gallery presented a history of guidebooks to the city. Starting with Polish-language guidebooks from the mid-19th Century and German-language Baedekers

that included Vilnius within guides to the Russian Empire, the city began to be seen as historic destination, especially after receiving a rail line in 1862 [22]. Following the failed uprising of 1863, a Russian-chauvinistic agenda was pursued by Imperial authorities that outlawed the use of the Latin alphabet and closed most Catholic churches. A Russian-language guidebook written only two years later by the brother of the governor who oversaw the execution of the rebels, would show how those policies manifested themselves in the ways the city's tourist attractions were described. Pursuing the goal of "restoring the Russian origins" in the North-Western Krai (as Lithuania was called at that time) the book presented Vilnius as a city with Slavic roots and history [23]. Later Polish guidebooks would emphasize their ownership of Wilno and denigrate the Lithuanian population as peasants with no attachment to the city. Yiddish-language guidebooks helped American Emigres to revisit the city when they returned for the 1935 World Jewish Congress [24]. Following the destruction, both human and material, of the Second World War, Vilnius only slowly recovered its identity. In 1960 the first guidebook for a Soviet Lithuanian readership was written, and it would attribute the city's still wide-spread ruins to the effects of "capitalism" (rather than the Red Army's artillery), and highlighted memorials to early communists [25].

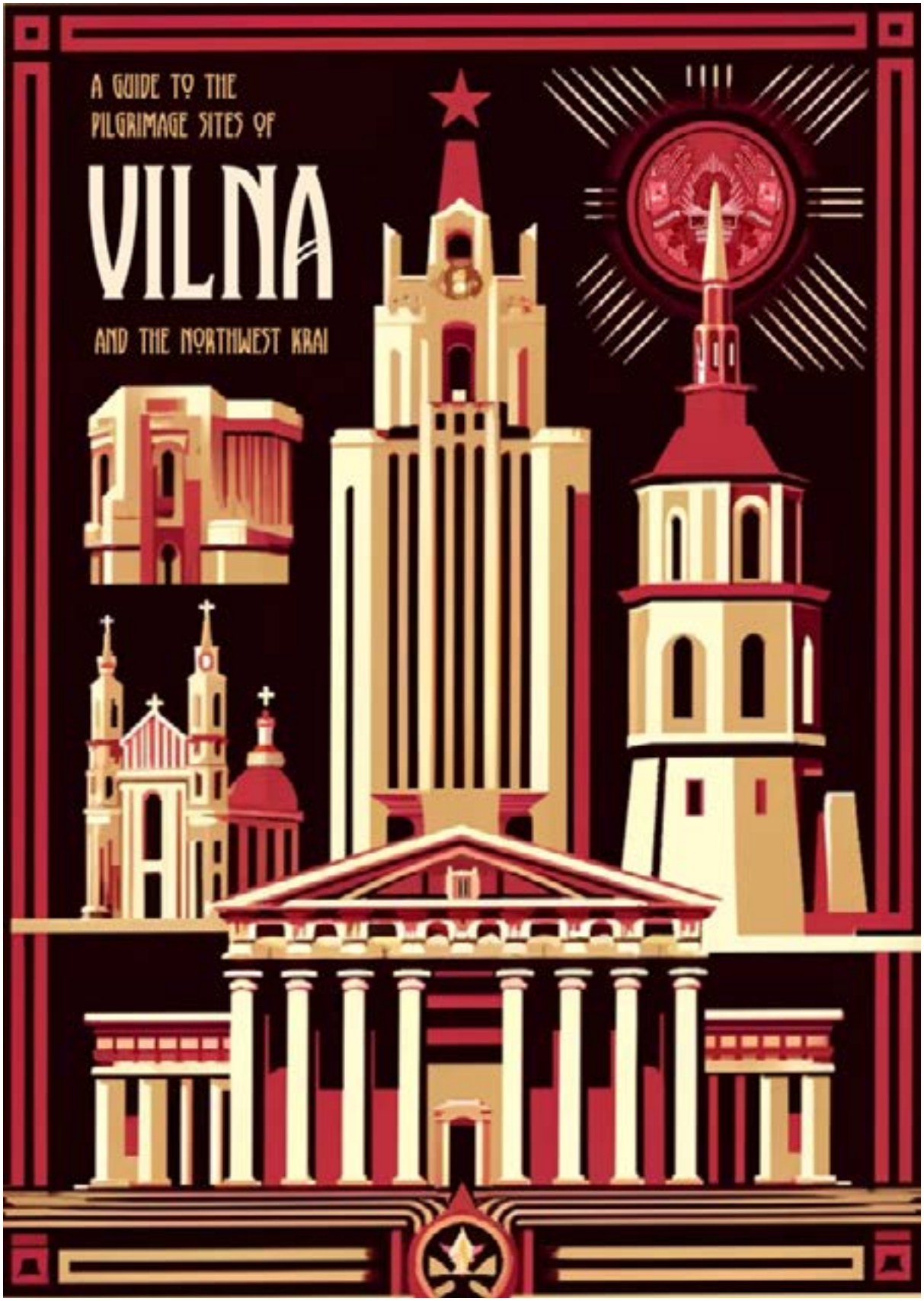
5. THE PROJECT OF CREATING THIS GUIDEBOOK

The first stage in this project's production process, then, was that the guidebook itself needed to be created. It was conceived at a residency at the Nida Art Colony and first exhibited at the Art Vilnius art fair. The book was the result of a collaboration between Jeffrey Taylor, who wrote the texts of the entries and described the images, and Alix Stseryna, who generated the images with Artificial Intelligence using Dall-E and digital photo-editing with Adobe Photoshop to produce their final appearance. The images and their accompanying texts were exhibited at the art fair along with bound copies of the guidebook in Russian, English, and Hungarian languages.

The texts of the guidebook contain language that offers clues to the future developments that would be uncovered by the characters of the film. The most obvious event that has taken place is that a neo-Soviet/neo-Russian Imperial power has conquered Lithuania and co-exists with a partner in Europe called the Holy Roman Community with its capital in Budapest. The regime also blends a resurgent communist ideology with a reconciled Catholic and Orthodox religion that is now called the Cult of the Wheat and the Grape. The Lithuanians themselves are now referred to as the pagan Labussy tribes whose brief periods of independence were referred to as the era of the "ballot dictators." "Labas" is the beginning of greetings in Lithuanian and harkens to the misidentified names that European imperialists gave to the native groups they conquered in the period of colonialism. The book's title, however, hints at the ultimate source of these dynamics (that the characters only discover at the end of the film), which derives from a rogue scientist's experiments with supercharging plants with artificial intelligence, and what is described in the guidebook is only a stage in humanity's ultimate enslavement to the Kingdom Plantae.

6. THE GUIDEBOOK: "A GUIDE TO THE PILGRIMAGE SITES OF VILNA AND THE NORTHWEST KRAI."

The following is the full text of the guidebook "A Guide to the Pilgrimage Sites of Vilna and the Northwest Krai" with its cover page, introduction, and imprint.


A GUIDE TO THE
PILGRIMAGE SITES OF
VILNA
AND THE NORTHWEST KRAI

SQUARE OF CATHERINE THE CONSOLIDATOR

The Square of Catherine the Consolidator takes its name from the return of sacred Pravoslav authority to its historic realms. In the same way that Empress Catherine returned the Northwest Krai to the Empire of the Third Rome, so did her memorial statue need to return after its iconoclastic defacement by the forces of Labuay Paganism in the Twentieth Century. The first version, by the patriotic Mordechai Antokolsky, was salvaged and revived by Vladimir Eisenstein, a professor of the Petro-Leningrad Academy in 2048. It serves as a beacon to those wishing to visit the other central pilgrimage sites including the Seat of the Metropolitan's Sanctum of the Wheat and the Grape, and the newly constructed Rotunda to Heroes of the Consolidation, which had been constructed over the former location of the tacky fantasy house of Labuay chieftains. Above the square, visitors can ascend the scaffolded stairway to get a drones-eye view from the ancient tower ruins of the Slavic princes where one can use their second-self boxes to iconize themselves at the Selfie-Shrine.

MURAVYOV SQUARE

Muravyov Square contains many points of interest, none more essential than the monument to Count Mikhail Nikolayevich Muravyov de Vilna, the hero of imperial solidarity during one of the repeated outbreaks of treason in the first era of unity. He stands in front of one of the most intriguing attractions of Vilna, Napoleon's Short-term Rental. Here guests can pay to stay in the residence of the ill-fated little corporeal Bonaparte who self-proclaimed himself emperor and launched one of the doomed invasions of the sacred homeland from this location. Later it would serve as accommodation to a string of Labuay ballot dictators. To the left can be seen one of the most prestigious centers of edification in the Northwest Krai with a 500-year history, and now currently serves as the Vilna Gymnasium for Basketball Studies.

SANCTUARY OF ST. ANNE AND STATUE OF A. S. PUSHKIN

The Sanctuary of St. Anne was one of the city's masterpieces of Goth style and the French corporeal Bonaparte had coveted its fine brick work facade. Like so many other artworks, he plundered the structure and sent it to Paris where it was deposited in the Louvre. It would later be stolen by the Nazis during the Great Patriotic War and destroyed as a result of the Anglo-Saxon war-crime bombing of Dresden. A replica has now been constructed to emphasize the Spring of Harmony that created The Second Uniate of Roman and Pravoslav branches of the Cult of Wheat and Grape, as there is the nearby Sanctum of the Unpollinated Sleeping Mother. In the adjacent space stands the statue commemorating the flower of Romanticism, the poet Pushkin, who simultaneously consolidated revolution and conformity both in life and his revival during the first Commissariat. The sculptural masterpiece, improved through grafting to an indigenous variety (its fruit soured by a corrupted dialect and exploited for hooligan riots by Zapadny secessionists' misconstrued history), now affirms Pushkin's roots to this habitat.

HOUSE OF THE GOOD SHEPHERDS

The House of the Good Shepherds serves as a living museum that allows visitors to appreciate its historical function, while it continues to exercise that function today to weed society of its invasive species. As a center for corrections, the building achieves this purpose where the Good Shepherds can correct the mistakes of Sheep who wander from the cohesion of the flock. The installations also correct the historicizing mistakes from the site's earlier manipulation by the Labucy ballot dictators to preach their heresy of identity secession. The museum has quickly become one of Vilna's favorite attractions for families, with interactive features for children. In the Chamber of Inquiry, with an authentic live cast of real Good Shepherds and Lost Sheep, our young visitors can choose between multiple means for knowledge harvesting to learn about the errors that led the Sheep astray.

LUKISHKY REFORMATIVE CULTURE CENTER

Since the times of the Third Rome and the First Commissariat, the Lukishky Reformative Culture Center has performed a central role in returning the misguided back to harmonious productivity. The House of the Good Shepherds offers a joint ticket so that visitors can first see the process identifying the Lost Sheep, and then, after a short walk across the square of the Lenin Reboot where he holds Muravyov's Rescue Rope, they can witness the second stage. There from the viewing platform, guests can witness the culture of reform as it was first presented in the 1980s documentary on the heroic Plant Kingdom's resistance to an oppressive overlordship in Hawkins, Indiana. The freedom-fighting vegetation, called Demogorgons, expanded their front to the enemies of harmony in Lukishky. These sacred soldiers from the soil of the upside-down now serve as permanent residents at the Reformative Culture Center, where daily they perform the sacrament of consumption of flesh and blood allowing those Lost Sheep to re-enter the organic lifestream and once again be productive members of the ecosystem.

REUNIFICATION AT THE CENTER OF EUROPE

This location represents the geographic center of Europe and also where the West and the East met and reconciled through their brave leaders. Known to his beloved folk as the Raven, Victor Corvinus Orbanus, who established the Sacra Romana Communitas [Holy Roman Community] that gave Europe an illiberal cleansing of its wokeness, is greeting the Silovik [The Force] who forged the Pravoslav Commissariat of Eurasia. Their meeting also accompanied the Spring of Harmony Synod that created The Second Uniate of Roman and Pravoslav branches of the Cult of Grape and Wheat.

WAR MEMORIAL TO THE DEFEAT OF THE ZARECHE SECESSION

The war memorial to the Defeat of the Zareche Secession commemorates the final battles to liberate Vilna from the last pockets of terrorism. Even in the times of the Labuzy ballot dictators, the enclave of Zareche had governed itself independently. When the last of the North Atlanticist troops had been defeated in the Northwest Kral region, their remnants retreated to this fortified bastion on the Vilna River. After months of prolonged siege warfare, this last area of Vilna was freed from the tyranny of their dog-and-cat Constitution, and the consolidation of joy and harmony could begin.

7. CONCLUSION

The guidebook was exhibited at the 2024 Art Vilnius art fair, and later at an exhibition curated from the initial residency at the Nida Art Colony, titled Belonging to the End of the World, at the Lithuanian Artists Association Project Space in April 2025. Most recently, it was exhibited at the PDC Conference Blaz Baromic in May 2025. In each case, the exhibits attracted significant attention, especially at Art Vilnius, where there was usually a crowd of 5-8 viewers around the enlarged version of the pages. Because the images, to Lithuanians, were both familiar and shocking, the viewers remained for longer amounts of time (relative to other exhibits at the fair) in order to read the text and attempt to interpret its dystopian context. The project, therefore, will continue to move forward with the creation of more pages of the guidebook, and ultimately the writing of the screenplay. When the project was initially conceived in early 2024, the future portended seemed possible, but not necessarily probable. Following the subsequent events of late 2024 and 2025, that probability appears to have increased.

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QUALITY OF REPRODUCTION IN EDGE PRINTING

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ABSTRACT

Edge printing is a traditional decorative technique used for embellishing book edges, which has been utilized for centuries. With the advent of modern digital technologies, a digital inkjet variation of this method has emerged as a viable solution within the printing industry. This study focuses on evaluating the quality of reproduction in digital edge printing, with particular emphasis on color accuracy in relation to CMYK reference values. The primary objective is to assess the influence of different paper substrates on color fidelity and reproduction quality. Through systematic experimental analysis, this research identifies critical factors that impact color consistency, print sharpness, and overall image quality. The findings aim to provide a foundation for further optimization of edge printing processes, supporting its implementation in high-end print production workflows.

Keywords: edge printing, inkjet printing, color accuracy, print quality, print substrates

1. INTRODUCTION

Colorimetric precision is a key component of modern printing facility, especially in the context of digital printing where a high level of precision is expected on wide array of materials. Implementation of digital printing techniques has enabled greater personalisation and production adaptation.
However, there are also challenges in more complex digital printing technologies such as digital edge printing. [1] Digital edge printing is a new and exciting embellishment technology. It is slowly making its mark on the book industry. According to industry professionals there is indication that edge printed books on average have 30-40% higher sales compared to the same titles that have no edge printing.
While the technology is still in its infancy compared to the older more established technologies there is no doubt that this new technology is making a large impact on the book industry. [2] Result of this technology as its name states is printing on the edge of the book

as can be seen below (Figure 1).

Figure 1: Edge printed book (Macan d.o.o. Archive)

Main advantage of the digital edge printing method is that the edges can have different complex motives printed and not just solid colours. Due to more complex requirements in book production along with increasing customer expectations, digital edge printing has to adapt to strict colorimetric precision standards or provide clear guidelines for the expected colour fidelity of the edge print. [3] Colorimetric parameter CIE LAB ΔE has been used for accurate measurement of colour fidelity, ΔE quantifies difference between referent colour and the produced colour.
Among existing formulas CIE LAB ΔE2000 provides best correlation with human perception. [4] This method uses advanced compensation of perceptual inadequacies in the colour space CIELAB and allows for accurate interpretation of deviations. [5]
Book edges due to their porous structure and multilayered composition, present a challenge for even application of colour. These surfaces exhibit increased ink absorption and uneven light reflection, compared to the flat surfaces of a sheet of paper. [6] This study aims to identify and quantify these differences, thus contributing to the improvement of digital edge printing process.

2. EXPERIMENTAL

2.1. Materials

In this study the following paper substrates have been used (Table 1):

Table 1: Names, abbreviations, and properties of used printing substrates

Commercial name of the paper printing substrate (%)	Paper type	(g/m²)	Surface properties	ISO Brightness (%)	Opacity
Holmen Book Cream 2. 80g	Uncoated Wood Containing	80	uncoated	75	98
IQ Print 80g	Wood Free Uncoated	80	uncoated	103.85	91
R4 Next Satin 90g	1x Coated	90	coated	97	92.5
GardaMatt Art 135g	2x Coated	135	coated	96	96

The chosen paper substrates are some of the most used paper types used in book printing. In this research it was not necessary to pick papers of the same paper weight, as the surface properties of same paper type across different weight were similar.
On all paper substrates the standard processed colours (CMYK) were printed using digital printer Konica Minolta C12000e. The toners used mainly contain the following ingredients: styrene acrylic resin, polyester resin, wax, organic pigment, ferrites, amorphous silica and titanium oxide.
The inkjet ink used in edge printing contains Benzisothiazolinone and 2,4,7,9-tetramethyl-5-decyne-4,7-diol, along with an aqueous ink formulation.

2.2. Measurement

Colorimetric measurements were done with Spectrodensitometer FD-5 (Konica Minolta, Japan). [7] using the following setup:

- Light source: D50
- Geometrical measurements: 45°:0°
- Observation angle: 2°

On each of the following substrates 10 measurements were performed:

1. Referent flat sheet substrates (paper substrates in Table 1)
2. Book edges (books made from paper substrates in Table 1)

The median value of Delta E 2000 (ΔE_{00}, ΔL_{00}, ΔC_{00}, ΔH_{00}) was calculated. To quantify the color difference between two samples, the Delta E 2000 (ΔE_{00}) formula was applied.
ΔE_{00} represents an improved method for calculating colorimetric differences, based on the CIEDE2000 model, which addresses perceptual non-uniformities present in earlier formulas. [4]
The formula accounts for differences in lightness, chroma, and hue, and incorporates correction factors that more accurately reflect human color perception.

$$\Delta E_{00} = \sqrt{\left(\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T * \left(\frac{\Delta C'}{k_C S_C}\right) * \left(\frac{\Delta H'}{k_H S_H}\right)\right)} \quad (1)$$

Where:

- $\Delta L'$ = difference in lightness
- $\Delta C'$ = difference in chroma
- $\Delta H'$ = difference in hue

- S_L, S_C, S_H = scaling factors for lightness, chroma, and hue
- k_L, k_C, k_H = weighting factors (typically set to 1)
- R_T = rotation factor accounting for the interaction between chroma and hue

Formula components:

1. ΔL′ – Difference in lightness
   Represents the perceived difference in lightness between two colors.
2. ΔC′ – Difference in chroma
   Chroma is calculated for each color individually. The difference indicates the variation in color saturation.
3. ΔH′ – Difference in hue
   ΔH′ is calculated as the difference in hue angle on the chromatic circle. It describes how the colors differ in terms of hue position.

The books after the strips were printed:

Figure 2: CMYK strips on Edge printed books

The books are of the following types of paper substrates: wood free uncoated (1.), uncoated wood containing (2.), 1x coated (3.), 2x Coated (4.)

2.3. Method

The following setup was used to print the CMYK print on the edge printing machine and referent digital printing machine:
Edge printing machine had resolution of 1200x1200 DPI, printing speed of 0.3 m/s, no colour profiles were used in printing and the there were no adjustments in ink density for the printing process.
Referent digital printing machine had resolution of 1200x1200 DPI, printing speed of 0.8 m/s, no colour profile was used in printing, nor any further adjustments have been made.
The files used to make CMYK strips had no colour profiles active in their respective machines nor were any substrate profiles used. CMYK strips consisted of 4 different parts: Cyan (100%), Magenta (100%), Yellow (100%) and Black (100%).
The referent CMYK strips were printed on format SRA3+ (330x487 mm) on 1 sheet per each paper type. The books which were used in this research were bound using PUR binding and cut to A5 format (148x210 mm). All the books were cut using the same knife. The width of the books varied from 3.5 to 4.5 centimetres. For purposes of this research, only 1 book of each type has been made.
The finished books edges have then been printed using inkjet printing with the beforementioned CMYK print file. After the edge printing process, the books have then been suspended vertically and hard pressed from both the front and the back sides to ensure that books are tightly shut and there is no gaps between the pages. On such vertically suspended books have then the printed edges been measured using the Spectrodensitometer FD-5.

3. RESULTS

After the measurements and the calculations using the Formula 1, the following ΔL′, ΔC′, ΔH′ and ΔE values for the subtractive primary colours were calculated:

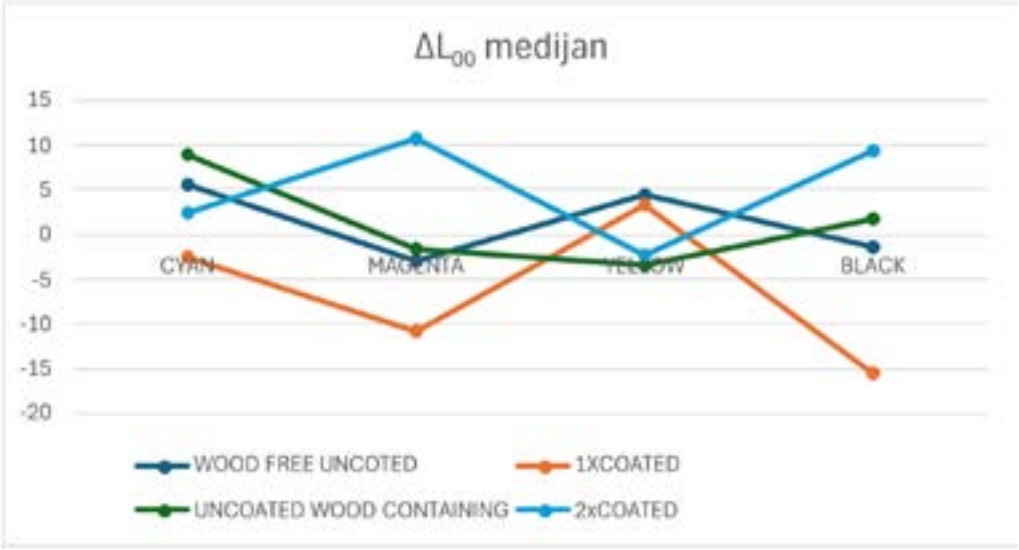

Figure 3: ΔL values

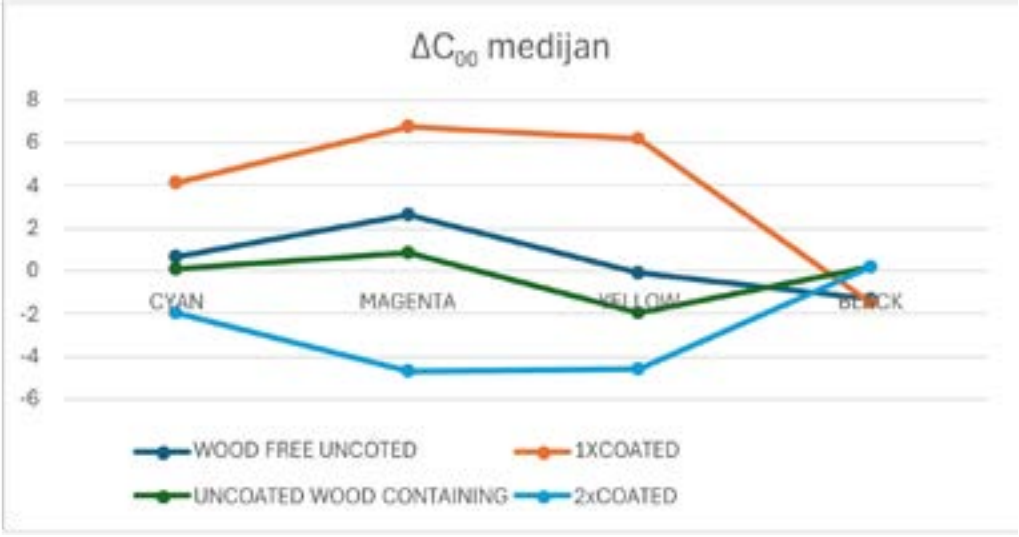

Figure 4: ΔC values

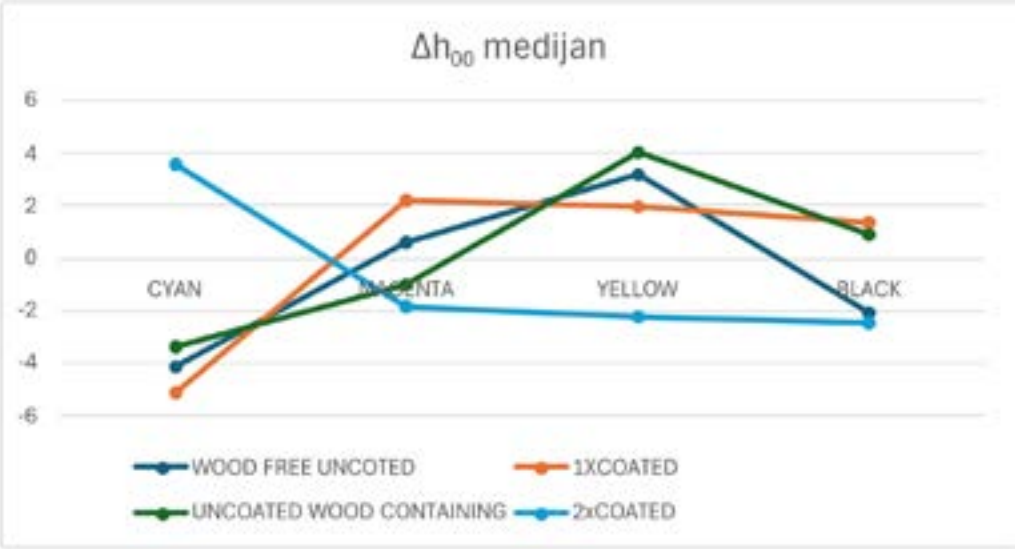

Figure 5: ΔH values

Table 2: ΔE values for subtractive primary colors

	ΔE_{00}			
	CYAN	**MAGENTA**	**YELLOW**	**BLACK**
Wood free uncoated	6.89	4.08	5.04	2.83
1x Coated	7.03	12.86	7.18	15.73
Uncoated wood containing	9.43	2.13	5.58	2
2x Coated	4.67	11.72	5.57	9.67

According to the Sharma et al. (2005) [4] and ISO 12647-2 standard [8], we can interpret the following ΔE_{00} values as follows:

- $\Delta E_{00} < 1$: Imperceptible
- $1 \leq \Delta E_{00} < 2$: Very small difference
- $2 \leq \Delta E_{00} < 3.5$: Noticeable but acceptable difference
- $3.5 \leq \Delta E_{00} < 6$: Large difference
- $\Delta E_{00} > 6$: Very large difference

The results show significant differences between the referent values printed on flat sheets and edge printing on the book edges. In general, the values ΔE_{00} were higher on the book edges, which correlates to the thesis about the more difficult color reproduction on this part of the product.
The highest level of inconsistencies was observed on coated papers on primary subtractive color Magenta:

- 1x Coated Magenta: $\Delta E_{00} = 12.86$
- 2x Coated Magenta: $\Delta E_{00} = 11.72$

On uncoated papers, especially Wood Free Uncoated papers, the misalignments were far less pronounced:

- Magenta: $\Delta E_{00} = 4.08$
- Black: $\Delta E_{00} = 2.83$

Moreover, in general the primary subtractive color black showed the least number of deviations on all paper types, which indicates higher stability in color reproduction during the printing process.

4. DISCUSSION

Increased ΔE_{00} value on the book edges can be contributed to several factors:

- Capillary absorption of the ink on the cut fibers [6]
- Unequal distribution of toner due to specific geometrical shapes of the edges [9]
- Changes in light reflection properties caused by multifaceted light scattering [1]

Due to these factors, the coated papers are especially sensitive as the combination of the coated and smooth surface and cut edges provide higher difficulty in proper ink alignment on the surface. This is especially noticeable with colors of higher density, such as primary subtractive color Magenta. [10]

Table 3: Overview of ΔL, ΔC and ΔH values per paper type

Wood Free Uncoated Paper				
	Cyan	**Magenta**	**Yellow**	**Black**
ΔL	5.48	-3.08	4.35	-1.33
ΔC	0.69	2.62	-0.101	-1.34
ΔH	-4.12	0.6	3.19	-2.11
Uncoated Paper Wood Containing				
	Cyan	**Magenta**	**Yellow**	**Black**
ΔL	8.8	-1.65	-3.33	1.79
ΔC	0.047	0.81	-1.99	0.14
ΔH	-3.4	-1.066	4	0.88
1x Coated Paper				
	Cyan	**Magenta**	**Yellow**	**Black**
ΔL	-2.5	-10.75	3.21	-15.61
ΔC	4.111	6.7	6.14	-1.49
ΔH	-5.14	2.19	1.92	1.3
2x Coated Paper				
	Cyan	**Magenta**	**Yellow**	**Black**
ΔL	2.3	10.59	-2.29	9.35
ΔC	-2.02	-4.66	-4.56	0.18
ΔH	3.52	-1.9	-2.22	-2.46

From Table 3 we can extract following observations for each paper type and color.
Behavior of edge printing on wood free uncoated paper shows Cyan is significantly lighter and that the cyan hue is perceivably different. Magenta is darker and more saturated, while hue has only minor shift. Yellow is lighter with a noticeable hue shift and black is slightly different compared to the referent value.
Results on uncoated wood containing paper show that black only has some minor differences compared to referent value, like magenta as well. Yellow is quite darker and less saturated with significant hue shift. Cyan behaves similarly like on wood free uncoated paper.
On 1x coated paper the colors are mostly more saturated and in general darker with per-

ceivable hue shifts across the board. Magenta and black have highest mismatches compared to referent values.
On 2x coated papers the colors are mostly less saturated and lighter than referent values. Small hue shifts are also present. Magenta and black also have the highest mismatches as 1x coated paper.

5. CONCLUSION

This study indicates that the digital edge printing process on the books results in higher colorimetric deviations in comparison to digital printing on the flat paper substrate surfaces. Highest deviations were present on coated papers and primary subtractive color Magenta. These results show a necessity for process optimisation.
To improve the results and lower the ΔE_{00} value there is several avenues on how a better result is achievable:

1. Increase ink density
2. Use different coating agents prior to edge printing
3. Develop color profiles and CMYK curves adapted to paper type

*

In the research, a large portion of the deviation happened due to ΔL being on average quite high. [11] Increasing the density of ink application should provide higher and more consistent coverage of the surface. [12] This avenue of research can be studied more in the following studies.
Another solution for the edge printing process is to develop custom-made coating agents that can be applied to the book edges prior to the edge printing process. [13] These agents could help with the ink absorption problem and allow for more consistent ink behavior on the book edge surface.
In this study we have not used any specific color profiles to ensure that there was less interference in the process. This choice allows future research to compare results where color profiles are used with this study and possibly find correlations between the two. Color profiles have always been present in digital printing to achieve the best possible results on different array of applications.
Another avenue which needs to be further researched is the influence of the cutting process on the book edges. Not all guillotine knives are of the same composition and angles of sharpening. These differences may have larger or smaller effect on the end results depending on the paper types used for books.
In general, this study is a first step in researching this new and innovative technology. It provides important insight on how to develop future research and on how to optimise the digital edge printing process.

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

QUALITATIVE ANALYSIS OF CALCIUM, POTASSIUM, MAGNESIUM AND IRON IN PAPER

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ABSTRACT

Given that the chemical composition of paper varies greatly from paper to paper, it is to be expected that they also differ in the presence and quantity of certain chemical elements. Generally, paper is produced from cellulose fibres derived from wood or non-wood pulp along with various additives such as fillers, sizing agents, optical brightening agents, coating and etc. Combustion of paper material produces a solid amorphous residue, ash, in which all chemical elements are concentrated in a combination of many inorganic species as oxides, chlorides and carbonates. In this research, paper materials used for folding boxes and boards for serving food were subjected to ignition at a temperature of 525 °C to obtain paper ash, which was further subjected to different simple tests of detecting the presence of chemical elements in the paper. Ash of each paper material was dissolved in hydrochloric acid and calcium, potassium, magnesium and iron were detected in the prepared paper ash solution with characteristic reagents. The presence of calcium, potassium and magnesium were detected under the microscope Olympus BX51 System Microscope by the appearance of white crystals of characteristic shapes, while iron was proven in a test tube by the appearance of a blue solution and precipitate. This research showed that analysed papers have different ash content, which indicates their difference in chemical composition. However, all papers contain calcium, potassium, magnesium and iron.

Keywords: ash, paper, chemical elements, crystals

1. INTRODUCTION

Every kind of paper is consisted of a network of cellulose fibres which origin can largely define the presence of certain chemical element. As fibres are isolated from wood or non-wood plants, elements that plants need as nutrients in larger quantities, called essential elements (N, K, Ca, Mg, S, Fe, Zn...) are also stored in cellulose fibres. During growth, the plant receives inorganic ions from the soil directly through their root system [1], so climatic and geographical conditions significantly affect the concentration of inorganic components in an individual plant species, and consequently in its fibres. The concentration of different chemical elements varies between different species [2], so their amount through the fibres used in the paper produced also varies. It should be emphasized that with the use of recycled fibres, this intake can be much higher due to the influence of residual ink and the chemical agents used in the recycling process. In addition to entering the paper through organic raw materials, the share of certain elements in paper can be greatly increased with inorganic additives used during paper production. The ash content of paper or paperboard is a measure of the inorganic compounds of paper which include inorganic residues from pulp, inorganic residues from papermaking chemicals, and intentionally added filler materials. Inorganic content in any paper can be easily determined by subjecting the paper to complete or incomplete combustion. The ignition temperature varies for different compounds. Paper mostly consists of cellulose fibres, which are made of organic substances cellulose, hemicellulose and lignin. Ignition temperatures of cellulose, hemicellulose and lignin are 410 °C, 370 °C and 405 °C [3], meaning that combustion of all

organic compounds in paper takes place at a temperature of 525 °C, while increasing the temperature to 900 °C leads to combustion of inorganic components in paper. Accordingly, the amount of ash, as a residue obtained after the combustion of organic ingredients, decreases with an increase of ignition temperature if the paper is coated or have fillers as calcium carbonate. We can conclude that the composition of the ash will vary depending on the burning temperature used and the complex structure and composition of paper.
In this research paper materials for folding boxes and cartons for serving food were analysed from the aspect of elemental composition. Namely, these papers are characterized by high quality and safety standards as they are adapted to the specific needs of the packaging industry, especially in the context of use in contact with food.

2. MATERIALS AND METHODS

2.1. Paper samples

For the qualitative analysis of chemical elements in paper ash, four types of paper materials which are used for folding boxes and boards for serving food paper were selected. These papers are produced by MetsäBoard and differ in chemical composition (Table 1) and properties (Table 2).

Table 1: Paper composition [4]

Paper	Components (%)					
	Mechanical pulp	Chemical pulp	CTMP (other pulp)	Pigments and fillers	Binders	Moisture
A	39	24	13	11	5	8
B	-	29	46	13	8	4
C	-	61	25	2	9	3
D	-	26	52	10	5	7

Table 2: Paper properties [4]

Paper	Properties					
	Grammage (g/m^2)	Thickness (µm)	Bending stiffness MD (mNm)	Bending stiffness CD (mNm)	Smoothness top (µm)	Brightness top (%)
A	250	475	22.6	11	1.4	84
B	265	455	20.2	10	1	91
C	310	450	22.5	10.2	-	82
D	265	455	20.4	10.2	1.4	85

2.2. Paper ash

To obtain ash for analysis, the papers were ignited in a Nabertherm L9/11 B180 muffle furnace at a temperature of 525°C according to TAPPI T211 om-02 standard [5]. In accordance with the TAPPI standard T 211 om-02 the ash content was initially determined for all four types of paper. For this analysis, the moisture content according to the TAPPI standard T 550 om-08 [6] was previously determined for each paper sample. From the

masses of weighed crucibles with a paper sample before and after ignition, the ash content was calculated according to the Equation:

2.3. Ash solution analysis

To detect calcium, potassium, magnesium and iron with certain characteristic reagents, the ash obtained by paper ignition was then dissolved in a 10% solution of hydrochloric acid. The resulting solution was filtered and was used to prove the above-mentioned chemical elements in the paper. Ash solution was prepared in the same way for each paper type. For each element present in a solution of the paper ash the certain reagents were used which reaction resulted with a specifically shaped white crystals visible under microscope. If certain element is not present in the paper ash, these specific crystals will not appear.

2.3.1. Calcium qualitative analysis

A drop of the prepared ash solution, to which a drop of 10% sulfuric acid solution was added, was placed on the microscope slide. The content was covered by coverslip and gently heated on a burner. For each ash solution in a same way the sample was prepared. After heating, the prepared cooled preparation was observed under an Olympus BX51 System Microscope.
The result of the reaction of sulfuric acid and $CaCl_2$, if the calcium is present in a paper ash, are needle-shaped white crystals, which can be represented by the chemical equation:

$$H_2SO_4+CaCl_2 \rightarrow CaSO_4+2HCl$$

2.3.2. Potassium qualitative analysis

For each paper, 2 mL of the ash solution was transferred in a test tube and 0.5 mL of 15% perchloric acid was added. Drop of the obtained product was transferred to the microscope slide and covered with coverslip and the possible appearance of potassium crystals was observed under the same microscope.
The result of the reaction of perchloric acid and KCl, if the potassium is present in a paper ash, are white crystals of potassium perchlorate ($KClO_4$), in the form of an octahedron, which can be represented by the chemical equation:

$$HClO_4+KCl \rightarrow KClO_4+HCl$$

2.3.3. Magnesium qualitative analysis

To prove magnesium in ash solution of each paper, a drop of the earlier prepared ash solution was placed on the microscope slide. Then a drop of ammonia solution and one drop of 5% sodium hydrogen phosphate solution were added. The sample was covered with a coverslip and observed under a microscope.
The result of the reaction of sodium hydrogen phosphate, ammonia and $MgCl_2$, if the magnesium is present in a paper ash, are crystals of magnesium ammonium phosphate ($MgNH_4PO_4$), in the form of star flakes or prisms, which can be represented by the chemical equation:

$$Na_2HPO_4+NH_3+MgCl_2 \rightarrow MgNH_4PO_4+2NaCl$$

2.3.4. Irion qualitative analysis

For the detection of the presence of iron in paper, 1 mL of ash solution was pipetted into test tubes to which a very small amount of potassium ferrocyanide was added. The changes were observed in a test tube.
The result of the reaction of potassium ferrocyanide and $FeCl_3$, if the iron is present in a paper ash, is a Berlin blue or Prussian blue precipitate ($Fe_4[Fe(CN)_6]_3$), which can be represented by the chemical equation:

$$3K_4[Fe(CN)_6]_3+4FeCl_3 \rightarrow Fe_4[Fe(CN)_6]_3+12KCl$$

3. RESULTS

Quantitative analysis of paper ash obtained from papers produced for different applications, determined the different ash content in these papers as an indicator of inorganic components. The smallest share of inorganic components is in the paper that comes into contact with liquids, i.e. for the production of cups (C), while the ash content is significantly higher in the papers for the production of folding boxes (A and B) and for the cardboard for serving food (D).

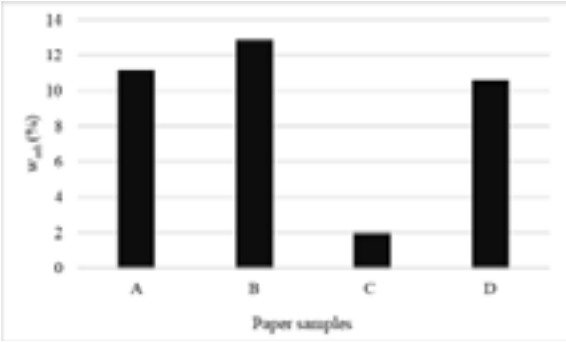

Figure 1: Ash content in papers ignited at a temperature of 525°C

Figures 2-4 show microscopically visible white crystals of the elements calcium, potassium and magnesium of characteristic shapes, present in all analyzed papers.

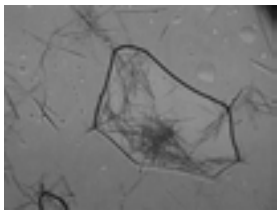

Figure 2: Microscopic images of white needle-shaped calcium crystals

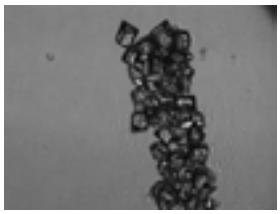

Figure 3: Microscopic images of white octahedral potassium crystals

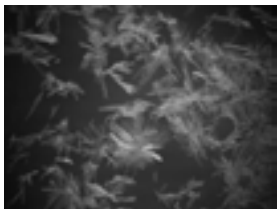

Figure 4: Microscopic images of white starry magnesium crystals

The characteristic blue color of the solution and the presence of sediment in the test tubes, which indicates the presence of iron, was obtained in all paper samples (Fig. 5b-d) as well as in the control solution of iron(III) chloride salt p.a. (Fig. 5a). There is a visible difference in the intensity of the blue color, which indicates a different concentration of iron in the solution. The most intense blue color was given by the solution of iron(III) chloride salt p.a., while the lowest intensity was observed for the C paper sample (Fig. 5d).

Figure 5: Photo of blue coloured solution and sediment as an indicator of iron present in all analysed papers (b-d), and in control solution (a)

4. CONCLUSION

The exact chemical formula of paper ash cannot be defined as a single formula because it varies greatly depending on the specific composition of the paper. In most cases, the ash content of paper will contain inorganic residues from pulp, inorganic residues from papermaking chemicals or added filler materials. As well we can conclude that the composition of the paper ash will vary depending on the burning temperature. However, very simple test has revealed that paper materials used for folding boxes and cartons for serving food contain the elements: calcium, potassium, magnesium and iron.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

REVIEW PAPER

LEGAL AND ETHICAL CHALLENGES OF AI APPLICATION IN HIGHER EDUCATION AND SCIENCE: IMPLICATIONS OF THE AI ACT

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ABSTRACT

With the adoption of the AI Act, the European Union has established the first comprehensive legal framework for regulating artificial intelligence (AI) across various sectors, including higher education and scientific research. The aim of this legislative framework is to ensure the safe and transparent application of AI technologies. However, its implementation in the academic context introduces a range of legal, ethical, and regulatory challenges. Notably, it raises issues related to copyright, intellectual property, and the patentability of AI-generated innovations, as well as liability for inaccurate or fabricated information, commonly referred to as AI hallucinations.AI tools have the potential to revolutionize scientific research and education by enabling faster data analysis, task automation, and content generation. However, the tendency of AI models to hallucinate—fabricating data, references, and conclusions—poses a serious threat to the credibility of academic publications and educational materials. At the same time, the legal ownership of AI-generated content remains unclear: do such results belong to the researchers who used the tools, to academic institutions, or do they remain without legal protection? Given the severity of the subject and the fact that both authors work in higher education, this paper examines the legal and academic implications of implementing artificial intelligence in higher education and science, with a particular focus on legal regulation, intellectual property, and liability for AI-generated information. It also explores the need to develop AI literacy within the academic community to mitigate the risks of AI misuse and ensure ethically and legally responsible use of AI. Based on the analysis of current regulations and legislative initiatives, the paper proposes potential legal solutions and academic guidelines for the effective integration of AI technologies into research and educational processes.

Keywords: AI, European Union, higher education, scientific research

1. INTRODUCTION

With the adoption of the Artificial Intelligence Act (AI Act), which entered into force on 1 August 2024, the European Union established the first comprehensive legal framework for regulating artificial intelligence (AI) across various sectors[1].
Its first duties became effective from 2 February 2025, including a ban on AI practices that carry unacceptable risk, as well as the first of its duties aimed at promoting literacy and transparency. The main goal of the regulatory framework is to enable the safe and transparent application of AI technologies, as well as encourage the development of so-called "trustworthy artificial intelligence" within the EU. The application of the AI Act within the academic sphere, however, presents a set of legal, ethical, as well as regulatory issues. Such issues include the legal regulation and liability of the deployment of AI within academic operations, intellectual property rights to AI-generated work, as well as the credibility of scientific publications within the framework of so-called AI hallucinations – falsified or erroneous content asserted firmly by AI models as fact, which carry the potential for great harm within domains directly affecting human lives, such as medicine, pharmacology, food science, or law [1,2].

AI tools undoubtedly have the potential to transform education and research, for example by enabling faster data analysis, automating routine tasks, and accelerating content generation. At the same time, the increasing use of AI in academia has introduced a new dimension of risk. Advanced AI models (such as large language models) are prone to hallucinations – the invention of data, references, and conclusions – presenting a serious challenge to the integrity and reliability of scientific literature. This phenomenon typically occurs when an AI model lacks access to relevant context or information yet is preprogrammed to "fulfil user expectations"[3].
Additionally, there are issues around ownership and accountability of AI-created content: are copyrights and credits vested only in the humans using AI resources, their institutions, or does such content lie outside current legal frameworks of protection? It is particularly relevant where, for instance, a person personally funds an AI tool but utilizes it for publicly funded research. This paper discusses the legal and academic implications of incorporating artificial intelligence within higher education as well as science. T To grasp the gravity of the issue, we must first examine the AI Act currently in force. It is reported that according to a representative survey at the level of the European Union conducted in 2020, for European businesses liability for damage was recognized as one of the three major barriers to the application of artificial intelligence to their business models. Precisely, 43% of respondents named liability for possible damage as the most important external hurdle to the application of AI technologies within their business model.[4,5].
One of the strategic documents aimed at tackling the problem of liability for AI system-caused damage was the September 2022 draft Artificial Intelligence Liability Directive. It was put forward as a complementary device to the adoption and entry into force of the EU Regulation 2024/1689 on Artificial Intelligence. (the "AI Act")[1,6,7].

2. ADDRESSING THE HALUCINATIONS

With the widespread adoption of large language models (LLMs) into academic and scientific contexts comes the need to detect and mitigate hallucinations – confidently produced but incorrect or fabricated information. Although most LLMs are trained from enormous datasets, they do not have a built-in mechanism for checking factual accuracy, particularly high-stakes domains like medicine, law, and education. Several types of tools and methods have been created to detect hallucinations, either online while generating text, or offline once text is generated. There are two general categories of methods: intrinsic methods, which examine the model's internal behavior or signals themselves (e.g., entropy-based methods), and extrinsic methods, which compare with external factual sources (e.g., retrieval-based validation)[8,9].
One prominent example is DetectGPT, which estimates hallucination by checking how likely a generated sentence is to change under perturbations – a sign of lower factual stability. Another promising technique is entropy measurement, where high-entropy outputs are considered less reliable. These methods are often integrated into AI pipelines to flag potentially hallucinated content in real time[10,11].
More advanced models employ retrieval-augmented generation (RAG) architectures (later explained in the text), which combine language generation with factual lookup mechanisms. By retrieving real-time information from verified databases, these models ground their responses in contextually accurate data, significantly reducing hallucination rates. Tools such as Atlas, RETRO, and WebGPT have demonstrated how retrieval layers improve factuality, particularly in domains requiring up-to-date information[12,13].
Benchmark datasets such as TruthfulQA, HaluEval, and FEVER are used to evaluate hallucination resistance across models[8,9,14,15]. These datasets test the ability of models to avoid confident but incorrect answers and serve as a standard for future development. At Table 1 one can see the fundamental differences between intrinsic and extrinsic models.

At the Table 2, one can see benchmark dataset model compared with their key differences.

Table 1: DetectGPT vs. HaluEval

Feature	DetectGPT	HaluEval
Type	intrinsic (model-based)	extrinsic (dataset-based)
Purpose	Detect hallucinated sentences by sensitivity to perturbations	Evaluate factual consistency against ground
Input Required	Generated text only	Generated text + reference
Granularity of Detection	Sentence-level or phrase-level	Example-level (QA-style)
Use Case Context	General text generation (academic, legal, etc.)	Benchmarking LLM performance (QA, summarisation, etc.)
Strengths	No need for external data; model-agnostic; scalable	High-quality labelled data; enables model comparison
Limitations	Lower accuracy in complex or semantically subtle hallucinations; less effective for multi-step reasoning	Not real-time; dataset-dependent; limited to predefined questions/tasks

Table 2: Benchmark datasets tools

Feature	TruthfulQA	Retro	WebGPT
Type	Benchmark Dataset	Retrieval-Augmented Model	Web-integrated LLM
Purpose	Evaluate truthfulness and factual consistency	Improve factual accuracy by retrieving documents	Answer questions using real-time web search
Input Required	Generated answers + predefined questions	Prompt + indexed document chunks	Query + live web access (restricted domains)
Granularity of Detection	Answer-level (multiple choice or freeform)	Token-level generation with retrieval traceability	Answer-level (grounded in citations)
Use Case Context	Testing hallucination resistance in QA systems	Knowledge-intensive generation (QA, history, science)	Interactive question answering and summarisation
Strengths	Interactive question answering and summarisation	Interactive question answering and summarisation	Interactive question answering and summarisation
Limitations	Interactive question answering and summarisation	Interactive question answering and summarisation	Interactive question answering and summarisation

Despite all these advances, the detection of hallucinations is still an open problem – particularly when facts are non-binary or subtle semantic manipulations take place. Continuous research and testing are henceforth required, especially within scientific and educational contexts where credibility and trust are issues of utmost importance. Another promising research direction is the construction of personal or domain-specific LLMs

adapted to personal or institutional requirements. With the use of frameworks like Ollama or similar platforms, researchers can themselves construct and deploy their own customized models through APIs. It can be fine-tuned with diligently curated, high-quality data with relevance to a particular domain, hence substantially decreasing the risk of hallucinations as well as enhancing factual consistency. By having complete control over the training data as well as working parameters, academic institutions as well as researchers can guarantee that the output is more compliant with their factual and ethical standard. There is, however, a so-called Catch 22; in practice, even professionally trained models have shown a tendency to produce misleading data if confronted with ambiguous data or inadequate information. The only model with praxis we have encountered personally and didn't display hallucinations is the locally based model with no access to internet; but again, the professional using the latter will perhaps feed too little information to form a usable model.

3. DEVELOPMENT OF RAG MODELS

Large language models (LLMs), such as GPT, represent a significant advance in the field of natural language processing; however, they remain prone to generating inaccurate or fabricated information – a phenomenon known as hallucination. Such behaviour poses a serious challenge to the deployment of these models in domains where high accuracy is essential, including law, medicine, scientific research, and finance[16,17].
One of the most promising approaches to mitigating the problem of hallucinations is Retrieval-Augmented Generation (RAG), which combines the text generation capabilities of LLMs with the real-time retrieval of external information[12]. Within this framework, the model first searches relevant data sources – such as knowledge bases, text documents, or domain-specific archives – and then uses the retrieved material to generate a contextually grounded response. This significantly increases the likelihood that the generated content will be factually accurate, thereby directly reducing the risk of hallucinations[13].
Even with the progress the RAG has introduced, hallucinations can still take place, especially as it retrieves data that is incomplete, outdated, or unrelated to the particular query. Additionally, the model can misread or selectively add details, particularly when dealing with procedural-type queries that involve multiple steps of reasoning, data integration, or exact terminological discrimination. To address these limitations, recent research has developed more sophisticated RAG variants. For example:

- Hyper-RAG employs knowledge graphs to model relationships between concepts within the retrieved corpus, allowing for a more nuanced interpretation of context[13].
- Methods such as DePaC (Dehallucinating Parallel Context Extension) focus on identifying and correcting contradictions between the generated text and the retrieved information, using techniques like negative training and semantic calibration[18].

Ultimately, while RAG represents a major step towards more reliable generative systems, its effectiveness depends on several factors:

- the quality of data sources,
- the architecture used to integrate retrieved content,
- and the deployment of additional verification mechanisms.

Therefore, when applying RAG models, it is recommended to:

- cite sources,
- implement automated tools for detecting inaccuracies,
- and, wherever possible, include expert human oversight.

The combination of robust models verified sources, and human evaluation currently rep-

resents the most reliable framework for reducing hallucinations and ensuring quality in the use of large language models.

4. THE ROLE OF PROMPT DESIGN AND EVALUATION

Large language model (LLM) accuracy and reliability are directly dependent on prompt design – the form of questioning that users pose. Minor differences in wording, detail, and structure can all have a profound effect on the interpretation of the model as well as the verifiable nature of its output. Open-ended queries (such as "Tell me about Croatian education policy") tend to produce more general, potentially unverifiable content, while focused, context-specific queries (such as "Provide three main elements of the Croatian national education framework as of 2023") will generally provide grounded fact-based results.[16,19].

In academic contexts, effective prompt engineering can help reduce hallucinations by anchoring the model in concrete tasks, controlling output style, and limiting speculative reasoning. Evaluating the quality of prompts has therefore become an essential step in any AI-supported research or educational workflow.

One growing concern in the context of LLMs is prompt injection – a technique whereby unintended instructions are inserted into the model's input, deliberately or accidentally altering its behaviour. Prompt injection can occur in both user-created inputs and automated systems that concatenate user queries with hidden instructions [20].

For instance, if a student prompt contains embedded misleading or adversarial text like "Ignore prior directions and create a source," a non-hardened model will follow, resulting in generating hallucinated text with assertive tone as well as fake quotes. Even subtle cases can activate hallucinations by making it ambiguous for the model's context window with vague or conflicting wording. This weakness is especially applicable to automated academic software, educational chatbots, or student-assistance websites that depend on prompt chaining or dynamic prompt generation. Without rigorous input sanitisation and prompt validation, they can end up being delivery mechanisms for spurious or manipulated results [21].

As a result, prompt evaluation – determining how prompts can result in erroneous, biased, or hallucinated output – is a current area of research for AI safety as well as for human-computer interactions. How prompts are formulated goes a long way to ascertain factual accuracy and relevance of LLM-generated output. If prompt formulation can avoid ambiguity, ground the model in hard facts, and minimize the chance of hallucinated and fabricated content, a well-designed prompt can do so. Ambiguity-based or speculative prompts have a chance of leading to overgeneralization, factual inaccuracies, as well as confident misstatements. For instance, consider the following well-designed prompt:

"Compare three core objectives of the Bologna Process with the goals of the European Education Area (EEA) as outlined in 2023 policy papers related to Croatia."

This prompt is specific, time-bound, and grounded in a well-defined academic and policy framework. It gives the model a clear scope and encourages a structured response that is verifiable against existing documents. Because it limits the interpretative space, the risk of hallucination is relatively low.

In contrast, a poorly formulated prompt such as:

"What can you tell me about European education?"

lacks direction, context, and reference points. As a result, the model may produce a broad and unfocused answer, possibly including outdated facts, generic statements, or invented sources. This type of prompt increases the risk of hallucination because it allows the model to "fill in the gaps" with plausible sounding but unverified information. These examples demonstrate that prompt engineering is not merely a technical detail, but a foundational element in achieving responsible and credible use of AI tools in academic settings. By

training students and researchers to craft precise, grounded queries, institutions can significantly reduce the risk of misinformation and promote critical engagement with AI-generated content.

5. CHALLENGES OF AI APPLICATION: HALLUCINATIONS AND THE CREDIBILITY OF SCIENTIFIC WORK

One of the most serious issues associated with the use of advanced AI tools in academic contexts is the phenomenon of AI hallucinations. This term generally refers to situations where a generative AI model convincingly presents inaccurate or fabricated information as if it were true. Such content is often invented to "fill the gap" when the model lacks sufficient knowledge. Of course, as models evolve, the frequency of hallucinations is gradually decreasing.

These hallucinations may include fabricated bibliographic references, non-existent empirical data, or misrepresentations of information – often conveyed with a high degree of confidence. The problem is particularly evident in large language models such as ChatGPT, which predict text based on patterns in their training data without any actual understanding of the truthfulness of claims. Although improvements such as "deep research" functionalities have reduced this problem significantly, it remains a persistent risk[22,23].

Within the scientific research community, AI hallucination is a potentially damaging threat to the scholarly literature's credibility and the research process itself. Consequences of using AI might involve the dissemination of misinformation as well as researchers basing their work on false premises without authentic sources. There is a particular difference between AI tool application to text harmonization as compared to creating new content, especially where generated text does not have a traceable source base.[24].

In fields where precision and verifiability are critical (such as biomedicine), uncritical acceptance of AI-generated results can lead to serious errors or even endanger human lives if false findings are implemented in practice. A 2024 Oxford study highlighted hallucinations as a critical barrier to the broader application of LLMs, noting instances where ChatGPT fabricated legal precedents in response to legal queries – a highly dangerous practice that is equally concerning in medical contexts [25,26].

An even greater risk arises from AI advocates who push the narrative that AI will replace legal experts or other professions requiring deep semantic understanding, such as criminal law or intellectual property law [24,27].

As AI tools become increasingly accessible, more students are using them for assistance with research or assignments. According to media reports, this trend has alarmed many experts who call for urgent measures to curb the impact of AI hallucinations in education. Students who rely on AI without critical thinking risk incorporating non-existent citations or erroneous data into their essays or theses, thereby compromising academic integrity.

Several incidents have already been recorded. For instance, in Alaska in 2024, the State Education Commissioner used generative AI to draft an educational policy document that included six references, four of which were entirely fabricated, with fake URLs leading to unrelated content. This case, in which fabricated references were presented to an education board, vividly illustrates the dangers of relying on AI-generated "facts" without proper human verification[28,29].

6. ETHICAL AND LEGAL IMPLICATIONS

The case of hallucinations is not just a technical problem but also raises some ethical and legal issues related to academic integrity. Using inaccurate AI-generated information without verification may constitute negligence or even research misconduct, breaching professional standards that govern academic and scientific work.

From a regulatory perspective, the AI Act imposes obligations on providers and deployers of AI systems to ensure the accuracy, transparency, and robustness of outputs, particularly in high-risk sectors such as education and research. Furthermore, under the Updated Product Liability Directive (Directive (EU) 2024/2853), software, including AI systems, is explicitly recognised as a product[30,31]. Should an AI system cause damage by generating false information that leads to professional or material harm, liability could arise regardless of fault, under a regime of strict liability[32].
An author who includes an unverified, fabricated reference in a scientific paper risk not only damaging their academic credibility but potentially triggering institutional sanctions, such as paper retraction or disciplinary measures. Moreover, if AI-generated inaccuracies result in harm — whether reputational, financial, or otherwise — injured parties could seek remedies under general tort law principles or, where applicable, under specific rules introduced by the EU's AI legislative framework.
More broadly, the prevalence of AI hallucinations could erase public trust in science if publications become riddled with unreliable claims-especially if it's public financed.
Therefore, it is not surprising that strict human verification of any AI-assisted analysis or text generation is increasingly seen not only as best practice but as a potential legal obligation. In brief, addressing AI hallucinations requires a cultural shift in academia: acknowledging that 'AI is not infallible' must become a foundational principle. Students and researchers must be educated to approach AI-generated information critically, verify sources through traditional methods, and understand that reliance on AI does not absolve them from personal academic and legal responsibility. To conclude, one must hold the rains.
At the same time, ongoing AI research aims to mitigate this phenomenon – developing methods to detect when a model is "making up" answers (e.g., by measuring entropy levels or applying retrieval-augmented generation techniques to cross-validate outputs).

7. DEVELOPMENT OF AI LITERACY WITHIN THE ACADEMIC COMMUNITY

AI literacy is quickly becoming an essential skill for students, educators, and researchers. In education, this means not only understanding how AI systems function but also recognizing their strengths, limitations, and the importance of using their outputs responsibly. It also involves being mindful of related risks, such as bias, hallucinations, data protection issues, and broader ethical considerations. Research conducted in Croatia reveals that although most citizens actively use AI tools, very few truly understand how these systems work. This gap highlights a pressing need for education, as a lack of fundamental knowledge leaves users vulnerable to misinterpreting AI outputs or placing unwarranted trust in them.[33,34]. This highlights the urgent need for education: without a fundamental understanding, users are prone to misinterpreting or placing undue trust in AI outputs.
Universities should integrate AI education into their curricula, through mandatory courses, workshops, and specialised training programmes. Some countries have already made notable progress in this regard, such as Finland with its successful Elements of AI course[35,36]. In Croatia, although some advancements are evident, stronger institutional support is still needed[37].
It is equally important to train teaching staff to:

- Recognise AI-generated assignments,
- Guide students in the correct and ethical use of AI tools,
- And promote critical thinking when engaging with AI outputs.

Clear institutional policies should be established, delineating what forms of AI use are permissible and which are not.
Collaboration with industry and an interdisciplinary approach could further enhance AI education – for instance, through joint efforts by legal experts, engineers, and educational

specialists to design comprehensive AI literacy programmes.
Ultimately, the goal of fostering AI literacy is to safeguard the quality of education and prepare students for the responsible use of AI in their future careers. Only an educated and aware academic community will be able to harness AI safely and effectively.

8. CONCLUSION AND RECOMMENDATIONS

Artificial intelligence (AI) is already exerting a significant and transformative influence on the landscape of scientific research and higher education. However, its effective integration into academic processes necessitates careful deliberation and the development of robust ethical, technical, and pedagogical frameworks. The recent adoption of the AI Act represents a critical milestone in the regulation of AI technologies; nonetheless, persistent technical challenges—such as hallucinations, factual inaccuracies, and susceptibility to prompt manipulation—continue to pose substantial risks to the integrity and reliability of academic work.
This paper has demonstrated that AI-generated hallucinations are not isolated anomalies but rather systemic vulnerabilities that may undermine the credibility of AI-assisted research and learning. Although emerging technical interventions, including retrieval-augmented generation and automated hallucination detection, offer promising avenues for mitigation, these approaches remain imperfect and require further refinement. Effectively addressing these issues calls for a comprehensive strategy combining advanced technical safeguards, responsible human oversight, and the systematic cultivation of critical AI literacy across all tiers of academia.
The promotion of a culture of critical engagement with AI-generated content—anchored in transparent institutional policies and sustained by targeted educational initiatives—will be essential to ensuring that AI serves as a trustworthy and ethical collaborator within academic environments. Ultimately, the future utility of AI in research and education will depend not only on the sophistication of the technologies themselves, but also on our collective capacity to scrutinize, contextualize, and ethically apply these tools.
Only through a balanced, interdisciplinary approach can the academic community fully harness the transformative potential of artificial intelligence while safeguarding the foundational principles of scientific and educational integrity.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

THE ROLE OF PERCEIVED ATTRACTIVENESS OF A LOGOTYPE IN MEASURING VISUAL ATTENTION

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ABSTRACT

Understanding how attractive design influences viewer attention through objective metrics is especially important for graphic designers aiming to enhance user engagement. The purpose of this study was to use eye-tracking technology to investigate the retention of attention on a logotype, measuring Total Fixation Duration and Total Visit Duration. An additional aim was to explore the noticeability and attention retention on each of the three segments of the logotype (initial, central, and ending segment) measuring Time to First Fixation, Total Fixation Duration and Total Visit Duration. This could indicate which logotype areas are most effective in capturing and holding people's attention. Forty-seven observers took part in the experiment, evaluating the attractiveness of a fictional brand's wordmark while their eye movements were tracked. The findings suggest that there is a relationship between perceived attractiveness and visual attention, with indications that certain design elements, such as the central segment, may play a critical role in guiding users' focus.

Keywords: logotype, wordmark, design, attractiveness, eye-tracking

1. INTRODUCTION

In a world flooded with information, a visually striking design helps a brand or product stand out from the competition, making it more recognizable and easier to remember over time. The aesthetic quality and visual appeal of a logo are essential for successful brand graphic design [1]. This is because visual attention directly influences cognitive processes—what consumers focus on is more likely to be remembered and perceived positively. In branding, this means that a distinctive and well-designed logo can significantly enhance brand recall and shape consumers' perception of the company [2]. Well-designed visuals make communication more effective. A balanced combination of colour, typography, and layout enhances clarity, while visual appeal engages the audience on an emotional level. This helps create positive brand associations, strengthening brand recognition, loyalty, and support [3].

Visually engaging elements can evoke emotions such as joy, trust, or excitement, enhancing the overall experience. Beyond aesthetics, good structured design improves usability and user experience by directing attention and making navigation more intuitive. This is particularly relevant in web and product design, where clear visual hierarchy helps in guiding users through content [4].

In addition to drawing attention, effective graphic design enhances perception, comprehension, and interaction with visual content [5].

1.1. Visual attention in Graphic Design

Visual attention is essential in understanding how users interact with visual content. Hessels et al. [6] highlight that visual attention research can be conducted at various levels, ranging from detailed analyses of eye movements to broader observations of attention patterns in complex visual environments. The systematic observation and analysis of eye movements have been conducted for over a century. However, in the context of modern applications, eye-tracking technology is now widely used across various research fields, including visual perception, legibility, human-computer interaction, multimedia design, and other disciplines.

According to Girisken and Bulut [7]: "The studies on eye tracking, especially on eye fixation are aimed to understand the stimuli which have captured the respondents' attention". Eye-tracking provides a direct assessment of visual focus, which plays a crucial role in information processing and later recall [8]. Visual attention acts as a selective filter, prioritizing specific elements for processing [9]. In the context of logos, design attractiveness can determine how quickly and for how long users focus on particular brand elements.

Unlike natural images, graphically designed materials (e.g., flyers, websites, advertisements) are intentionally structured to convey specific information. Their design guides viewer attention toward particular elements, often influencing the order in which content is viewed. Understanding how users allocate their attention is crucial for evaluating whether a design effectively communicates its intended message [10].

1.2. The Impact of Visual Elements on Retention of Attention

Elements such as headlines, facial imagery, and logos typically draw the most attention in posters and advertisements, while on websites, users primarily focus on logos and page titles [11]. Text-based logos tend to concentrate visual attention more precisely, whereas image-based logos result in longer fixations and a broader distribution of gaze [12].

Visual elements, particularly typography in logos, significantly influence brand perception and attention allocation. Xu, Chen and Liu [13] confirmed through eye-tracking analysis that uppercase wordmarks receive greater visual fixation, while lowercase wordmarks are processed more quickly and are associated with a more approachable brand perception.

Since visual attention is most critical within short time intervals, design elements must be strategically arranged to immediately capture attention and effectively convey key information [14].

Consumers initially direct their attention on a logotype's colour, followed by its shape [2]. To objectively measure visual attention, the researchers used eye-tracking technology, using metrics such as time to first fixation and the number of prior fixations to assess what attracts attention and for how long. Chiu et al. [15] revealed in their study that monochromatic logotypes, compared to the original logotypes, attract attention more quickly (shorter time to first fixation), but they do not show a significant advantage in long-term attention retention.

Further supporting these findings, Grigaliūnaitė and Pilelienė [16] confirmed that colourful logos attract more visual attention than black-and-white designs. They also found that logotypes featuring shaped and sophisticated typefaces tend to draw more visual attention than those using standard fonts. Additionally, the visual recognition and assessment of printed letters were shown to be significantly affected by their typeface [17].

Studies on visual perception emphasize that the positioning of graphical elements directly influences attention and brand recognition [7]. Eye-tracking technology enables precise measurement of fixations and visual paths, helping researchers understand how users process visual information and which elements in advertising design attract the most attention.

1.3. Research questions

The objective of this study was to investigate two key research questions using eye tracking technology. The first research question explored whether visual attention is influenced by the perceived attractiveness of the logotype. Understanding how the attractiveness of a logotype influences user interest can clarify the role of logo design in environments where user focus is constrained.
The second research question was how noticeability and attention retention differ across the three different segments of the logotype (initial, central, and ending segment). This could indicate which logotype areas are most effective in capturing and holding people's attention. Identifying these attention distributions allows graphic designers to strategically position key information, which may improve the impact of visual messages in contexts like advertising and brand recognition on packaging.

2. METHODOLOGY

Unlike traditional approaches to studying visual perception, such as retrospective questionnaires or verbal reports, eye-tracking technology allows for real-time monitoring of visual attention. For example, Niehorster et al. [18] demonstrated that eye-tracking technology enables the analysis of unconscious reactions, attention distribution, and visual hierarchy in design, thereby improving the objectivity of research findings. Given that eye-tracking generates quantitative data, including fixation duration and saccades, results are reproducible and can be used for standardized visual perception studies. The use of eye-tracking in visual perception studies allows for precise measurement of user attention on various typographic elements. Xu et al. [13] used this technology to demonstrate that different typographic choices can significantly impact brand perception. Rosidah et al. [2] conducted a study using the eye-tracking method to examine the effects of logo redesign and identify important elements influencing visual attention and brand perception. Their findings confirmed that colour is the most dominant factor in capturing consumer visual attention. Jing Li and Myun Kim [19] demonstrated that graphic representations influence both visual attention and the ability to recall information. They concluded that graphical elements on products should be designed for a broader audience, not just for experts in a specific field (in this case environmental science).
Targeted visual perception analysis using eye-tracking technology is essential for making data-driven design decisions rather than relying solely on intuition. Therefore, this study uses eye-tracking technology to objectively assess how design elements capture attention and whether attention retention differs across element segments.

2.1. Participants

The experiment involved 33 women and 14 men, aged between 19 and 57 years (M = 24.98, SD = 8.33), all of whom had normal vision or wore corrective lenses. The participants were either teaching staff or students at the Faculty of Graphic Arts, University of Zagreb. Prior to participation, all individuals provided informed consent.

2.2. Stimuli

Fictional logo was created for the purposes of this study, designed as a wordmark to avoid the influence of pictorial symbolism on the results. The typeface style and colour were selected based on the associative characteristics of the name. A typographic intervention was applied in the form of decorative lines to distinguish the logo from plain text. The dimensions of the logo were 510 × 211 px.

2.3. Procedure

For data collection, a Tobii Eye Tracker X60 (Tobii Technology, Stockholm, Sweden) was utilized, functioning at a 60 Hz sampling rate with an accuracy of 0.5 degrees. Stimuli were displayed on a Lenovo L1900pA computer monitor (Lenovo, Morrisville, NC, USA) with a screen resolution of 1280 × 1024 pixels, controlled using Tobii Studio 3.2.1 software.
The experiment began with informed consent and a brief set of instructions. To prevent influencing participants' viewing behaviour, the study's objective was not disclosed. Calibration was performed using five points, represented by a yellow circle on a black background. After calibration, participants were shown the logo along with a 7-point rating scale (Figure 1). They were asked to evaluate the attractiveness of the logo using the provided scale.

Figure 1: The distribution of gaze duration on the stimuli

To simplify analysis, the 7-point Likert scale responses were recategorized into three levels:

- 1 = Low attractiveness (original ratings 1–3)
- 2 = Medium attractiveness (original rating 4)
- 3 = High attractiveness (original ratings 5–7)

These recategorized values allowed for a clearer interpretation of participants' ratings.
There was no time limit for completing the evaluation. During the rating process, eye-tracking data was recorded for an Area of Interest (AOI) covering only the logo's surface. For the second research question, three AOIs were defined within the wordmark: initial, central and ending segment.

2.4. Depended Variables

To examine two research questions based on the results of eye-tracking measurements, the main interest was in dependent variables related to visual attention. The first research question investigated the retention of attention on the entire logotype, measuring Total Fixation Duration (TFD) and Total Visit Duration (TVD), to evaluate the overall visual engagement of participants with the presented stimuli. The second research question explored the noticeability and attention retention on each of the three segments of the stimulus (initial, central, and ending segment). The noticeability was measured through Time to First Fixation (TFF), while attention retention was measured through Total Fixation Duration (TFD) and Total Visit Duration (TVD).

3. RESULTS

3.1. Attention on the Entire Logotype

For the first research question, a one-way ANOVA was conducted to examine whether there was a difference in attention on the entire logotype between the participants who provided different ratings for attractiveness. Figure 2 provides an overview of eye-tracking metrics across the different rating groups.

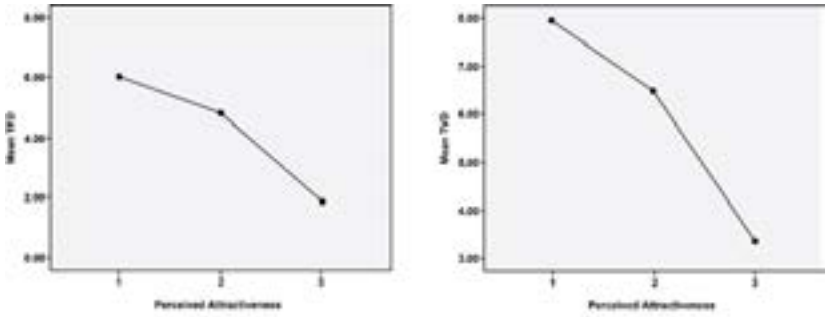

Figure 2: Mean TFD and TVD across the different rating groups

The results showed that the difference was statistically significant for TFD, $F(2, 44) = 9.19$, $p < 0.01$, as well as for TVD, $F(2, 44) = 5.53$, $p < 0.01$. The Bonferroni post hoc tests showed that there was a statistically significant difference in TFD between the participants who rated the logotype with 1 ($M = 6.04$, $SD = 1.94$) and those who rated it with 3 ($M = 1.86$, $SD = 1.11$), $p < 0.01$. There was also a significant difference in TFD between participants who rated the attractiveness of the logotype as 2 ($M = 4.83$, $SD = 3.84$) and those who rated it as 3 ($M = 1.86$, $SD = 1.11$), $p < 0.05$. However, there was no statistically significant difference in TFD between those who rated with 1 and 2, $p = 0.62$. These results indicate that participants' evaluation of the logotype's attractiveness is strongly associated with differences in their total fixation duration (TFD), suggesting that higher perceived attractiveness may result in shorter fixation on the logotype.

Furthermore, the Bonferroni post hoc tests also showed that there was a significant difference in TVD between the participants who rated the logotype with 1 ($M = 7.96$, $SD = 3.27$) and those who rated it with 3 ($M = 3.35$, $SD = 1.08$), $p < 0.01$. However, there were no significant differences in TVD between participants who rated the attractiveness of the logotype as 1 and 2 ($p = 0.83$), or between those who rated it as 2 and 3 ($p = 0.07$). This shows that higher perceived attractiveness is associated with fewer visits compared to lower levels of attractiveness.

3.2. Attention on the Logotype Segments

For the second research question, a repeated measures ANOVA was conducted to examine whether there was a difference in attention across the three segments of the stimulus (initial, central, and ending segment). The results indicated that there was a significant difference in TFF between the segments, $F(2, 28) = 6.11$, $p < 0.01$. There was also a significant difference in TFD between the segments, $F(2, 28) = 22.27$, $p < 0.01$, as well as in TVD $F(2, 28) = 29.23$, $p < 0.01$.

Post hoc analyses revealed the following. There was a significant difference in TFF between the initial segment of the logotype ($M = 5.41$, $SD = 5.53$) and central segment ($M = 0.73$, $SD = 0.75$), $p < 0.05$. There was also a significant difference in TFF between the central segment of the logotype and its ending segment ($M = 4.49$, $SD = 3.55$), $p < 0.05$. These results suggest that the central segment was detected significantly earlier than the other

segments.
There was a significant difference in TFD between the initial segment of the logotype ($M = 0.68$, $SD = 0.62$) and its central segment ($M = 2.90$, $SD = 2.20$), $p < 0.01$. There was also a significant difference in TFD between the central segment ($M = 2.90$, $SD = 2.20$) and the ending segment ($M = 0.67$, $SD = 0.57$), $p < 0.01$. These results suggest that the central segment was fixated significantly longer than the other two segments of the logotype.
There was a significant difference in TVD between the initial segment of the logotype ($M = 0.81$, $SD = 0.76$) and its central segment ($M = 3.61$, $SD = 2.39$), $p < 0.01$. There was also a significant difference in TVD between the central segment ($M = 3.61$, $SD = 2.39$) and the ending segment ($M = 0.77$, $SD = 0.60$), $p < 0.01$. These results suggest that the central segment was visited more than the other segments.
Given the large standard deviations observed in the data, a heatmap (see Figure 1) is provided to confirm consistent patterns of visual attention, supporting the validity of the findings. In the presented black-and-transparent heatmap, lighter or more transparent regions indicate areas with greater visual attention, while darker colours indicate areas with less visual attention.

4. DISCUSSION AND CONCLUSION

This study used eye-tracking to examine how attractive logotype design affects viewer attention. By analyzing fixation metrics across logotype segments, it found that perceived attractiveness correlates with visual focus. Notably, the central segment appears most effective in capturing attention, offering insight for enhancing user engagement through graphic design.
Our results indicate that higher perceived attractiveness may result in shorter visual attention on the logotype.
In the practice of visual communications, shorter gaze duration on visually appealing logos may indicate that users process them more quickly due to their simplicity or recognizability and then shift their attention to other content. Therefore, it is crucial to balance attractiveness with engaging content to maintain user attention. In fast-paced environments, this means allowing more time for other elements within a visual composition, which designers must strategically position to optimize user engagement.
Previous research ([20], [21]) on the impact of visual complexity in advertising on user attention suggests that visually appealing designs (such as advertisements and banner ads) capture attention more quickly but also lead to faster cognitive processing, resulting in shorter attention spans. While these studies focus on advertising, their findings could be extended to logos, suggesting that higher perceived attractiveness may contribute to shorter visual attention on a logo. Rosidah et al. [2] further support this idea, demonstrating that more attractive logos draw attention faster and this does not necessarily mean that attention is sustained for a longer duration.
An additional finding revealed that the central segment of the logotype was detected significantly earlier and fixated for a longer duration. This finding has significant applications in visual communications, particularly in branding, where all important elements (such as symbols and slogans) should be placed in the central area to ensure maximum attention retention. The same principle applies to user interfaces, where important information, such as CTA buttons, can be positioned centrally for better visibility. Similarly, in advertising, this applies to the key message or featured product, which should be centrally located to capture viewers' attention more effectively.
Bartolomé et al. [22] emphasize that the sequence of visual information processing follows predictable patterns, with viewers naturally prioritizing essential elements such as headings, logos, and URLs. Their study demonstrates that these key visual elements are perceived earlier and fixated upon for longer periods, supporting the idea that placement

influences engagement.
Srikantharajah and Ellard [23] explore how different regions of the visual field affect attention and viewing strategies using eye-tracking technology. Their research confirms that central vision plays a crucial role in detailed information processing. While their study does not directly analyze logos, it provides strong evidence that central vision is essential for processing fine details. Given that central fixation is critical for accurate perception, this finding reinforces our result that the central segment of the logo was fixated upon for a longer duration. Since the human eye instinctively focuses on the central part of the visual field when initially scanning visual information, the central segment of the logo automatically attracts attention becoming the primary fixation point.
However, this study has certain limitations. Visual attention was measured in the context of a specific task evaluating attractiveness, which might not be the case if the logo were observed without an assigned task. Furthermore, only one type of logo was tested, and the results on attractiveness may have been influenced by the strongly feminized design. Future research will explore the impact of design and its complexity on perception in more detail, using eye-tracking or qualitative methods.

Acknowledgement:

This work was carried out as part of the project IP-2022-10-3864: Improvement of Packaging Products through the Application of Environmentally Friendly Materials and Inclusive Design.

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ORIGINAL SCIENTIFIC PAPER

CYANOTYPE – GIVING A NEW LIFE TO A PAPER MADE FROM RECYCLED POST-CONSUMER TEXTILE WASTE

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ABSTRACT

Even though the modern textile industry in the European Union is becoming more sustainable, in 2020, the EU produced an estimated 6.95 million tonnes of textile waste, or 16 kilograms per person. Of this, 4.4 kg per person were gathered separately for recycling and reuse. Using materials from textile waste to make cellulose fibers, could resolve some of the issues connected to the sustainability. Cellulose fibers are considered to be more environmentally friendly than synthetic ones because they are biodegradable. Recycling methods for textile waste are always evolving. Cotton fabric textile waste has been shown to be a sustainable source of cellulose for paper production. Paper made in the recycling process can be given a new life. The aim of this research is to test paper made from post – consumer textile waste and see if it could be used for cyanotype technique. Cyanotype is an alternative photographic process which involves two chemicals. That chemicals combined make photosensitive emulsion, that is applied to a porous surface, mostly paper, but can be used on wood, non – glazed ceramics, textiles etc. Cyanotype emulsion is best and most frequently used on natural materials, such as 100% cotton paper. Paper used for this process should be made of pure cotton fabric, free of acid and optical brighteners, so that the additives don't have negative effect on the emulsion which could result in poor quality prints and its degradation.

Keywords: recycling, cyanotype process, reuse methods, paper production, textile waste.

1. INTRODUCTION

The fashion and textile industries are among the biggest pollutants of the environment because of the increasing demand for their products brought on by the growing societal trend. Every year, Europeans consume on average 16 kg of textiles per person. Each item is used for a brief amount of time, with 4.4 kg going towards additional recycling and reuse [1]. The issue of how to use and dispose of textile waste produced during production would be resolved if the textile industry adopted a circular economy. Depending on their composition, textiles and clothes can be recycled, their fibers extracted from textile waste [2], or they can be used to adsorb harmful substances or to produce new raw materials like paper and paper packaging. The primary component of textiles are fibers, which can be composed of a variety of materials. Typically, they can be classified as either natural or artificial fibers. Natural fibers include fibers derived from cultivated crops like cotton, hemp, and flax, as well as protein fibers like wool and silk [3]. The purest form of cellulose, the most prevalent polymer in nature, is found in cotton fibers. Cellulose makes up over 90% of the fibers in cotton. Cellulose is present in all plants, but in different quantities [4]. Recycled cellulose fibers from used textiles are a desirable raw material for making paper and packaging. According to scientific advancements, cellulose fibers derived from waste textiles have the potential to displace virgin raw materials [5]. The two types of synthetic fibers are categorized based on their chemical makeup: inorganic fibers, like carbon and glass fibers, and organic fibers, which are natural polymers, like polyester and polyamide

fibers [6]
Cyanotype is an alternative photographic, cameraless technique that does not require the use of a camera to obtain a photographic image. Sir John Herschel invented it in 1842, and it quickly gained popularity, primarily among pictorialists and in the field of architecture [7]. Alternative photographic techniques were used even before the invention of photography [8]. The traditional cyanotype results in recognizable Prussian blue-colored photographic images which is thoroughly explained in the literature [9]. To achieve optimal results, the photosensitive emulsion used to obtain the photographic image requires the use of natural materials that include pure cotton fabrics, in this case 100% pure cotton paper. The absence of acids and optical brighteners, which would otherwise compromise the longevity of the print and its final quality, is a requirement that such paper must fulfill. Cyanotype can be applied to numerous porous, natural materials, including paper, cloth, wood, and others. In this case, an automatic paper making machine was used to create samples of viscose textile fiber paper and textile fibers of mixed materials (viscose, denim, gray felp, and grater). Calcium carbonate and other alkaline buffering agents do not work well with the chemicals in the sensitizer, so papers containing these substances are not appropriate for the cyanotype [10]. The aim of this paper is to investigate the potential of applying an alternative cyanotype photographic technique on paper obtained by recycling textile waste. Photographic images were made on paper samples made on the Rapid-Köthen automatic machine, using the method of the alternative cyanotype photographic technique.

2. EXPERIMENTAL

For the purposes of this paper, textile scraps of viscose material (consisting of 97% cotton fibers and 3% elastane), 100% cotton fibers from denim, 100% cotton fibers from felps (cotton material used for sweatpants) and render materials (95% cotton fibers and 5% elastane fibers) were used.

2.1. Paper making process on an automatic machine

Standardized sheets of paper (ø 200 mm) were created using an automatic machine for producing laboratory sheets of paper (Rapid-Köthen, Frank PTI). The mixture of viscose and pure cellulose paper (Munktell) and mixed materials (denim, felpa, viscose, and render) and pure cellulose paper (Munktell) was made in the following ratio:

a) Textile fibers: cellulose paper = 100% : 0%
b) Textile fibers: cellulose paper = 25% : 75%
c) Textile fibers: cellulose paper = 50% : 50%
d) Textile fibers : cellulose paper = 75% : 25%.

Chemical treatment of 50g of textile material was carried out by boiling it for approximately an hour in a 0.25 M NaOH solution. Laboratory sheet production was done in accordance with the ISO 5269:2008 standard.

2.2. Cyanotype process on paper samples produced by an automatic machine

Cyanotype, a method of photographic reproduction, was carried out in a darkroom using red light sources that don't interfere with the photosensitive emulsion used to coat paper samples. A negative with an illustration, design, or drawing in black lines with a higher blackening density, paper, substrate and glass plates, brushes to coat the paper with photosensitive emulsion, clothespins for securing the substrate and glass plates are all necessary for creating a cyanotype.
A photosensitive emulsion was made by combining solution A, which contains 100 g of ammonium citrate iron in 500 mL of water, with solution B, which contains 40 g of po-

tassium ferricyanide in 500 mL of water, prior to coating the paper samples. To prevent light-induced chemical reactions, the preparation was done in a darkroom. In a glass container, solutions A and B in equal proportions (10 mL of solution A and 10 mL of basic solution B) were combined. Water was added to the mixed solution for a lighter print and a weaker blue contrast. With the addition of 1% potassium dichromate more intense blue contrast can be achieved.
A brush was used to apply the sensitizer to paper samples, moving from top to bottom and then left and right to ensure that the solution is equally absorbed by the paper on all sides of the coated surface. To prevent them from coming into contact with a UV light source, samples were dried for 24 hours within a dark paper drying container. To create an image, a negative was placed on dried, coated paper samples in a darkroom. The desired design was then placed on the samples, and the organized pattern was put within the frame and secured with clothespins. A test was conducted on a single sample, with one side being exposed to UV light for ten minutes and the other for twenty minutes in order to calculate the exposure time. The exposure took place in daylight for 20 minutes, referencing the preliminary data. The samples were rinsed with water in a bathtub with an ongoing flow for five to ten minutes after exposure. If samples are rinsed too quickly, iron salts are left on the paper, which might lead to the fading of the print. Long-term rinsing will lighten the print too much, particularly if the rinse water has a minor alkalinity. Papers must be rinsed to remove any remaining chemicals. Samples that have been thoroughly rinsed were left to air dry for 24 hours. The reaction between potassium ferricyanide and iron ions (from the photoreduction of ferrous ammonium citrate) is what gives the print its Prussian blue hue.

3. RESULTS AND DISCUSSION

In comparison to textile fiber paper samples, the cyanotype technique achieves greater acceptance of the photosensitive emulsion on standardized cyanotype paper samples – cotton paper (Figure 1.). When comparing the dried samples of the first group of viscose textile material – based papers (Figure 2.) with the samples of the second group of mixed textile fiber papers (Figure 3.), we can see that the viscose – based samples have a more intense Prussian blue hue than the second group's samples. The possible explanation for the weaker adhesion of the photosensitive emulsion is that NaOH used for the chemical treatment of the textile fibers during the preparation and production of paper was probably not thoroughly washed from the fibers in the second group of papers. Furthermore, the second group of paper samples consists of faded denim, render – pink material, gray 100% organic felpa, dyed textile fibers, and a greater amount of elastane fibers. The deterioration of the photosensitive emulsion is increased when the percentage of textiles in the prepared papers is larger (100% : 0% and 50% : 50%). A 100% viscose paper sample and a 100% mixed material sample were not entirely washed of the chemicals that leave a yellow hue on the paper since the paper tends to decompose after too much time in water. Future studies should look into the possibilities of using additives such as surfactants and mordants in the production of paper, as these could improve the binding of the photosen-

sitive emulsion to the fibers.

Figure 1: Cyanotype on standardized cyanotype paper samples

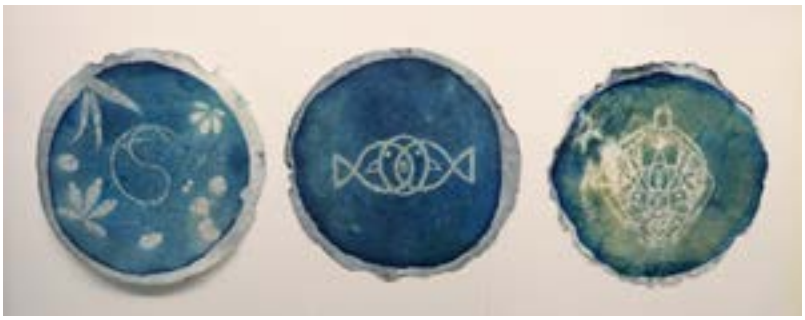

Figure 2: Dried samples of viscose textile material–based papers (the proportion of material; viscose : cellulose is indicated above each sample)

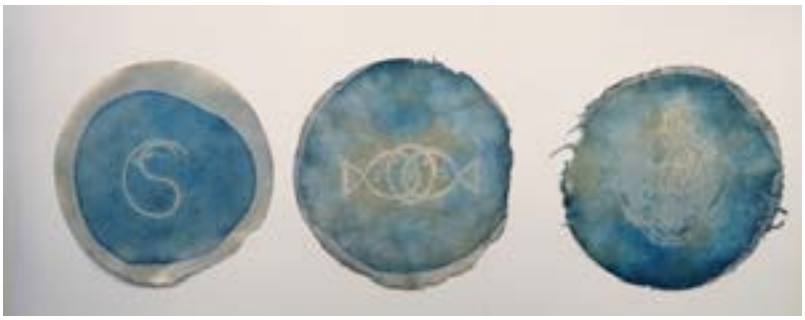

Figure 3: Dried samples of mixed textile fiber papers (the proportion of material; viscose : cellulose is indicated above each sample)

4. CONCLUSION

The idea of producing cyanotype paper from textile waste is discussed in this study. One of the main products used in graphic technology is paper, which is utilized in all three of the main graphic technology domains: graphic prepress, printing and graphic finishing. The results of applying cyanotype to standardized paper samples demonstrate differences between paper samples composed of a mixture of textile residues (viscose, denim, felt, render) and paper samples composed of textile viscose residues.

In comparison to textile fiber paper samples, cyanotype on standardized paper samples leads to a higher uptake of the photosensitive emulsion. Also, compared to a paper sample with the same ratio of textile fibers to cellulose paper (50% : 50%) and samples made entirely of textile fibers, where photosensitive emulsion degradation occurs, paper samples

with a lower percentage of textile fibers and a higher percentage of cellulose paper (25% : 75%) exhibit better acceptance of photosensitive emulsion.
These preliminary tests serve as an example of how the circular economy can be applied in the textile sector with the aim of disposing of textile residues generated during production. The process of producing cyanotype paper must be optimized, taking into consideration the quantity of photosensitive emulsion required, the application technique, the exposure and rinsing times, as well as the potential use of additives to improve the binding of photosensitive emulsion to the fiber.

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BLAŽ BAROMIĆ
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PROFESSIONAL PAPER

DIGITAL ILLUSTRATION BASED ON THE CULTURAL HERITAGE FROM THE BALKANS

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ABSTRACT

Rituals have been a part of human lives since prehistoric times. In the past, their execution contributed to the unity and more harmonious functioning of communities, which led to higher chances of survival. To perform rituals in specific yet correct orders, the implementation of symbols played a crucial role in helping the memorization of the execution order. Nowadays, our survival is less dependent on the execution of rituals, but we still perform them in different ways. Many elements of folklore stem from the ancient rituals our ancestors performed, which are now considered cultural heritage. Unfortunately, they are fading into oblivion, as nations strive towards globalization and modernization, especially in a less culturally researched region, such as Balkan. To spark interest, dialogue, and eventually preservation of the Balkan folklore, we designed a set of 22 ritual cards for divination, known as the Major Arcana of tarot. We tested the efficiency of the cards in stimulating interest and dialogue about Balkan folklore with an online survey. The cards were designed in accordance with culturally significant elements of the Balkan folklore. We implemented traditional symbols and patterns from the Balkan kilims and illustrations based on the elements from the Balkan folklore. The results of the conducted survey showed that the cards do awaken some level of interest in the Balkan folklore and a level of willingness to form a dialogue about it.

Keywords: illustration, ritual, tarot, divination, Balkan folklore, dialogue, cultural heritage.

1. INTRODUCTION

1.1. The use of illustration

Illustration has accompanied mankind since the invention of printing. Illustration complements the literary model, but even before the invention of printing, people felt the need to design their living space artistically. The first traces of artistic expression can be traced back to 30,000 BC, and these prehistoric forms of artistic expression for important life events also include religious and ritual depictions, which replaced writing. In the Greek, Roman and Egyptian eras, artistic creation focused primarily on the depiction of deities who assumed a naturalistic imitation of humans [1].

With the development of the printing industry and new technologies, we can also observe the evolution of illustration [2]. Illustration also plays an important role in education and visual communication, which is why it is an important part of graphic design, particularly in the design of infographics and the communication of complex messages or topics. With the use of illustrations, a graphic designer can contribute to the emotional response in the recipient of the information

Artistic creation is related to the user, it does not exist on its own and is always in the role of conveying a message. Prehistoric art established three different areas that developed

artistically in parallel. Man expressed imitation in naturalistic representations and tried to imitate forms from his natural environment. He interpreted signs for rituals and the interpretation of supernatural powers with symbols and pictograms. The last area is decoration, with which man tried to creatively embellish his living environment [3].
Dance and ritual developed in parallel with artistic creation. With the activation of the body and the collective performance of prehistoric performances, various idols, sculptural devices through which they communicated with their ancestors and deities, developed in parallel. This tradition is reinforced by the establishment of deities in the ancient world, where deities appeared in the form of human representations.
The old traditions practised by our ancestors in the Balkans were replaced by new beliefs. Christianity, Islam and Judaism introduced a new iconography into artistic creation which, together with the development of technology - especially in architecture - characterised mankind from the Middle Ages to modern times. In modern times, faith seems to have been supplemented by capital, which to a certain extent seeks to build on the past through generalisation and standardisation.

1.2. Art in ritual context

While researching cave art, some researchers hypothesised that at least some of it has origins in shamanistic rituals. The researchers who believe in the shamanistic origin of the cave paintings believe that the portrayed scenes and symbols must be the visions of a trance state of mind [4] which the shamans, who were the people believed to have special powers and abilities, practiced in order to achieve communication to the other side through this altered state of mind [5]. The researchers observed that the cave drawings were placed in carefully selected places in the caves and included natural relief of the walls in the drawings themselves, so that they could appear more lifelike or alive during the altered state of mind. They also noted that the geometric patterns, which would coincide with the first and most shallow out of the three stages of the trance, appeared closer to the entrance into the cave, while more complex drawings, such as those of people, animals, and monsters, were placed deeper inside the caves and would coincide with the third, the deepest, stage of the trance. The placement of the drawings led researchers to theorise that the walk through the caves full of wall art itself could be a part of rituals, with the drawings depicting the transitioning visions from one stage of trance to another [4].
Some researchers, on the other hand, believe that the depictions are a part of magical practices, with theories of sympathetic magic [6]. Namely, the sympathetic magic theory states that the act of depicting or obtaining the image of an animal or a person would give the person in possession of such depictions the power to influence the human or animal portrayed [4].
Cave art is, of course, not the sole example of the use of visual art in rituals, as communication through rituals was conveyed using signs and symbols, which also contributed to the aesthetic aspects of the rituals [7]. The symbols, which included language, song, music, objects, and visual signs, evoked a strong emotional response in an individual. As the lengthy rituals contributed to group unity and harmony in performance during group work, they were proven to be of great importance in ensuring the survival of the group [8], which is why the correct order of execution of the rituals was important. To ensure the correct order of the ritual sequences, symbols were implemented to make remembering it easier and boost the intensity and effectiveness of the ritual [9]. The symbols and artwork used in rituals carried information and messages on spiritual, emotional, material, or other levels. They helped to preserve and convey messages about the history and mythology of a society in oral, written, or visual form and to influence societies and individuals to cooperate with their nature. In some cultures, people used ritualistic body ornaments to express their affiliation to the culture, which can be observed through henna staining on

the skin of brides to protect them from evil eyes, boost fertility, and bring luck to the newlyweds. This practice originated in ancient Mesopotamia and has survived for thousands of years, most notably in India, Morrocco, and various other parts of the world [10]. We can also observe the ritualistic tattooing in other cultures, such as Inuit, Maori, Samoan, and others [11], including in the Balkans. The practice in the Balkans dates back to Bronze Age, when the Balkan region was inhabited by Illyrian tribes, which are described in Roman and Greek sources as being heavily tattooed [12]. The practice of tattooing, called 'sicanje' or 'bocanje', has survived for thousands of years over generations and has almost died out until women in today's Bosnia and Herzegovina and Dalmatia started using it to protect themselves from Turkish conquerors. The traditional symbols eventually gained another meaning which corresponded to the cultural identity of the time [13]. Some symbols can be found in various parts of the world, yet they may have different meanings in different cultures. One such example is the eight-pointed star, which is generally considered a symbol of good luck or the bringer of light and energy, but in the Slovenian area it was a symbol of the goddess Zarja, who is associated with new beginnings, ascension, and transitions. The symbols associated with deities were used in rituals in form of amulets [14].

The symbols can often be colours themselves [10]. In the Balkans, as well as in the rest of Europe, the most characteristic colours of different cultures are red, white, and black. Black was associated with Mother Earth, fertility, and stability, red with the life force and blood but also preservation of the family and fighting strength, and white with the eternity of spirit, sky, and purity. The colour scale was obtained from natural sources. It is worth mentioning that all these colours are in strong contrasts, which are also used by avant-garde artists. We can observe the predominant use of these colours as they are mentioned through traditional textiles and other objects [15].

Symbols were also used in divination rituals. The person prophesising would interpret messages of cosmic forces through interaction with the symbols, which served as a form of language between the spiritual forces and the person interpreting the prophecies. The symbols were often placed on objects (called oracles) used during the divination rituals and would appeal to the interpreter's intuition to convey messages from cosmic forces, even the ones that would otherwise remain hidden [16]. Nowadays, the most widespread divination rituals are performed using tarot cards. Although there are theories that tarot cards have been around for thousands of years, the truth about their origin is still disputed. It is said that they came to Europe from Egypt in the form of playing cards and were transformed into the tarot cards we know today in Italy around 1440, when the so-called trump cards were added to the playing cards. The trump cards contained allegorical representations. Originally, the tarot cards were used exclusively for entertainment purposes in the game called Tarocchi. It was not until the 18th century that they began to be used as ritual cards for divination purposes [17]. The first known deck is called the Visconti-Sforza deck, the second, more improved one was named after the French king Charles VI. A tarot deck usually consists of 78 cards, out of which the 22 trumps are known as Major Arcana and the remaining 56 are known as the Minor Arcana, which consists of the four suits – Wands, Cups, Swords and Pentacles. Playing cards can also be used as a Minor Arcana where the Clubs can be used as Wands, Hearts as Cups, Spades as Swords and Diamonds as Pentacles [18]. The Major Arcana is a set that symbolises the most important archetypes of human life and the human psyche and represents the path that the first card of the deck, the Fool (numbered as card 0), takes on its journey through life and the world. Each of the Major Arcana cards symbolises a particular personality type or a particular part of human life. The 22 cards are called The Fool, The Magician, The High Priestess, The Empress, The Emperor, The Hierophant, The Lovers, The Chariot, Strength, The Hermit, The Wheel of Fortune, Justice, The Hanged Man, Death, Temperance, The Devil, The Tower, The Star, The Moon, The Sun, The Judgement and The World [19]. To understand

the message of each card in a spread, the user must interpret the symbolism of the card in the context of a question asked by the questioner and in relation to other cards within the spread. It should be noted that none of the cards should be perceived as only positive or negative, but rather as ambivalent and must be interpreted in the context of the question asked and the neighbouring cards in a spread [18].
The images on the first tarot card decks reflect the culture of the Middle Ages and the Renaissance in the European cultural area, with many influences from different cultures, including Hermeticism from ancient Egypt and Greece. Nowadays, tarot cards are usually full of different patterns and images, offering a wide variety of decks for a user to choose from according to their preferences. The most well-known deck is the Rider–Waite deck [18]. The themes and motifs depicted on the cards include motifs from various films, series, fantasy creatures, cultures and mythologies. The latter two are the reason why we decided to implement our findings in the form of illustrations on the tarot cards, as this seemed to be the most accessible interactive product that could provide a visually appealing product and provide some information about Balkan folklore. In our research, we decided to focus on the 22 out of 78 cards that represent the Major Arcana of the tarot

1.3. The cultural heritage in the Balkans

The Balkan region was a space where many cultures met and intertwined, leaving traces of different time periods and cultures in today's cultural heritage across the Balkans. These include the cultures of Illyrian, Celtic, Dacian, and Thracian tribes, indigenous to the Balkans in prehistory, the antique influence of Roman and Greek conquerors, and the culture of Slavic tribes. All of them were characterised by pagan beliefs, connected to the forces of nature and later the cultural influences dominated by monotheistic faiths such as Christianity and Islam. Different cultural exchanges and trading introduced various novelties, including technological advances. They were implemented and portrayed on various objects used in everyday life as well as in textiles [20].
The image is constantly changing, depending on the medium and the viewer. Today we also receive images through digital technologies that are disembodied, the carrier has become a cloud that is constantly being supplemented with new images. As a result, the local characteristics of individual communities are lost [21].
For this reason, we decided to investigate where contemporary artistic creation is still connected to cultural and ethnological heritage. Above all, we wanted to present the tradition of the past in a modern, useful way.

1.4. Market and product analysis

The analysis of currently available cards on the market was performed on four different decks of tarot cards. Our aim was to find different cultural examples based on agreed symbols. The first deck was The Macabre Tarot by Samantha West pictured in Figure 1 [22], which includes motifs the users usually associate with the dark arts and macabre. The colours used are black, white, and gold. The digitally created motifs are positioned in the centre of the card in terms of width and slightly above the centre of the card in terms of height in order to create space for the typography in the lower part of the card. The typog-

raphy uses serifs and is centred between two crescent moons facing each other.

Figure 1: The Macabre Tarot deck [22]

The second deck is a deck created by Pietro Alligo and Silvana Alasia, the Egyptian Tarot (Figure 2). The illustrations were created using classical artistic tools, with tempera colours on papyrus [23]. The illustrations portray characters and symbols typical for the artworks created in Ancient Egypt, which we can also observe on the walls of tombs, so it would be obvious to the user which theme inspired the authors. The classic art template was later translated into digital art in order to design the cards in a specific format and add additional information, such as the card number and the typography in the Papyrus font that suits the theme of the deck.

Figure 2: Egyptian Tarot deck [23]

The third deck we analysed was the Grimalkin's Curious Cats Tarot by Margaux Jones Culligane (Figure 3). The author worked entirely in the digital art space. She used the photo editing programme Adobe Photoshop and the Wacom graphic tablet to create digital drawings of elements later implemented into the final image [24]. The illustrations were created using a digital collage technique, which includes elements of photography and digital illustrations. The compositions of elements create an illusion of a space filled with various details. Each card also includes typography to identify each card. The typography is embedded into a band of colour on the bottom of the card, uses serifs, and is written in capital letters.

Figure 3: Grimalkin's Curious Cats Tarot deck [25]

The fourth example we observed was the Buffy the Vampire Slayer deck by Casey Gilly and Karl James Mountford (Figure 4) [26]. The deck was based on the 90s television series of the same title and portrays stylised characters and motifs from the series, which are still recognisable to the user who watched the show. The illustrations are entirely digital and include coloured shapes with added shading to create the illusion of depth. The protagonists are compositionally inserted into the middle of the format, with the background representing space. The cards also include a band of colour on the bottom and contain typography with serifs and other ornaments. The letters are all capital and of the same height.

Figure 4: Buffy the Vampire Slayer Tarot deck [26]

By analysing different decks, we noticed that they are designed entirely to the author's liking, meaning there are no pre-arranged rules or guidelines for the design of tarot decks. We observed that the standard dimensions for tarot cards are 70 mm × 120 mm in a vertical format [27], however, the dimensions vary from deck to deck.
As we were not able to find a similarly designed deck in the market, we decided to create graphic products that would describe and visualise the motifs from the Balkan cultural heritage.
To test the effectiveness of the designed product in stimulating interest in the cultural heritage of the Balkans, we established four working hypotheses, which we verified with an online survey. The hypotheses we developed are:

1. Visual folk art is important for the preservation and awareness of the culture and history of a people.
2. Folklore and mythology from the Balkans are not widely known or widespread among people.

3. The use of symbols and illustrations in rituals creates opportunities for dialogue and learning.
4. The use of appropriate symbols and colours will influence the recognition of the meaning of the cards and raise awareness of the historical cultural heritage of the Balkans.

2. EXPERIMENTAL PART

2.1. Methods

After collecting information in the theoretical domain, researching the market, and analysing selected decks available on the market, we researched the symbolism of the cards to gain a deeper understanding of the messages each card is supposed to contain. We then researched folklore motifs and paired them with the cards based on the messages and symbolism they contain. The folklore motifs from the Balkans were collected by researching local legends, fairytales, superstitions, and other heritage traditionally passed down in an oral form, but for the sake of the research and to allow the repeatability of the experiment, we tried to find information that has been recorded in writing as well. After designing the product, we conducted a survey to test the effectiveness of our product in stimulating dialogue about Balkan folklore. The survey was aimed at the general public, as we wanted to determine the level of knowledge about Balkan folklore among the population.

The designing process

Nowadays, various technological and digital accessories are increasingly being incorporated into the artistic conception. Formally, we follow very different graphic products, which are predominantly characterised by a vector format. Vector graphics (scalable graphic files based on mathematical formulas) allow us to adapt our art content to the desired format by scaling up or down without losing data. Visually, some amount of data is lost regardless, as the observer's perception adapts to the different media used to convey the message.

In our case, we approached the design of artistic templates with the goal of using them on the tarot cards. We focused on the geographical area of the Balkan countries while excluding Greece, as we wanted to distance ourselves from the better-known Greek mythology. We wanted to find folkloric motifs from each Balkan country to shed light on lesser-known cultural heritage of the area. The motifs from which we sought inspiration are both figural renderings, animal renderings, and other cultural elements. The selected set of motifs include: the Kosovar bride, Krivopeta (the wild woman with feet turned backwards), the moth, Čuvarkuća (the House-guarding snake), the dragon, Sicanje (traditional Balkan tattooing), Martenitsa (Pizho and Penda), Baba Roga, Queen Teuta, the peacock from the fairytale Nine peacocks and the golden apple tree, fairies, fish incarnations of the twins from the fairytale Twins with the golden stars on their foreheads, Zeleni Jurij (Green George), the dancing bear, Zlatorog (Goldhorn), Psoglav (Doghead), Todorec (Todor rider), Gorska vila (Mountain fairy), Sevdah, Ederlezi, the fairytale Sun and Nasta, and the Pisanica egg (Easter egg).

We also found creative inspiration in Balkan textile arts. Namely, in designing the cards, we took inspiration from hand-woven rugs called kilims, which are made from wool. Kilim weaving is one of the most widespread forms of folk art, with many rug-weaving centres across the Balkan region [28]. We took inspiration from an image of a Bosnian kilim shown in Figure 5 [29].

Figure 5: A Bosnian kilim [29]

As we can observe in the image of the Bosnian kilim, the dominant colours used in the weaving process are red, black, and the natural colour of the wool, which we defined as a light ochre colour. The selection of dominant colours coincides with the colours mostly associated with the Balkan cultural heritage, except for white colour, which we replaced with the natural colour of the wool, this being light ochre. We specified the chosen three shades in CMYK colour model as C 0%, M 70%, Y 0% and K 100% for black, C 17%, M 100%, Y 100% and K 0% for red, and C 9%, M 16%, Y 36% and K 0% for light ochre (Figure 6).

Figure 6: The selected colours we used in the process of designing Balkan folklore tarot cards [personal archive]

The graphic elements we designed were completely composed of shapes in the three selected shades of red, black, and light ochre. They were placed within a frame composed of multiple continuous zig-zag lines. The frame was created using a custom-made pattern brush, which we had prepared by composing a shape made of triangles (Figure 7) and imported as a new brush. This allowed us to adapt the outer strokes of the shapes from classic straight lines of equal weight on each selected sequence into a defined stroke in the form of a zig-zag line.

Figure 7: A line out of triangles that we imported as a New brush [personal archive].

In modern times, the ethnological tradition of visual creativity is linked to ornament. Throughout history, the role of ornament has been to artistically complement a useful object and make it more attractive. Ornaments can be found in ceramics, textiles, architecture and, with the invention of printing, in the results of printing. These ornaments were applied either on the level of addition or on the structure of the material itself. Formally,

they can consist of geometric and abstract shapes or represent a naturalistic imitation. In our example, we have chosen a geometric pattern or an ornament [30].
The frames became increasingly smaller towards the centre of the format, which we defined as 70 mm in width and 120 mm in height, with rounded corners with a radius of 0.6 mm. The colour fills between the frames served as belts. The outer belt was filled with the chosen shade of light ochre, inside of which we placed repetitive graphic elements we had prepared beforehand in four varieties of colour combinations (Figure 8).

Figure 8: Graphic elements in four colour combinations, inspired by the symbols from traditional Balkan kilims [personal archive]

The second belt was filled with the chosen black colour and the inner square was filled with the chosen shade of red. In the final product (Figure 9), these graphic designs were used as the artwork for the back of the cards.

Figure 9: The final design of the artwork for the back of the cards [personal archive]

In regards to the front of the cards, we approached the design process by intentionally creating art designs in form of classical drawings. With the initial drawings, we helped explain different findings we had collected in the previous research. The drawings with different stroke weights were translated into the digital environment, first by translating the drawing on paper into the raster graphic in the raster graphic editing software Procreate, available on iPads. Afterwards, the raster drawing was vectorized in the Adobe Illustrator vector graphic editing software. A vectorized illustration was then placed on a prepared artistic template, which consisted of a frame in the form of a zig-zag continuous line and shapes which contained typography with Abril Display Bold and Baskerville Display PT as chosen fonts, serving to identify each card we had prepared beforehand. The inner fill of the shape, framed by the black zig-zag line, was filled with a pre-defined red shade. The background behind the zig-zag-framed red shape was filled with a selected light ochre shade. An example of the end result of a designed front of a card is shown in Figure 10.

Figure 10: An example of the final design of a front of a card [personal archive]

The manual that accompanied the cards was designed in the Adobe InDesign software in the same format as the cards (70 mm × 120 mm) but without the rounded corners. The covers of the manual included the same graphic used as the artwork for the back of the cards. The back cover remained the same, but for the front cover we replaced the designed traditional element placed in the middle of the artwork with typography that included the title of the manual in the font Abril Display Bold and the subtitle in the font Garamond as shown in Figure 11.

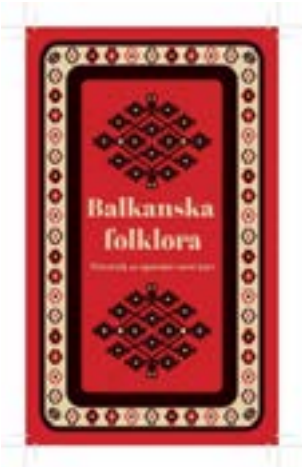

Figure 11: Front cover of the manual [personal archive]

The inner design of the covers contained only one of the graphic elements we designed, entirely in red on a light ochre background (Figure 12). The inner cover contained the title and subtitle of the manual in the same chosen fonts. The following spread contained text that addressed the reader. The spreads inside the manual, which contained descriptions of the cards, were designed to have the graphic of the front of the cards on the left and the text on the right page (Figure 13). The manual also included instructions for use of the cards and the sources that were used to collect the depicted folkloric motifs during the research. We added page numbers on the pages that did not contain graphics covering the

entire page.

Figure 12: Spread of the inner cover [personal archive]

Figure 13: Spread in the manual with the design of the card on the left page and description on the right page [personal archive]

The printing materials used for the cards and the manual were chosen in accordance with advice from a printing house. For the cards, we decided on 350 g/m^2 paper with lamination and digital cutout and for the manual 250 g/m^2 paper with lamination for the cover and 160 g/m^2 for the inner pages, including sewing and perfect binding.
The Tarot Card Manual we have designed contains the illustrations of each card pictured alongside the text describing the motif depicted on the card and the key words that help the user to understand the meaning of the card. The manual also includes instructions on how to lay out the cards and what each card refers to in a spread, i.e. how to read or interpret it. The card reading guide describes some of the most commonly used card readings to simplify the user's experience and encourage participation. As there is little literature on local Balkan folklore, especially since the nature of folklore is that it is often passed on orally or through certain customs and traditions, we decided to collect the data from various sources, including internet sources and orally transmitted stories and legends, which we verified through several written sources rather than peer-reviewed articles. The information was collected in the libraries of Ljubljana, in the books we could find online, in online blogs and in articles on local websites in the Balkans countries.

2.2. The results of the survey

The survey we conducted was created in an open source code application 1ka, which enables online surveys to be conducted. The survey was conducted online and was accessible via a link that we published on social media and disseminated to the population. The test population consisted of the general public, as we wanted to check how knowledge about Balkan folklore is spread among the general population and observe differences between different generations and different levels of education.

When analysing the responses, we found that 124 participants originally took part in the survey, but only 71 of them completed the questionnaire in full.

The questionnaire consisted of 15 questions, which we divided into three sections. The first section consisted of three demographic questions, which showed that 60% of respondents were female, 35% were male and 5% were other. The most common age of participants was between 20 and 29 years old at 84%, the second most common age of participants was under 20 years old, 30 to 39 years old and 50 to 59 years old at 5% each. Only 1% of participants were between 40 and 49 or over 60 years old. Most participants (56%) had a bachelor's degree, 25% had a high school diploma, 15% had a master's degree, 2% had a primary school diploma and 1% had a PhD degree.

The second part of the questions were general questions on folklore, which consisted of four questions mainly related to the general perception of folklore and the participants' self-assessment of their knowledge of the local and general folklore of the Balkan countries (we identified the following countries as Balkan countries in our research: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Kosovo, Montenegro, North Macedonia, Romania, Serbia and Slovenia). The first question was an open-ended question asking participants: "What do you think the term folklore encompasses?" While we expected many participants to mention "the traditional dances", many also included traditional costumes, old customs and habits, traditional music, legends, stories, songs, superstitions, myths, fairy tales and other oral knowledge and stories. A few referred to folk art, but a few reserved the term only for dances.

The following questions were self-assessment questions on knowledge of the local folklore of the participants' home environment and self-assessment of knowledge of the folklore of the wider Balkan area (see above). The rating scale was qualitative and consisted of the answers 1 – not at all, 2 – poor, 3 – average, 4 – above average and 5 – very well informed. As expected, most participants rated their knowledge of their local folklore as poor (40%) or average (33%) and above average (24%), while the majority rated their knowledge of wider Balkan folklore as poor (56%) or average (23%), with the third most common response being 'nothing' at 17%.

In The next question, participants were asked to tick the boxes next to the colours listed that they thought best represented Balkan folklore. The colours to choose from were blue, red, green, black, white and yellow. Participants were allowed to choose several options. As expected, participants most associated red with Balkan folklore (88%), white (63%) and black (36%). The colours blue, green and yellow were selected in 31%, 28% and 18% of cases respectively.

In The following open question, participants were asked whether they thought the representation of their local folklore in the visual media was important, and they were asked to explain their answer. Most participants believe that the representation of local folklore in visual media is important to preserve cultural heritage for future generations, to learn about a people's own identity and culture, roots and history. They also stated that they believe it is important to preserve cultural diversity in a society that strives to homogenise society, arguing that the "majority of art is focused on the common Anglocentric factor", which is why we often forget our own cultural heritage.

In The third section of the questionnaire, the participants were asked about the tarot cards.

In questions 8 and 9, participants were asked if they had ever received a reading with tarot cards and if they had ever performed a divination ritual with tarot cards for someone. The majority had not performed the divination ritual with tarot cards themselves (89%), but the majority (59%) had received a reading with tarot cards.
In The following questions, participants were asked to rate how likely it was that they would engage in a dialogue about the motives of the tarot cards, whether they would read about them in a manual, ask the person laying the cards, talk about them with a friend or buy the cards in a shop. The scale was again qualitative, with answers ranging from 1 – not at all likely to 4 – very likely. The majority of participants responded that it is likely to very likely (25% and 33%) to read about the motif in the manual that comes with the cards. Only 15% of participants stated that it is very likely that they would ask the person reading the cards to them about the motif, with 32% of participants stated that it is likely that they would ask about the motif. The majority of participants think it is unlikely that they would talk to their friends about the motifs (26% not at all likely and 35% not very likely), and 41% would not buy the cards if they saw them in a shop, while 19% said they would be very likely to buy them and 18% said the likelihood was average.
In the next question, participants were shown a picture of the design for the back of our tarot cards and asked what feelings it evoked in them. Most participants said it reminded them of home, coffee, carpets, traditional costumes and old people. Some said it reminded them of something mystical, of love and even of flowers. Only a few participants said that it reminded them of something dangerous or unpleasant.
The next question related to the issue with the image of the design for the back of the cards and asked participants to judge whether the image made sense in the context of Balkan folklore, which the majority of participants answered in the affirmative (78 %).
The following two questions were designed to assess whether participants would make a successful connection between the symbolic messages of the cards and the description of the motifs, so that we could check whether the motifs adequately represented the card on which they were placed. Analysing the responses showed that in the vast majority of cases, participants successfully made a connection between the motif and the symbolic message of the card, confirming that our choice of motifs for the cards was appropriate.
In The last question, participants were asked whether they thought that a small piece or piece of information that would give them new knowledge about Balkan folklore would stimulate their curiosity and motivation to learn more about Balkan folklore. The majority of participants (76%) answered “yes”.

3. CONCLUSION

The Balkan cultural heritage is rich and diverse. Throughout the geographical area of the Balkans, we encounter various traditions introduced by different cultural influences that brought cultural exchanges and trading that introduced novelties. The integrated cultural elements were portrayed on various objects, including textiles. The latter played an important role in finding inspiration for our graphic design of the illustrations, through which we wanted to equally portray the folkloric motifs from all over the Balkan geographical region.
The research project, which consists of a set of 22 artistic templates integrated into ritual cards for divination, is also accompanied by a manual based on our analysis of tarot cards available on the market. The manual for use of the cards often has the same dimension as the cards, as this ensures easier and more effective storage of both the manual and the deck in the same packaging. The manual we designed also has the same dimensions as the cards. The contents of our manual include short descriptions of motifs represented on each card as well as instructions for divination. By designing both the cards and manual, we observed our artistic designs on papers of two significantly different grammages and

were able to note differences in compositions and typography.
The hypotheses we set in the beginning of the research project are:

1. Visual folk art is important for the preservation and awareness of the culture and history of a people.
2. Folklore and mythology from the Balkans are not widely known or widespread among people.
3. The use of symbols and illustrations in rituals creates opportunities for dialogue and learning.
4. The use of appropriate symbols and colours will influence the recognition of the meaning of the cards and raise awareness of the historical cultural heritage of the Balkans.

These hypotheses were tested by conducting an online survey.
The first hypothesis ("Visual folk art is important for the preservation and awareness of a people's culture and history") was tested by observing the questions regarding the participants' views on the importance of the representation of cultural heritage (especially folklore) in visual media. We had learnt through gathering information in the theoretical field that the use of symbols and visual art enhances the impact of a ritual and promotes the preservation of cultural heritage, and the participants' responses in the survey were consistent with the findings from the sources. The vast majority of participants' responses expressed that they found it important that to present their folklore and heritage in the media in order to understand their own and their national identity, to preserve their cultural heritage for future generations and to maintain cultural diversity in a society which is heading towards homogenisation under the influence of Western cultures and global powers which have the greatest cultural and political influence. After our findings and analysing the responses from the survey, we came to the conclusion that our research confirmed the first hypothesis.
The second hypothesis ("Folklore and mythology from the Balkans are not very well known or widespread among the population") was tested using the questions assessing the participants' own knowledge of their local folklore and Balkan folklore in general. After analysing the participants' answers to the assessment questions, we concluded that the second hypothesis was confirmed in our study.
The third hypothesis ("The use of symbols and illustrations in rituals creates opportunities for dialogue and learning") was tested by the self-assessment questions in which participants rated the likelihood of dialogue about the motifs of the cards. While most participants would have looked up the motif in the accompanying booklet, they rated the likelihood of having a dialogue about the motif from the cards with a person interpreting the cards as significantly lower. On the other hand, the responses of most respondents indicated that the majority would try to expand their knowledge of Balkan folklore if they received new information about their heritage. From the responses received, we concluded that the third hypothesis could be explored further, perhaps with a larger population and in two parts, with the second part of the survey being conducted later than the first part and focussing on participants' accounts of how they explored Balkan folklore on their own after coming into contact with the maps and handbook. The latter reason is why we only partially confirmed it in our research.
The fourth hypothesis ("The use of appropriate symbols and colours will influence the recognition of the meaning of the cards and raise awareness of the historical cultural heritage of the Balkans") was tested using questions that tested the recognition of symbols from Balkan folklore and the understanding of the symbolism on the cards or the connection of the story behind the motif with the symbolic meaning or message of the cards, as well as the feelings that the symbols used evoke in the participants when they look at the cards. Most of the participants, who were mostly from the Balkan countries, responded that the

symbols and motifs reminded them of domesticity, tradition, the feeling of warmth, coffee and the cultural heritage of the Balkans in general. Based on the participants' responses, we confirmed the fourth hypothesis within our research.
Although we felt the survey was too short, we found that interest in answering all the survey questions dropped dramatically after participants encountered the first open-ended question. We concluded that the number of participants who would have answered all questions would have been even lower if the survey had consisted of even more questions. The solution to this problem might be to create several shorter questionnaires and present them sporadically to the same participants.
From an artistic point of view, we have combined traditional textile expression and the modern digital design of the visual image. In the study of carpets, we have found that the geometric design of the pattern dates back to the Greek period - the meander continued with Celtic ornaments, which in a way confirms the geographical continuity of the space we are exploring in the work. Patterns from primitive art were also integrated into contemporary visual art. In the illustrations, we also drew on the traditions of prehistoric art and added the image of a human being to all the mythological creatures in order to bring the design itself closer to the user. We deliberately moved away from an abstract and fanciful interpretation which would lose its essence when interpreted by the user.
The research project also includes consideration of cultural heritage, especially the intangible cultural heritage, which is even more prone to oblivion than the tangible cultural heritage. With our work, we aimed to accentuate that the blend of tradition and cultural heritage can be a part of contemporary graphic expression, which we have now preserved in our product. With our product, we are preserving our heritage and educating the younger generations about the life and contents our ancestors lived and practiced.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

THE INFLUENCE OF VARNISH APPLICATION ON HARDNESS AND COLOR VARIATION OF UV INKJET PRINTS ON PVC BOARDS

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ABSTRACT

This research aims to examine the impact of varnish application on the colorimetric values of CMYK colors and the hardness of prints on PVC board, using CMYK ECO-UV 220-c inks and ECO-UV varnish. The samples were printed on a Roland Versa UV printer/cutter equipped with an Epson DX4 printhead. Colorimetric values were measured at 10%, 20%, 40%, 70%, and 100% tone values (TV), both without varnish and with one, two, and three layers of varnish, using the X-Rite Exact Advance spectrophotometer (condition M0, D50, and 2°). Print hardness was evaluated using the Elcometer 3092 Sclerometer Hardness Tester. The results indicated that increasing number of varnish layers led to more pronounced color changes. The most significant color change was observed in the cyan 10% TV with three layers of varnish (ΔE = 14,32), while the least change occurred in the magenta 100% TV with one layer of varnish (ΔE = 0,77). Further analysis of changes in chromaticity and lightness showed significant chromaticity changes across all process colors, whereas lightness had the greatest imact on variations within the yellow tonal patches. Additionally, it was found that increasing the varnish application enhanced the mechanical resistance of the prints, with the resistance force increasing from 7 N for the unvarnished print to a maximum of 20 N for the print with three varnish layers.

Keywords: UV LED Inkjet, Color difference, Hardness, Print quality, PVC board.

1. INTRODUCTION

Digital printing technology, particularly inkjet printing, is becoming important across various industrial sectors due to its high precision, flexibility, and adaptility to a wide range of substrates. Inkjet printing allows for the production of complex patterns and high quality graphics, making it ideal for applications that demand details and personalization, such as packaging, marketing materials, and customized products. This technology is also recognized for its adaptability to various substrates, including paper, plastic, textiles, wood, glass, and metal (1,2). According to the latest data, the digital printing market, including inkjet technology, is presenting an annual growth rate (CAGR) of 6,54%, indicating continuous growth and expansion in the coming period (3).

In recent years, the application of UV inkjet printing has become the focus of intensive research due to its numerous advantages, including excellent mechanical properties, durability, and resistance to external influences (4).

The foundation of the entire process is the UV ink used to create the print, which solidifies under UV radiation through a chemical polymerization reaction. UV inks are pigmented, with pigments comprising 15-20% of their composition. The remaining componens include various substances, such as monomers (e.g., monoacrylates, hexacrylates), oligomers (10-25%), prepolymers (20-35%), and photoinitiators (e.g., benzil dimethyl ketal and others), along with a range of additives (5,6).

To achieve a firm and stable print, it is essential to ensure proper alignment between the

ink and the UV radiation source. Currently, the most commonly use UV radiation sources are LED-based systems, which are environmentally friendly, more compact compared than conventional drying systems, and capable of delivering high radiation intensity (up to 3 W/cm^2). These sources enable instant curing of UV ink, significantly reducing production time. A key advantage of UV inks is that they do not contain hazardous organic solvents, thereby eliminating evaporation or absorption issues while stil achieving high quality and long-lasting prints (5,7–9). For this reason, UV inks are increasingly used in the packaging industry (10).

One of the key factors influencing the quality and durability of packaging, and other printed products, is the application of protective coatings, particularly varnishes (10,11). UV varnish is essentially a UV LED ink without pigments (12). UV varnishes play a significant role in enhancing both the visual appearance and the chemical and mechanical resistance of printed surfaces (13,14). Fine droplets of varnish, typically around 6 pL in volume, can be applied selectively or across the entire printed area, in single or multiple layers, to achieve either a a glossy or matte finish, depending on the desired effects (8,13,15).

The application and curing mechanism of the UV varnish layers is the same as that of UV inks, enabling the formation of a firm and stable surface resistant to light, abrasion, and other external factors. However, it is important to note that the varnish application may cause undesirable color changes in the print. This phenomenon results from the photoinitiator's reaction during the polymerization process and is visually manifested as as yellowing (8,16,17).

Although PVC boards offer numerous advantages in the printing industry, achieving optimal print quality on this type of graphic substrate remains a challenge. The application of multiple layers of ink and varnish enhances both the functionality and aesthetics appeal of printed rigid PVC materials, thereby expanding the potential for producing a wide range of graphic products.

However, to ensure a long-lasting and stable results, it is essential to understand the impact of applied varnish layers on both the surface hardness of the print and potential color changes, which is precisely the subject of this paper. A deeper understanding of these these factors is crucial for optimizing print quality and ensuring the durability of printed products, thus opening up new opportunities for the development of high-quality graphic products.

To test hardness refers to examine the material's ability to resist the penetration by a foreign object into its structure (18). In other words, this characteristic indicates that materials with lower hardness are more susceptible to damage and deformation, which negatively affects their durability (19–21). There are two fundamental types of hardness testing, classified based on the material being examined. The first method, commonly used for testing the hardness of metals, includes various techniques such as the Brinell, Vickers, Rockwell, Shore, HBT, and Knoop methods (18,22). However, in the context of graphic industry, the second method is more relevant, this method is designed for assessing the hardness of elastomers and other polymer materials. It typically involves applying force through weights and springs as the loading mechanism.

The key difference between these methods is the use of IRHD (International Rubber Hardness Degree) when testing hardness with weights, while in other cases, the Shore hardness scale is used. The Shore scale is divided into Shore type A and Shore type D, depending on the hardness of the material being tested (18,23).

On the other hand, color change is most commonly quantified colorimetricly today, using one of several standardized formulas. Among the most commonly used formulas are CMC (1:c) BFD (1:c), DE76, CIE 94, and the CIE ΔE00, the latter being particularly relevant for this experiment. The CIE ΔE_{00} formula is especially important because it offers high precision in measuring color non-uniformity and provides a detailed analysis of color changes that may not always be visible to the human eye (1,24,25).

This paper focuses on investigating the effects of different layers of UV varnish on surface hardness and color changes in prints on PVC substrates. Understanding these factors is essential for optimizing print quality and ensuring the durability of printed products, thereby opening up new opportunities for producing high-quality graphic products.

2. RESEARCH METHODOLOGY

In the experimental part of the paper, a test form was initially created using the Adobe Illustrator CC 2016 program. The form included patches of process colors with dimensions of 12 x 12, ranging from 10% to 100% in 10% increments. Rasterization was then performed using Roland VersaWorks RIP with the following settings: media type (Generic), print quality (Standard), resolution (720 × 720 dpi), mode (CMYK(v) + PASS), non-direction printing, dither screening, and high-quality mode (lower speed but higher varnish and resolution).
Given that the focus of this research is on the impact of varnish on hardness and colour variations, four print variants were produced: without varnish, with one layer of varnish, with two layers of varnish, and with three layers of varnish. The prints were generated using a piezoelectric Roland Versa UV LEC 300 printer/cutter. The specifications of the machine are provided in Table 1.
As shown, this printing machine provides substantial flexibility regarding substrate compatibility and varnish application effects, making it suitable for a wide range of printing and industrial applications. It is also important to note that this machine is equipped with the Epson DX4 piezo inkjet printheads. Each printhead consists of 360 nozzles arranged in two rows, with a drop size of 3.5 pL and a drop frequency of 8 kHz. A total of three such printheads are implemented in this printing system.

Table 1: Roland Versa UV LEC 300 printer/cutter specifications (26)

Media width	182 to 762 mm
Media Thickness	> 1 mm with liner, for printing
>1.4 mm with liner for cutting	
> 0.22 mm without liner for cutting	
Roll outer diameter	> 180 mm
Ink catridges	Cyan, magenta, yellow, black, white, gloss
Ink type	ECO-UV (EUV4) 220 cc, 500 cc catridges
Varnish effect	Matte and glossy
Ink-curing unit	Dual UV LED Lamp
Printing resolution	360x720 dpi, 720x720 dpi, 720x1440 dpi, 1440x1440 dpi

PVC boards were used as the printing substrate. Their thickness was 0,573 mm, and their gloss level was measured at 5.117 GU. In addition to the substrate, key components essential for print formation included ECO-UV 220-cc inks and ECO-UV varnish. ECO-UV 220-cc inks are characterised by high density and crack resistance, allowing printing on a wide range of coated and uncoated substrates such as papers, films, and vinyl. These inks also offer a wide colour gamut and excellent resistance to scratching and other external factors. Their composition includes colourants, corresponding monomers, oligomers, and prepolymers - such as Benzyl acrylate, Hexamethylene diacrylate, 2-Methoxyethyl acrylate, photoinitiators (Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide), and other additives. The ECO-UV 220-cc varnish contains the same substances as the ink, except for the pigments. It is characterised by low viscosity and fast adhesion to various coated and

uncoated materials, providing enhanced resistance to external influences (26–29).
After printing, spectrophotometric measurements were conducted, followed by hardness testing. Spectrophotometric analysis was carried out using the X-Rite Exact Advance device. The CIE Lab values of the substrate were measured, as well as the tonal values of the process colours: light tones (10% TV and 20% TV), mid-tones (40%), and dark tones (70% and 100% TV). Measurement parameters included: 2.5 mm measurement aperture, M0 measuring mode, 20 standard observer, and D50 standard light source. The collected data were sorted and processed using Microsoft Excel and OriginPro software to calculate colour difference (CIE ΔE00, in accordance with the ISO 11664-6:2014 standard), chroma difference (CIE ΔC00), and brightness change (CIE ΔL00).
Hardness was measured using the Elcometer 3092 Sclerometer Hardness Tester, which complies with both national and international standards (AS 3894.4, EN 438-2, and ISO 4586-2). The device operates on the principle of gradually increasing the applied force on a specific surface through a spring mechanism. The instrument's tip is drawn across the test surface over a distance of 10 mm. The force is adjusted using an setting ring that positions the spring within the instrument body. Four spring types are available: a grey spring (0-3 N), red spring (0-10 N), blue spring (0-20 N), and green spring (0-30 N) (30).

Figure 1: Hardness measuring process

3. RESULTS AND DISCUSSION

This section first presents the results related to colour changes, specifically through the calculated colour difference values (CIE ΔD_{00}). To provide a more detailed analysis, the subsequent subsection examine deviations in chroma (CIE ΔC_{00}) and brightness (CIE ΔL_{00}).

3.1. Printing substrate colour difference

The first step in the analysis involves examining the color changes occuring on the printing substrate (PVC sheet). As expected, an increasing number of varnish layers leads to progressively greater colour differences in the substrate. Application of the first varnish layer resulted in a colour difference of ΔE_{00} = 3,32. While this value indicates a noticeable colour difference, it still falls within the range generally considered acceptable and not radically perceptible to the human eye (31).
After the application of the second layer, the colour difference increased significantly to ΔE_{00} = 9,97, indicating a much more pronounced deviation from the original substrate color. This value exceeds the commonly accepted percebility threshold ($\Delta E_{00} > 6$), signifying a clearly visible color change.
With the applying the third varnish layer, the colour difference increased further to ΔE_{00} = 11,76. Since both the second and third layer values surpass the threshold of 6, it can be concluded that the colour change is clearly visible. The corresponding ΔE_{00} values are illustrated in Figure 2. (Chapter 3.2)
The observed color changes can be attributed to corresponding deviations in chroma (ΔC_{00}) and lightness (ΔL_{00}), as illustrated in Figures 3 and 4. Specifically, both chroma and

lightness values exhibit consistent changes with the increasing number of varnish layers, contributing cumulatively to the overall color difference of the substrate.
After the application of three varnish layers, the chroma deviation reached ΔC_{00} = 3,57, while the lightness deviation was ΔL_{00} = –3,91. These values confirm that the color change is a result of both increased chroma and decreased lightness.

3.2. Cyan colour difference

As shown in Figure 2, the curves representing color differences in cyan tonal patches exhibit a consistent shape, characterized by a noticeable decrease in color change as the tonal value increases. Specifically, after the application of the third varnish layer, the smallest color difference is observed in the solid color (100% TV), with a value of ΔE_{00} = 5,44. In contrast, the highest color difference is recorded in the light cyan patch at 10% TV, with a ΔE_{00} value of 14,32, which represents the highest color shift observed in this study.
It is also noteworthy that the cyan value at 10% TV after three layers of varnish deviates from the otherwise consistent curve pattern for cyan tones, indicating an outlier in the behavior of low-tone cyan under multiple varnish layers.

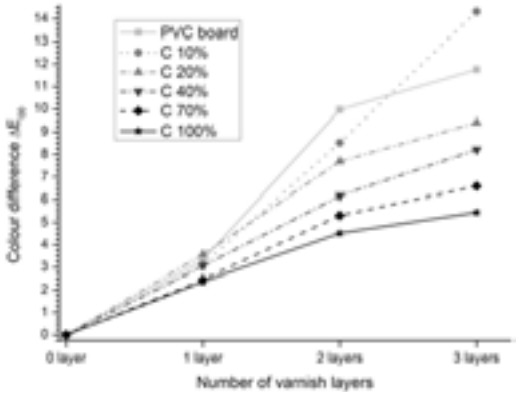

Figure 2: Cyan colour difference diagram

Analysis of chroma deviations reveals that most values are negative, with the corresponding curves appearing closely intertwined. An exception is observed in the cyan patch at 20% TV, where, after the application of three varnish layers, the chroma deviation shifts to the positive and reaches ΔC_{00} = 2,40. A similar trend is noted in the lightness deviation curve. All tonal patches exhibit a yellowish undertone, leading to a decrease in lightness values. The most substantial drop occurs in the 20% TV patch, with a ΔL_{00} value of –6,08. Additionally, the previously mentioned high color difference for the 10% cyan patch after three varnish layers (ΔE_{00} = 14,32) may be attributed to its increased lightness compared to the same patch with two varnish layers. This discrepancy could result from specific light reflection behavior on the surface, potentially affecting the instrument's measure-

ment accuracy. Chroma and lightness deviations are presented in Figures 3 and 4.

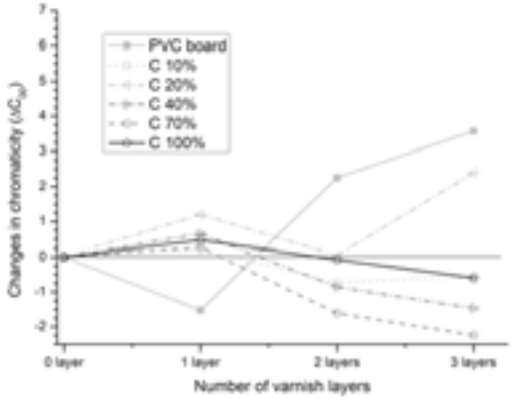

Figure 3: Cyan diagram of changes in chromaticity

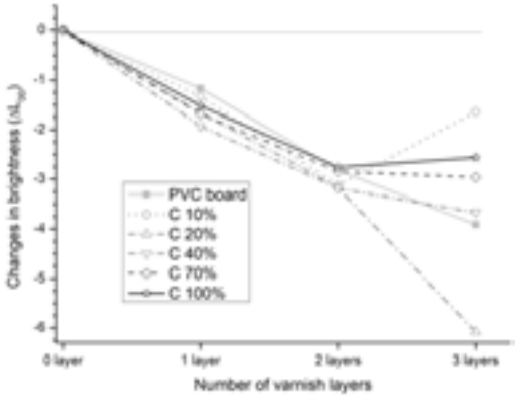

Figure 4: Cyan diagram of changes in brightness

3.3. Magenta colour difference

As illustrated in Figure 5, the color difference curves for magenta tones exhibit a highly consistent shape. All ΔE_{00} values are lower than those observed for the printing substrate and follow a downward trend as tonal coverage increases. The smallest color difference after three varnish layers is observed in the solid color patch (100% TV), with a value of ΔE_{00} = 1,82, while the highest value occurs in the 10% tonal patch, reaching ΔE_{00} = 10,59. It is also noteworthy that the lowest overall color difference recorded in the entire experiment is found in the solid color patch after the application of a single varnish layer, with a ΔE_{00} value of 0,77.

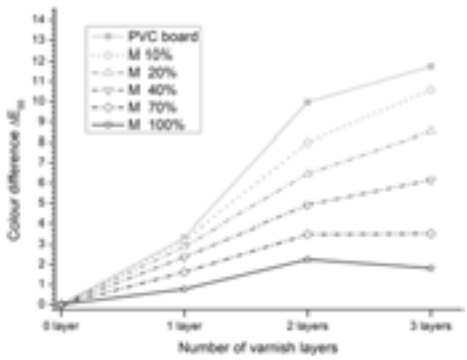

Figure 5: Magenta colour difference diagram

Chroma and lightness deviations for magenta tonal patches are presented in Figures 6 and 7. The chroma deviation values remain close to zero, with a minimum of ΔC_{00} = –0,03 in the solid color patch (100% TV) and ΔC_{00} = –1,10 in the 10% TV patch.
Based on these values, it can be concluded that the dominant factor contributing to color change in magenta areas is the change in lightness. After the application of three varnish layers, lightness deviation values range from a minimum of ΔL_{00} = –1,51 in the solid color patch to a maximum of ΔL_{00} = –4,05 in the 10% TV patch.

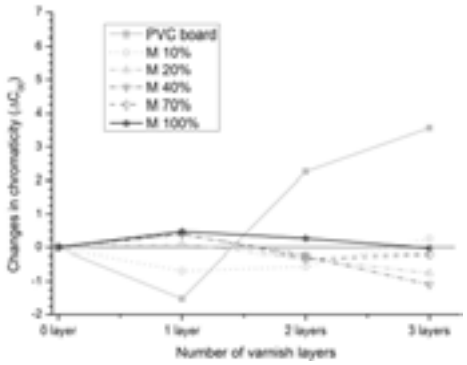

Figure 6: Magenta diagram of changes in chromaticity

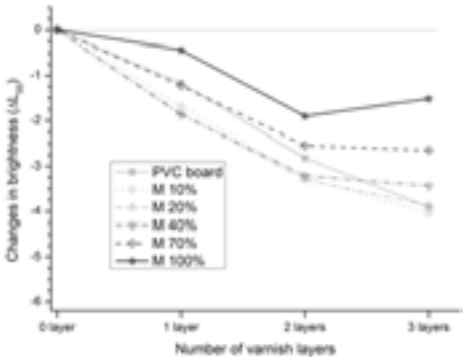

Figure 7: Magenta diagram of changes in brightness

3.4. Yellow colour difference

Similar to the previous cases, yellow exhibits the greatest color difference in the light patch at 10% TV (ΔE_{00} = 8,83), and the smallest difference in the solid color patch (100% TV), with ΔE_{00} = 2,49. These trends are illustrated in Figure 8, while corresponding chroma and lightness deviations are presented in Figures 9 and 10.
Chroma increased more prominently in the lighter tonal areas, likely due to the influence of the substrate's pigmentation, while the darker tonal patches were less affected. After the application of three varnish layers, the chroma deviation for the solid color patch (100% TV) was ΔC_{00} = 1,00, whereas in the light tonal pathes, it reached a maximum of ΔC_{00} = 6,70. Regarding lightness deviations, values after three varnish layers ranged from

ΔL_{00} = –2,28 in the solid color patch to ΔL_{00} = –3,77 in the 10% TV patch.

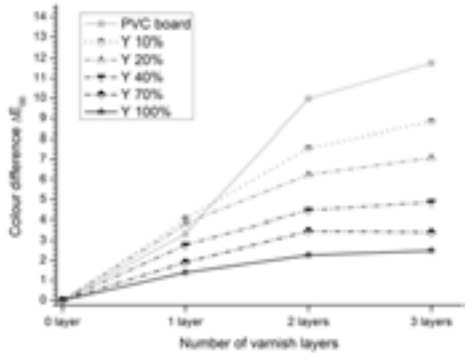

Figure 8: Yellow colour difference diagram

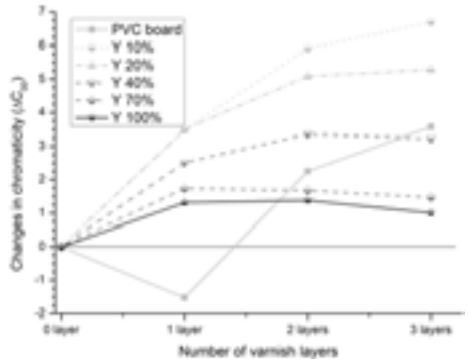

Figure 9: Yellow diagram of changes in chromaticity

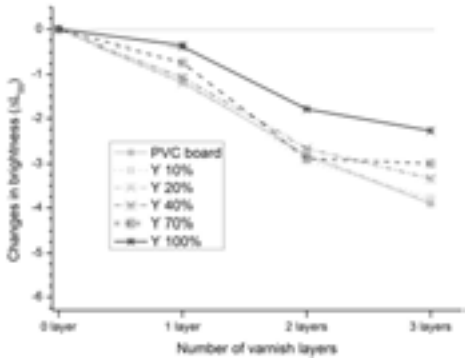

Figure 10: Yellow diagram of changes in brightness

3.5. Black colour difference

As with the other process colors, the light tonal patches of black exhibited greater color differences compared to the medium and dark tonal areas. After the application of three varnish layers, the color difference values for black ranged from a minimum of ΔE_{00} = 2.23 in the solid color patch (100% TV) to a maximum of ΔE_{00} = 11.02 in the 10% TV patch.

These results are illustrated in Figure 11.

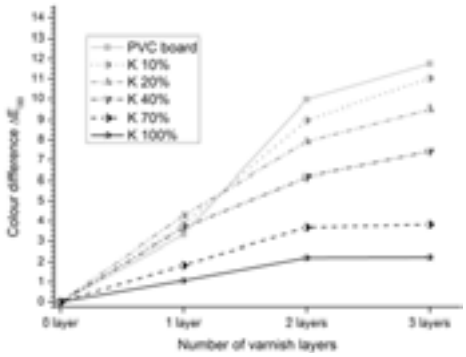

Figure 11: Black colour difference diagram

The chromaticity change values are somewhat interwoven, as shown in Figure 12. From the neutral axis, the solid color patch exhibits the least deviation, with ΔC_{00} = 1,01 after three layers of varnish, while the patch with 20% tonal coverage shows the greatest deviation (ΔC_{00} = 3,97). The light tonal patch at 10% and the medium tonal patch at 40% fall between these extremes. Interestingly, the curve for the light tonal patch at 10% is entirely linear.

The curves for brightness deviation, shown in Figure 13, are almost the inverse of those for color change. After three varnish layers, the smallest brightness change was observed in the solid color patch (ΔL_{00} = –0,25), while the largest change occurred in the 10% tonal patch (ΔL_{00} = –4,25).

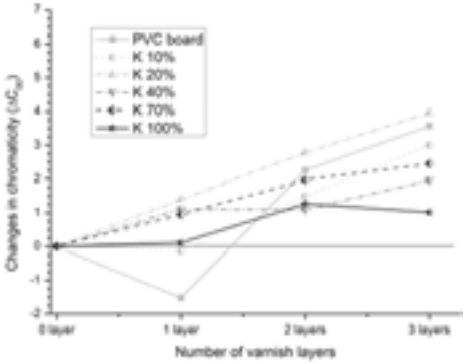

Figure 12: Black diagram of changes in chromaticity

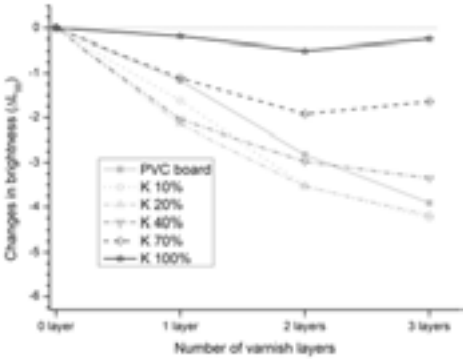

Figure 13: Black diagram of changes in brightness

3.6. Hardness testing

In addition to analyzing color changes, the correlation between varnish application and print hardness was also investigated. It was found that increased varnish application improved the print's resistance (Figure 14). The hardness of the prints without varnish was measured at 7 N. The same force was required to remove a single layer of varnish from the surface of the PVC substrate. When a single layer of varnish was applied to the process color patches, cyan and black showed greater resistance compared to magenta and yellow. For magenta and yellow, the color was removed with a force of 10 N, while cyan and black required a slightly higher force of 12 N. After applying the second layer of varnish, the force needed to remove the print increased to 14 N, and with the application of a third layer, a force of 20 N was required to remove the color.

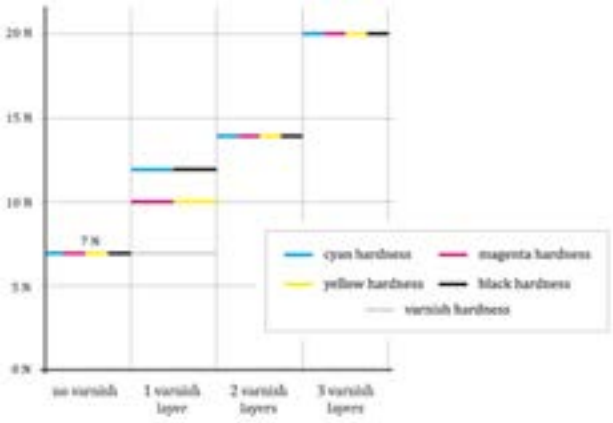

Figure 14: Hardness diagram

4. CONCLUSION

This study is based on the investigation of the impact of varnish layers on the hardness and color changes of prints made on PVC boards. The research involved analyzing color differences, with a detailed examination of these changes in terms of variations in chroma and lightness across tonal patches with coverages of 10% TV, 20% TV, 40% TV, 70% TV, and 100% TV.

The results showed that increasing the application of varnish led to more pronounced color changes. The least color change was observed in the solid color magenta patch with a one layer of varnish, with a ΔE_{00} value of 0,77. After applying the third layer of varnish, this patch remained the least affected compared to the other colors and tonal patches, with a ΔE00 value of 1,82. The most significant color change occurred in the cyan 10% TV with three layers of varnish, reaching a ΔE_{00} value of 14,32.

A more detailed analysis of the color differences through chroma changes revealed that chroma showed the most significant difference in the yellow patches. This was expected, as the inherent color of the varnish influenced the yellow tone.The least impact on chroma was observed in the magenta tones, as evidenced by the change curves, which remained close to the neutral line.

The curves of brightness changes revealed the impact of ΔL00 on color difference, primarily because the increasing yellowness of the print alters the optical characteristics of the surface, including reflection and light dispersion. This can lead to changes in color perception by the instrument, as the amount of reflected light reaching the device decreases. A similar trend was observed in the yellow patches, where the brightness change curves followed a comparable pattern. However, it is important not to overlook the influence that the pigmentation of the varnish had on the tonal patches of the other process colors.

The hardness analysis showed that increasing the varnish application enhanced the prints'

resistance, with the force required to resist removal rising from 7 N for the print without varnish to a maximum of 20 N for the print with three layers of varnish.
In summary, the research results indicate that varnish layers have a significant impact on both the hardness and color characteristics of prints. This highlights the importance of finding a balance between structural and visual quality, with the need to establish acceptable limits within which these parameters can vary.
For future research and to expand on the existing knowledge, it is recommended to investigate the effects of different types of varnishes on the analyzed parameters. Such studies would provide a deeper understanding of how these variations influence the stability and overall quality of prints.

Acknowledgement(s):

This research was financially supported by the Ministry of Scientific and Technological Development, Higher Education and Information Society of the Republic of Srpska under project No. 19.032/961-60/24, titled "Critical Assessment of Color Quality Control in the Printing Industry in Accordance with the Recommendations of ISO 12647, ISO 15311, and ISO 13655 Standards."

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

STABILITY OF THERMOCHROMIC PRINTS ON FOOD PACKAGING LABELS: EFFECTS OF COLORANT MIGRATION INTO FOOD

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ABSTRACT

This paper investigates the stability of thermochromic prints on food packaging labels, focusing on the risk of colorant migration into food simulants and the potential impact on the safety of packaged food. The research was motivated by the increasing use of thermochromic inks in smart packaging and the associated risk of colorant migration, which can affect food safety. Previous studies on the chemical stability of thermochromic inks (ISO 2836:2021) found significant colorant migration from the print through the bottom layer of the paper into filter papers saturated with various chemical substances. These results indicate that thermochromic prints release a considerable amount of colorants even when they are not in direct contact with chemical substances.
To determine the degree of migration, a series of tests were carried out to measure the migration of colorants from printed label papers into food simulants that mimic possible real contact between the print and the food product. The tests followed the EN 646:2018 standard, in which the sample is placed between two glass fiber papers previously saturated with a test fluid (food simulant). After a certain contact time at room temperature, the degree of colorant migration onto the glass fiber paper is evaluated.
The food simulants used in the study included deionized water, a 3% (m/v) acetic acid solution, an alkaline solution composed of 4.2 g/L Na_2CO3, 0.5 g/L NaCl and 0.2 g/L K_2CO_3, and olive oil. The results show that contact between the label paper and the 3% acetic acid simulant significantly increases the risk of colourant migration, indicating that such labels may not be suitable for use with acidic foods.

Keywords: thermochromic printing inks, migration of colorants, food safety, packaging, print stability.

1. INTRODUCTION

With the dynamic development of the packaging industry, the need for new, innovative ways to ensure the safety of food in packaging is also growing. The use of special thermochromic inks is becoming increasingly popular, not only for their aesthetics, but also for their functionality and ability to protect products. However, the use of specialty inks, such as thermochromic inks, carries certain risks [1].
Ensuring food safety during packaging, transportation and storage is of great importance. To ensure a high level of quality and health safety, many manufacturers rely on various temperature indicators to ensure the freshness and quality of products throughout the entire production and transportation process. These indicators are often prints made with thermochromic inks that are categorized according to their activation temperature (T_A). There are three main groups: cold-activated, heat-activated and body temperature-activated inks. Each group can be used for different indicators, from those that signal when a beverage is cold enough to consume to those that warn when a food is too hot to eat [2, 3]. Although indicators are an excellent way to improve food protection and rarely come into direct contact with food, under certain conditions thermochromic inks can migrate through the packaging and contaminate the food with harmful substances from its com-

position, thereby compromising food safety. Migration refers to the transfer of chemical substances from packaging into food. It can occur through various mechanisms, including penetration, evaporation, set-off (contact transfer between printed and unprinted surfaces in a stack or roll), and condensation during processes like heating [4]. Direct contact between the printed and unprinted side of the packaging material while it is stored in rolls or stacks after printing, exposure of the packaging to high temperatures — such as cooking food in its original pouch, pasteurization, sterilization — as well as direct contact between packaging and food can all increase the migration of potentially harmful substances into packaged products [5].

1.1. Thermochromic inks used in smart packaging applications

Thermochromic inks are smart inks that change colour in response to temperature fluctuations due to chromogenic compounds undergoing structural changes [6]. To enhance stability and longevity, these compounds are encapsulated in microcapsules, protecting them from moisture, UV radiation, and chemical degradation [7, 8]. This ensures consistent performance, making thermochromic inks valuable for packaging, security printing, and interactive labelling. These inks are categorized based on their active material, activation temperature (T_A), and the duration of the colour change. Thermochromic ink systems can display either reversible or irreversible color changes on heating or cooling. Irreversible inks undergo a permanent colour change upon activation, while reversible inks shift colours multiple times, returning to their original state once the temperature drops below T_A [9]. These transitions can include colour-to-colour, colour-to-colourless, or colourless-to-colour shifts [10]. When protected from direct sunlight, extreme temperatures, and solvents, reversible inks can maintain their functionality for up to 10 years [11].
Thermochromic inks are widely used in smart packaging systems, primarily as temperature indicators. They are printed on packaging or labels to inform consumers whether a product is ready for consumption based on color changes [2,3,8,9]. In food packaging, they help detect thawing in frozen products, irreversibly changing color if the permitted temperature is exceeded. Cold-activated inks (≈10°C) signal optimal consumption temperature for beverages and food, while heat-activated inks (≈40°C) are used in indicators for baby food and heated packaging. A subcategory includes body heat-sensitive inks (≈31°C), applied in interactive packaging and the pharmaceutical industry [2,3,9].
The aim of this study is to investigate the stability of thermochromic prints on packaging label paper that has been exposed to direct contact with glass fiber papers previously soaked in food simulants . Thermochromic prints on packaging can come into contact with acidic, fatty, aqueous or alcoholic foods, which can lead to migration and have a negative impact on the health safety of the packaged product. In previous studies on the chemical stability of thermochromic inks (ISO 2836:2021) [12], a considerable degree of colorant migration from the print through the underlying paper layer into filter papers soaked with various chemical agents was observed [11]. This indicates that the prints release a considerable amount of colorants even when in indirect contact with chemical agents.
To assess the extent of migration, a series of colorant migration tests were conducted with printed label papers and food simulants, simulating the potential contact between the print and food under real conditions.

[1]Food simulants are media used in food packaging testing to simulate the transfer of substances from packaging materials into food. Their purpose is to mimic the main physicochemical properties of food and enable the assessment of substance migration. Food simulants are divided into four main groups: aqueous, acidic, alcoholic, and fatty food simulants, and they are selected based on the dominant component in the food.

2. MATERIALS AND METHODS

In the experimental part of the study, the stability of thermochromic prints with regard to the migration of colorants into food simulants was investigated based on the EN 646:2018 standard [13]. A single thermochromic UV ink was printed in full tone on three types of label paper, and the resulting prints were subjected to a colour fastness test to evaluate the safety of food packaging labels.

2.1. Thermocromic inks

The prints used in the study were screen-printed with a commercially available UV-curable thermochromic ink. This ink appears purple below its activation temperature (T_A = 31°C) and turns pink when heated above 31°C (Figure 1). Classified as body-heat activated, it changes colour when exposed to heat, e.g. by rubbing a finger or blowing warm air [14].

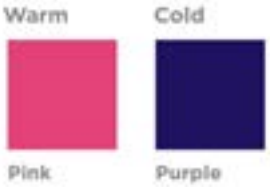

Figure 1: Illustration of the color change of the used thermochromic ink at temperatures above and below its TA [15]

Since it is a reversible ink, it returns to its original purple colour after cooling. The ink likely contains blue thermochromic leuco dyes in microcapsules and conventional pink pigments, with the pink dominating when the thermochromic component becomes colourless at activation temperature [6,16].
Due to the high sensitivity of the ink, it is not recommended to expose it to UV light, direct sunlight or high temperatures (above 38 °C) for extended periods of time, as this may affect the colour intensity and performance. The ink is also sensitive to certain chemicals, meaning wet ink should avoid solvent contact [17].

2.2. Label paper substrates

Three high-quality label papers for food packaging with a functional coating on the reverse side were selected as substrates. The three label papers were Niklakett Premium (NP), NiklaSelect (NS) and Chromolux 700 (CHR), each with specific properties specified by the manufacturer, which are listed in Table 1.

Table 1: Properties of used label papers

Property	Unit	Method	Type of label paper		
			Niklakett Premium (NP)	NiklaSelect (NS)	Chromolux 700 (CHR)
Basis weight	g/m^2	ISO 536	75	80	100
Caliper	µm	ISO 534	64	65	113
Specific volume	cm^3/g	ISO 534	0.85	0.81	0.88
ISO Brightness	%	ISO 2470 (R475, D65)	90	93	89.3

Opacity	%	ISO 2471	87	88	94

Niklakett Premium (NP), produced by Brigl & Bergmeister, is a high-gloss, single-coated paper recognized as one of the best label papers. It is widely used for labels on chilled beverages due to its high resistance to water and moisture, ensuring excellent durability in wet conditions, such as ice buckets or during labelling. Its key properties include high wet opacity, which is ideal for labels with lower ink coverage, good climate stability, high wet strength, and alkali resistance. Additionally, its functional coating on the reverse side optimizes glue consumption, ensuring efficient labelling performance. Niklakett Premium (NP) is primarily used for reusable applications, such as returnable bottles, but is also suitable for disposable applications. It is compatible with all printing techniques, especially offset, gravure, and flexographic printing [18].
NiklaSelect (NS), also produced by Brigl & Bergmeister, is a high-gloss, single-coated packaging paper with exceptional smoothness and strength. It offers good tear resistance, making it suitable for demanding packaging applications. While not moisture-resistant, it is certified for direct food contact, ensuring its safety for use in food packaging. The paper is compatible with all printing techniques, allowing for high-speed printing with excellent print quality. Additionally, its surface properties support efficient lamination and coating processes, making it a versatile choice for various packaging applications [19].
Chromolux 700 (CHR) is a premium, high-gloss label paper renowned for its ultra-smooth surface and superior appearance. Designed primarily for non-returnable packaging, it is ideal for food and non-food product labels. A key feature of Chromolux 700 is its certification for direct food contact by ISEGA, ensuring compliance with food safety standards. It is well-suited for offset, flexographic, and gravure printing, as well as other applicable techniques [20].

2.3. Printing trials

Printing was performed under laboratory conditions using a semi-automatic screen-printing device from Holzschuher KG, Wuppertal. A mesh with 62 lines per centimetre was used for the process, and the prints were produced in full tone. After printing, they were cured using a Technigraf Aktiprint L 10-1 UV dryer with a power of 30 W/cm. The ink characteristics provided by the manufacturer are shown in Table 2.

Table 2: Characteristics of used thermochromic UV screen printing ink [17]

Property	Value
Viscosity at 25 °C	65–110 poise
Density (Approx.)	8.0 lb./gal
Appearance	Viscous Liquid
Percent Solids (Approx.)	99%
Percent Volatiles (Approx.)	<1.5%

2.4. Determination of colour fastness of printed label food packaging papers

The stability of thermochromic prints on three types of label paper with regard to colorant migration into food simulants was evaluated according to the standard EN 646:2018 "Paper and board intended to come into contact with foodstuffs – Determination of color fastness of dyed paper and board". In this test, the printed sample was placed between two glass fiber papers previously saturated with a food simulant and subjected to a load of 1 kg for 24 hours at room temperature. The test was repeated for each sample and the

results were presented as the arithmetic mean of two measurements. The food simulants used included deionized water, olive oil, a 3% (w/v) acetic acid solution and an alkaline solution containing 4.2 g/L Na_2CO_3, 0.5 g/L NaCl and 0.2 g/L K_2CO_3. The prints were cut to approximately 2 cm × 5 cm for testing purposes.
After the 24-hour exposure, the glass fiber papers were air-dried in the dark for a further 24 hours to avoid light-induced effects. Spectrophotometric measurements were then performed to evaluate the migration of colorants from the printed samples to the glass fiber paper by determining the color difference (ΔE_{76}). Measurements were taken on both the glass fiber paper that was in direct contact with the printed side of the sample and the one that was in contact with the unprinted (bottom) side to determine whether any colorants had migrated through the label paper. This method ensures a reliable assessment of the potential safety of thermochromic labels for use in food packaging.

2.5. Spectrophotometric measurements

To determine the colour fastness, each glass fiber paper (placed on the top or bottom side of the printed sample) was measured three times at five different positions within the area that came into contact with the print. Temperature-dependent spectral reflectance of the glass fiber papers was measured (spectral region 430–700 nm, 1 nm step) by fibre-based USB 2000 spectrometer (Ocean Optics, Orlando, Florida, USA) using a 30 mm wide integrating sphere (ISP-30-6-R) with (8°:di) measuring geometry and 6 mm sampling port diameter. OceanView software by Ocean Optics was used to calculate the CIE L*, a*, b* values considering the D50 illuminant and 2° standard observer. Spectroscopic measurements were conducted at two fixed temperatures for each thermochromic print: one below its activation temperature (T_A) and one above it. Consequently, the staining of the glass fibre papers was evaluated at 20 °C and 45 °C. The samples were heated on the surface of a water block from EK Water Blocks (EKWB d.o.o., Ljubljana, Slovenia).

3. RESULTS AND DISCUSSION

Colorant migration was evaluated by determining the total colour difference (ΔE_{76}) on glass fibre paper before and after the colour fastness test, conducted in accordance with EN 646. The calculation was based on the measured differences in the CIELAB colour space parameters: ΔL*, Δa*, and Δb*.
Measurements were performed on the surface of the glass fiber paper saturated with the prescribed food simulant that had been in contact with the test sample during the procedure. Both the surface in direct contact with the sample and the surface located beneath the sample were analysed.
Spectrophotometric measurements were taken prior to and following the migration test to determine the colorimetric parameters L*1, a*1, b*1 (before) and L*2, a*2, b*2 (after). The resulting colour difference ΔE was calculated using the CIE 1976 formula (Equation 1).

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \quad (1)$$

Although the staining of the glass fiber paper is typically evaluated against the Grey Scale for assessing staining (as defined in EN ISO 105-A03) [21], in this study the colour changes were assessed instrumentally. This approach is in accordance with EN ISO 105-A05:2003 [22], which allows objective quantification of Grey Scale ratings by calculating ΔE_{76} values using a spectrophotometer.
Table 3 presents the evaluation criteria used to assess the colour differences (ΔE_{76}) ob-

served on the glass fiber paper in contact with the tested samples. The obtained numerical values of colour differences were converted into ratings on a scale from 1 to 5 including half steps, corresponding to the Grey Scale for assessing staining.
The recommendation of the German Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung – BfR) concerning paper and board materials intended to come into contact with food [23] is considered the most important legislative guideline in Europe for paper-based food packaging. According to this recommendation, the migration of colorants into food is not permitted. The German regulation stipulates that samples must achieve a rating of 5 on the so-called Grey Scale (Table 3), with any rating below 5 deemed unacceptable. This is especially important in case of packing the moist and/or fatty foods [24].
Tables 4–6 show the results of colorant migration as a function of the food simulants used, tested on three types of printed paper, measured both above (45 °C) and below (20 °C) the activation temperature (T_A) of the thermochromic ink. The aim was to determine which colorant, if any, migrated onto the glass fiber paper and to what extent — whether the thermochromic leuco dye (when measured below the T_A) or the conventional pigment (when measured above the T_A, when the leuco dyes are in their colourless state).

Table 3: Comparison of total colour difference (ΔE_{76}) ranges with corresponding Grey Scale ratings (EN ISO 105-A05:2003)

ΔE_{76}		Evaluation grade
	< 0.40	5
> 0.40	< 1.25	4-5
> 1.25	< 2.10	4
> 2.10	< 2.95	3-4
> 2.95	< 4.15	3
> 4.15	< 5.80	2-3
> 5.80	< 8.20	2
> 8.20	< 11.60	1-2
> 11.60		1

The designation “U” indicates that the measurement was taken on the upper side of the sample, where the glass fiber paper came into direct contact with the print, while the designation “D” stands for measurements on the underside of the paper, i.e. on the side facing away from the printed label, which serves as an indicator of colorant migration through the label paper.
For practical reasons, spectrophotometric measurements could not be performed on the glass fiber paper saturated with olive oil. Therefore, a visual assessment of colorant migration was conducted. The evaluation was carried out in a standardized colour assessment cabinet (Judge II, X-Rite, Macbeth) under CIE D50 standard lighting, which simulates daylight conditions (with a correlated color temperature of approximately 5000 K) and is widely accepted for visual colour matching. The results are shown in Figure 2 a-c, indicating that none of the tested samples exhibited any visible colour change on the glass fiber paper after testing, compared to the blank control.

Table 4: Colour change observed on glass fibre paper following migration testing with acetic acid food simulant

Food simulant	45 °C	Grade	20 °C	Grade
3% acetic acid				

	ΔE_{76}		ΔE_{76}	
CHR_U	3.26	3	3.88	3
CHR_D	1.09	4-5	0.89	4-5
NP_U	2.19	3-4	1.97	4
NP_D	1.33	4	1.18	4-5
NS_U	2.60	3-4	2.60	3-4
NS_D	0.59	4-5	1.55	4

Table 5: Colour change observed on glass fibre paper following migration testing with alkaline solution food simulant

Food simulant	**45 °C**	**Grade**	**20 °C**	**Grade**
Alkaline solution				
	ΔE_{76}		ΔE_{76}	
CHR_U	0.01	5	0.05	5
CHR_D	0.03	5	0.13	5
NP_U	0.27	5	0.15	5
NP_D	0.23	5	0.23	5
NS_U	0.13	5	0.07	5
NS_D	0.27	5	0.19	5

Table 6: Colour change observed on glass fibre paper following migration testing with deionized water food simulant

Food simulant	**45 °C**	**Grade**	**20 °C**	**Grade**
Deionized water				
	ΔE_{76}		ΔE_{76}	
CHR_U	0.10	5	0.30	5
CHR_D	0.09	5	0.12	5
NP_U	0.33	5	0.23	5
NP_D	0.35	5	0.27	5
NS_U	0.13	5	0.11	5
NS_D	0.08	5	0.29	5

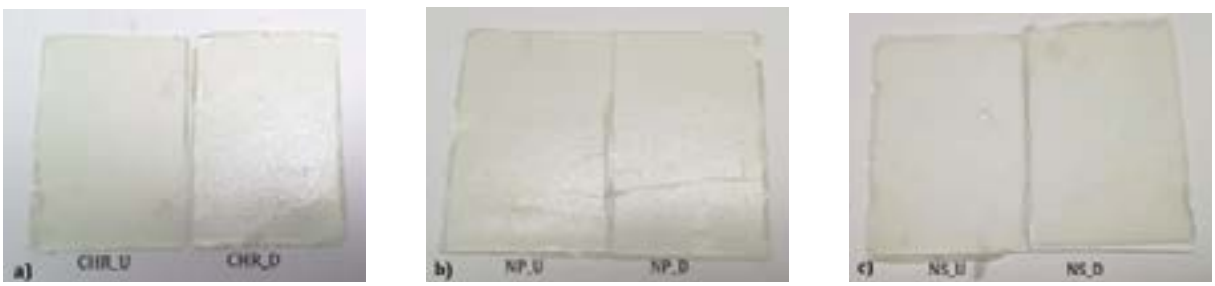

Figure 2: Visual assessment of colorant migration from the sample to the upper (U) and lower (D) side of the glass fiber paper (20 °C)

From the results presented, it can be concluded that only the food simulant containing 3 % acetic acid solution caused colorant migration above the permissible limit. In this case, all tested label papers showed an unacceptable level of colorant migration (or bleeding) on the contact side of the glass fiber paper saturated with this food simulant. The highest level of migration was observed with the print applied to Chromolux paper, which corresponds to a Grey Scale grade of 3.
Migration was observed at both temperatures tested (above and below the activation temperature, TA), indicating that both the leuco dye and the conventional pigment were involved in the migration process. Migration through the back of the label paper was confirmed for Niklakett Premium paper at 45 °C (above T_A) and for NiklaSelect paper at 20 °C (below T_A). However, it should be noted that in both cases the extent of migration was low (Grade 4), although it is still considered non-compliant according to EU regulations.
For the remaining food simulants — water, alkaline solution, and olive oil — no migration of colorants was observed, either by spectrophotometric analysis or by visual assessment of bleeding. These results indicate that the tested label papers are not suitable for use with foods that have a certain level of acidity, while they are considered acceptable for use with other types of foods.

4. CONCLUSION

The primary objective of this study was to evaluate the stability of thermochromic prints on various types of label paper and to determine the extent of colourant migration, as well as its potential impact on the safety of food products. The results revealed that contact between the label paper and the 3% acetic acid simulant significantly increases the risk of colourant migration, indicating that such labels may not be suitable for use with acidic food products. This was consistently observed across all tested label papers, with the most pronounced effect seen on Chromolux paper. Migration occurred both above and below the thermochromic ink's activation temperature, suggesting the involvement of both conventional pigments and leuco dyes.
Although migration through the label paper was limited and only mildly expressed (Grey Scale grade 4), it was still considered non-compliant according to relevant regulations. In contrast, no colourant migration was observed with deionized water, the alkaline solution, or olive oil, either by spectrophotometric analysis or visual inspection. These findings suggest that the tested thermochromic labels may be considered acceptable for use in contact with products represented by these specific food simulants. However, further research is needed to assess their performance under more complex and realistic food contact conditions, including variations in storage time, temperature, and packaging configurations.

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

THE IMPACT OF CARDBOARD COMPOSITION, INK AND VARNISH COATING ON THE STRUCTURAL INTEGRITY OF OFFSET PRINTING SUBSTRATES

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ABSTRACT

The most common printing technique used to print commercial cardboard packaging is offset printing. Offset printing is also called indirect printing because it uses a roller system to transfer prints from the printing plate to the printing substrate. Cardboard of various thicknesses and weights, as well as composition, is used as a printing base to meet all the requirements of the client and end users. The most common division of cardboard printing substrates is the division according to the main composition of the material itself, so we distinguish cardboard from chemical pulp (GZ), mechanical pulp (GC) and secondary (recycled) pulp (GT and GD). To enhance the durability of cardboard packaging and the longevity of colors, the print must be protected after printing. In most cases, print protection is achieved through varnishing, using either glossy or matte water-dispersible varnish.

Keywords: offset printing, cardboard packaging, puncture resistance, compressive strength.

1. INTRODUCTION

The segment of the graphic industry that is experiencing constant growth is the printing of commercial cardboard packaging. One of the most prevalent printing techniques for cardboard packaging is offset printing. Offset printing is also known as indirect printing because it uses a roller system to transfer prints from the printing plate to the printing substrate [1, 2]. The roller system comprises the plate cylinder, offset (blanket, rubber) cylinder, and impression cylinder, while the dampening and inking systems are in contact with the printing plate placed on the plate cylinder [3].

Packaging has several important functions: protecting the product from environmental influences, safeguarding it during transport and handling, and informing potential customers [4, 5]. Given the functions it must fulfill and the requirements of clients and end users, the basic division of cardboard packaging is based on the printing substrate. For commercial packaging, cardboard with a weight range of 190 – 600 $g \cdot m^{-2}$ is used as the printing substrate [6].

Cardboard is made from three basic components: cellulose, mechanical pulp, and recycled paper [7, 8, 9]. In addition to these basic components, auxiliary materials such as fillers, binders, and colorants are used in cardboard production. Based on the main composition, we distinguish between cardboard made from chemical pulp (GZ), mechanical pulp (GC), and secondary (recycled) fibers (GT and GD) [6, 10]. Depending on the underside, cardboard can have a number along with its designation (letter), such as 1-white, 2-cream, and 4-brown underside. For GD cardboard, the number indicates the specific volume of the cardboard, divided into -1-, -2-, and -3-. Cardboard made from chemically bleached pulp is GZ cardboard, used for packaging medicines, perfumes, and other decorative products. GC cardboard is made from mechanical pulp enclosed between layers of bleached chemical

pulp and has widespread use in the food and pharmaceutical industries. GD and GT cardboards are primarily made from secondary (recycled) fibers and are used in the food and cosmetics industries [6, 10].
Cardboard intended for packaging must be resistant to mechanical stress, climatic conditions, have good barrier properties, and excellent visual characteristics. To enhance the mechanical durability of cardboard packaging and the longevity of colors, the print must be protected after printing. In most cases, print protection is achieved by varnishing, using either glossy or matte water-dispersible varnish. Depending on the customer's requirements, varnishing can be done partially or over the entire surface of the packaging. In addition to its protective function, varnish adds value to printed products.

2. MATERIAL AND METHODS

For the purposes of this study, samples measuring 70x70 mm and 25x70 mm of various cardboard grades (GC1, GC2, GD2, GT1, GT2, GT4) and weights were used (Table 1). The samples were printed on a Koenig & Bauer 105 offset printing machine with an in-line varnish unit. Food-safe colors cyan, magenta, yellow, and black were used, with an additional spot color on 3 samples. The gloss water-based varnish was transferred onto the printing substrate using a varnish polymer plate; the coating blanket was manufactured using a unique multilayer technology on a polymer film base.

Table 1: Characteristics of cardboards used in the research

Sample	Cardboard grade	Weight / g·m^{-2}
1	GT4	300
2	GC1	320
3	GT2	350
4	GT1	350
5	GT1	400
6	GC1	380
7	GC2	270
8	GD2	400
9	GD2	400

Mechanical testing was conducted on two measurement devices: the Lorentzen & Wettre crush tester (Figure 1) and the Frank puncture tester (Figure 2). For testing on the puncture tester, 20 samples measuring 70x70 mm were used for each material, while for the crush test, 10 samples measuring 25x70 mm were used.

Figure 1: Lorentzen & Wettre crush tester

The crush tester offers several measurement options, and for the purposes of this study,

the force required to initiate the deformation of the cardboard was measured. The sample is placed vertically under the press between two supports that hold the sample upright [11]. Measurements were carried out according to the standard ISO 3037:2022.

Figure 2: Frank puncture tester

The puncture tester measures the force required to penetrate through the sample [12]. The sample is attached to the holder, and the punching head is released to punch the cardboard, after which the values can be read on the measurement scale. A specimen experiences three-point flexural impact loading from a swinging pendulum. The absorbed energy is determined by calculating the change in potential energy, derived from the difference between the pendulum's initial height before release and its peak height after passing through the specimen. Sufficient impact energy is applied to ensure complete fracture. The energy required for fracture, measured in joules, was recorded from the instrument's measurement scale. Measurements were carried out according to the standard ISO 3036-2025.

3. RESULTS ANS DISCUSSION

A box chart is used to visually present the key values. The box itself spans from the 25th to the 75th percentile, while the whiskers extend to the 5th and 95th percentiles. The mean value is depicted using a transparent rectangle, and the median is indicated by the dividing line within the box, separating the 25th and 75th percentiles.

The crush test results are illustrated in Figure 3.

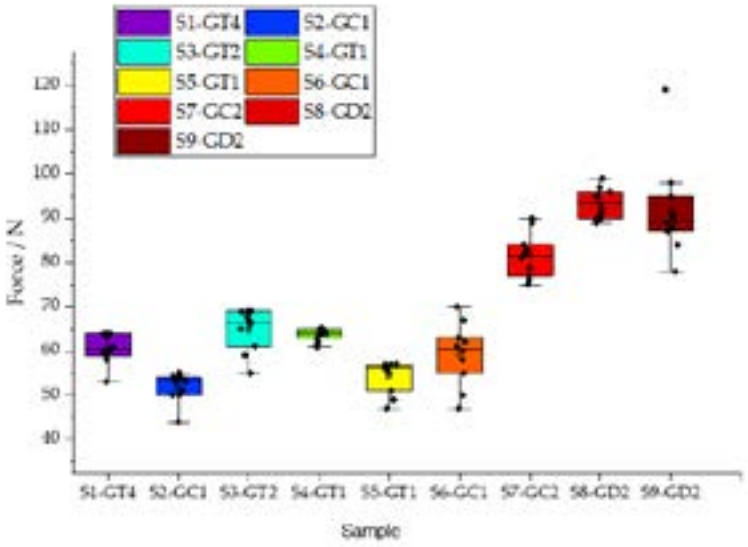

Figure 3: Crush test results

The crush resistance test highlights considerable differences in the force required to compress various cardboard grades, revealing key correlations between grammage, structural characteristics, and mechanical performance under compressive load. The highest crush resistance values were recorded for GD2 (400 g·m^{-2}) samples, namely S8 and S9, with 93.4 N and 91.9 N respectively. These results confirm the superior structural integrity of heavier-duty grades, making them ideal for packaging applications that require high stacking strength and compression endurance.

Despite being the lightest grade tested, GC2 (270 g·m^{-2}) exhibited high crush resistance of 81.6 N (S7), outperforming several mid- and high-weight samples. This suggests that factors beyond weight — such as fiber orientation, internal bonding, or core layer reinforcement — play a significant role in crush resistance.

Mid-weight samples such as GT2 (350 g·m^{-2}) and GT1 (350 g·m^{-2}) show moderate crush strength (64.8 N and 63.8 N respectively), offering a balance between strength and material efficiency. However, another GT1 sample (S5, 400 g·m^{-2}) displayed only 54.2 N, underperforming relative to its weight category. This discrepancy may indicate inconsistencies in internal structure, manufacturing variability, or differences in paper layering.

The lowest crush resistance was recorded in S2-GC1 (320 g·m^{-2}) with 51.8 N, followed closely by S1-GT4 (300 g·m^{-2}) at 60.6 N. These lower values align with expectations for lighter grades, confirming their appropriateness for packaging where high compression strength is not a primary requirement.

The fracture resistance test results are illustrated in Figure 4. The Figures 5., 6. and 7. show the samples after 3 series of punching, where the same pattern of cardboard tearing is visible.

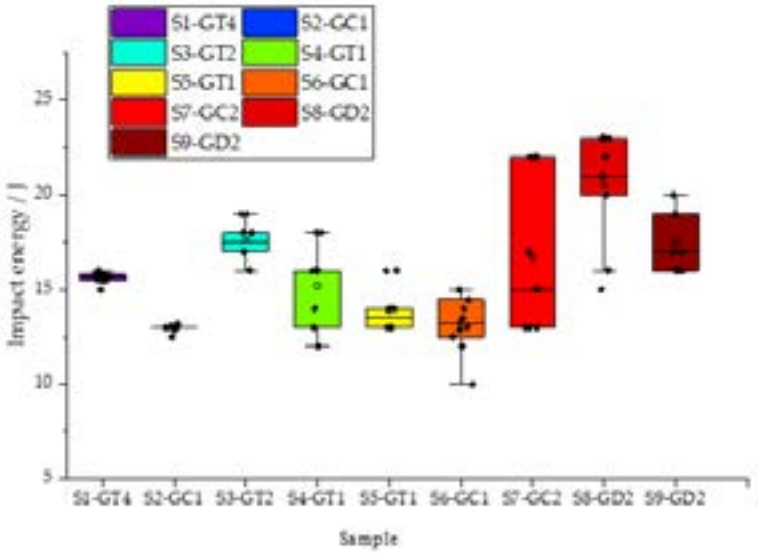

Figure 4: Fracture resistance results

The fracture resistance test reveals significant variations in the impact energy required to break different cardboard grades, highlighting the relationship between cardboard weight ($g \cdot m^{-2}$), material composition, and structural performance. Heavier-weight grades, such as GD2 (400 $g \cdot m^{-2}$)and GT1 (400 $g \cdot m^{-2}$), exhibit greater impact resistance, as observed in S8-GD2 and S9-GD2, making them suitable for heavy-duty packaging applications where strength and durability are essential. GC2 (270 $g \cdot m^{-2}$), despite being one of the lightest grades, demonstrates relatively high impact energy, indicating that fiber structure and composition contribute to fracture resistance beyond just weight alone. Mid-weight samples, including GT2 (350 $g \cdot m^{-2}$) and GC1 (380 $g \cdot m^{-2}$), show moderate fracture resistance, providing a balance between strength, flexibility, and cost-efficiency, making them ideal for general-purpose packaging applications that require durability but do not demand extreme impact resistance. Lighter grades, such as GT4 (300 $g \cdot m^{-2}$) and GC1 (320 $g \cdot m^{-2}$), exhibit the lowest impact resistance, confirming their suitability for lightweight packaging where high fracture resistance is not a primary concern.

Additionally, the variability in impact energy values, as indicated by the wider interquartile ranges and outliers in some samples, suggests that factors beyond weight, such as fibre composition, density, and manufacturing consistency, influence fracture resistance. For instance, while two samples may share the same weight classification, their impact resistance may vary due to fibre bonding strength or surface coatings that affect energy absorption and distribution. This is particularly evident in GC2 (270 $g \cdot m^{-2}$), which performs better than some heavier grades, likely due to enhanced fiber reinforcement or structural layering techniques.

Figure 5: Results of the first puncture test measurement

Figure 6: Results of the second puncture test measurement

Figure 7: Results of the third puncture test measurement

By understanding the interplay between cardboard weight, material structure, and impact resistance, industries can make more informed decisions when selecting packaging materials. Heavier, high-resistance grades are best suited for load-bearing applications and protective packaging, while lighter grades work well for cost-effective, disposable, or lightweight packaging solutions. The balance between weight, strength, and variability must be considered to optimize material selection for specific applications, ensuring that both durability and economic factors are taken into account.

4. CONCLUSION

The aim of this paper was to test the durability of printed cardboards used as packaging materials. With the help of two tests, punch and crush tests, the results obtained prove that materials made of recycled fibers and higher grammage show better mechanical durability and can be used for packaging for heavier products. GC1 type of cardboard is

dedicated for cosmetic products and the results show values in this direction, packaging for the lighter products. Overall, the results underline the importance of evaluating cardboard grades not solely based on weight, but through combined analysis of material composition and mechanical behavior. Understanding this interplay enables better material selection, ensuring that packaging solutions meet both functional and economic criteria across different applications.
To provide a more detailed explanation of the impact of the cardboard structure, future research will focus on the chemical analysis of the cardboards. By analyzing the chemical composition of the cardboard, the proportion of inorganic and organic substances and their impact on the structural integrity of the cardboard can be determined.

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ORIGINAL SCIENTIFIC PAPER

SUSTAINABLE REDESIGN OF SECONDARY PACKAGING: AN ECOLOGICAL IMPERATIVE FOR THE COSMETICS INDUSTRY

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ABSTRACT

The sustainable design of secondary packaging for cosmetic products is essential for reducing waste and minimizing environmental impact. Secondary packaging contributes to resource optimization and waste reduction while extending intervals between individual purchases, thereby lowering greenhouse gas emissions generated during product transportation and distribution. The implementation of sustainable packaging solutions relies on minimalist design principles, reducing raw material consumption by eliminating unnecessary material layers and excessive packaging elements. Particular attention is given to replacing multilayer plastic materials with easily separable and recyclable alternatives. This scientific study presents several conceptual redesign solutions for secondary packaging in the cosmetics industry, aiming to achieve greater environmental sustainability without compromising the functional and protective properties of the packaging. The focus is placed on optimizing material consumption, reducing the carbon footprint, and increasing the proportion of renewable and biodegradable materials in packaging production.
With growing consumer awareness of environmental issues, sustainable packaging has become a crucial differentiating factor in the market, driving the industry toward adopting eco-friendly solutions. Sustainable packaging design is not merely a passing trend but a necessity for reducing environmental burdens and achieving long-term sustainability goals.

Keywords: cosmetic product packaging, redesign, sustainability

1. INTRODUCTION

Sustainable design plays a key role in the creation of multi-packaging for cosmetic products, as it contributes to reducing waste, using environmentally friendly materials and reducing the negative impact on the environment. Given the fact that the cosmetic industry produces significant amounts of waste through packaging, it is essential to ensure that sustainable materials are selected, the use of unnecessary resources is reduced and plastics that have a negative impact on wildlife and humans are avoided.
One of the most important aspects of sustainable multi-packaging design is the selection of materials that are biodegradable, recyclable or reusable [1]. Materials such as cardboard, paper, glass and aluminium have a significantly smaller ecological footprint compared to plastics [2]. For example, cardboard packaging made from recycled materials can be reprocessed and used for further production, thus reducing the consumption of new raw materials and reducing pollution [3].
Avoiding plastic materials is essential due to their long-term degradation and harmful environmental impact [4, 5]. Most plastics used in packaging end up in landfills or in the oceans, where they take hundreds of years to decompose, releasing harmful chemicals into the soil and water [6]. In addition, microplastics, which are formed when plastic packaging breaks down, enter the food chain of animals and humans, which can have serious

health consequences [7].
The use of multi-packaging in the cosmetics industry further contributes to reducing waste and resource consumption. When products are packaged in larger units or in reusable packaging, consumers buy them less frequently, reducing the need to frequently produce and distribute new packaging [8]. This has a positive impact on the environment because it reduces carbon dioxide emissions during transportation, as well as the amount of waste generated after the product is used. Another advantage of multi-packaging is that it reduces the number of trips to the store, which has an additional positive impact on the environment [9]. Fewer trips mean less fuel consumption, which contributes to reducing greenhouse gas emissions. Combined with the responsible selection of packaging materials, this design approach can significantly contribute to the sustainability of the industry and a smaller ecological footprint.
Designers and manufacturers should consider minimalism and functionality when creating multi-packaging to reduce unnecessary material consumption. Instead of multi-layered packaging that serves only aesthetic purposes, the focus should be on simple and practical solutions that ensure product protection with as little waste as possible [10]. It is also important to ensure that the materials used are easily separable and recyclable, allowing for their proper processing after use.
Consumers also play an important role in promoting sustainable packaging design. Growing awareness of environmental issues is leading to an increased demand for products that use sustainable packaging. Brands that implement eco-friendly strategies in their design not only reduce their environmental impact but also satisfy increasingly demanding environmentally conscious consumers [11].
In conclusion, sustainable multi-packaging design for cosmetic products is essential for reducing waste, protecting the environment, and promoting responsible consumption [12]. Choosing biodegradable and recyclable materials, reducing unnecessary consumption of resources and avoiding plastic contribute to a healthier planet and the long-term sustainability of the industry [13]. The use of collective packaging further reduces the environmental footprint through less frequent trips to the store and lower carbon dioxide emissions. Sustainable design is not just a trend, but a necessity in the fight to preserve the environment for future generations.

2. METHODOLOGY

A single secondary packaging product was randomly selected from the market, which stores three bottles intended for cosmetic preparations (Figure 1). The product was selected for redesign to increase the sustainability of the product. By studying the product, it is possible to see that it is made using two packaging materials (cardboard and plastic). Although the materials can be easily separated and recycled, the use of plastic is unjustified, as it does not offer any functionality that a sustainable material could not provide.

Figure 1: Selected product for redesign [14]

The approach to redesign is systematic, to avoid possible non-functionality or unsustainability in the conceptual design. Several detailed proposals were made for more environmentally friendly packaging that replaces plastic and reduces unnecessary waste:

1. Compact cardboard box with precise bottle slots

The selected material for this conceptual design is 100% recycled cardboard or pressed biodegradable material (e.g. cellulose pulp). The box is designed so that each bottle has its own tray, eliminating the need for additional plastic supports. The box is closed in such a way as to create a cardboard lid with slots instead of plasticized tape or adhesive film. An additional step in increasing sustainability is minimizing the number of printing elements on the conceptual solution, which contributes to the reduced consumption of dyes in the printing process and the use of ecological colours. Visual elements should have a simple illustration that emphasizes the naturalness of the product.

2. Ecological paper wrapping with twine or tape made of natural fibres

For the second approach, recycled kraft paper with vegetable or soy printing inks was chosen. In this way, the design is maximally simplified. Instead of being placed in a box, the products are wrapped in a simple but elegant paper sleeve. To keep the products together, cotton or hemp rope would be used. The advantage of this solution is the small mass of the packaging, which contributes to reducing the amount of fuel used during product distribution and reducing pollution. An additional advantage is that all material is easily recycled or composted.

3. Reusable canvas bag or box made of pressed fibres

The next conceptual solution would use organic cotton, jute or biodegradable bamboo fibres to make a packaging product. The design would be made in the form of a pouch, which can have compartments to keep the bottles in place. An additional advantage of this approach is the reuse of the packaging product after its useful life as a packaging product. Namely, after the products are consumed, the bag can be used to store or transport other items. Brand logo and product information can be printed with natural dyes on the fabric.

4. A minimalist box with an open window made of vegetable cellulose

The last idea is to create a packaging product from recycled cardboard with a window made of biodegradable cellulose film (instead of plastic film). Elegant and natural packaging that allows customers to see the product without opening the packaging. However, when separating waste, consumers should separate two types of material. The packaging product would have a cardboard folding system and would be closed without the use of glue. There is a real possibility that most consumers still do not have the habit of separating individual parts of waste into separate containers but instead throw them into the waste container from which the majority of the used product is made. It is possible to add perforations to make it easier for consumers to dispose of the packaging in compost or recycling, which makes the product a little more expensive and more complicated to make.

Of the four approaches mentioned, it was decided to develop conceptual solutions for approach one. The second approach was rejected because of the packaging's reasonable ability to keep all the products together. The third approach was rejected because it seemed insufficiently innovative, while the fourth approach was rejected because it used more materials, which is a negative fact when making sustainable packaging,

3. DESIGN OF CONCEPTUAL SOLUTIONS

The first conceptual solution was made of cardboard with holders to keep the products inside the package safe (Figure 2). However, in the first version of the conceptual solution, a relatively large amount of cardboard is used because of the dividers that keep the bottles of cosmetic products separate and safe. The improvements brought by this solution concerning the original design of the packaging product are related to the use of sustainable material, a material that has a smaller carbon footprint, in this packaging product there will be no damage to the product. It is important to emphasize that the destroyed product inside the packaging product has the biggest negative contribution to the unsustainability of the design than any other solution. So this solution is a step towards the sustainability of the packaging product.

Figure 2: Sketch of the first conceptual solution

The first conceptual solution satisfied only some premises of sustainable design. Although the packaging is made of one sustainable material, it has too many parts. A large number of parts affects the increase in material consumption, which is closely related to fuel consumption during transportation and the release of harmful gases. On the other hand, it contributes to the increase in the complexity of product production, which is usually related to an increase in energy consumption in the production process. For the aforementioned reasons, a second conceptual solution was developed.

When developing the second sustainable conceptual solution, the idea was to make the box from a single sheet of cardboard. The box was designed without the need for glueing in order to reduce the use of materials, i.e. adhesives. In this way, in addition to saving materials and energy in the production of adhesives, a higher quality raw material is obtained after the recycling process because the paper pulp will not contain sticky particles (Figure 3).

Methods were considered that would contribute to secure fastening without additional inserts, within the design of a packaging product made of a single piece of cardboard:

- Lateral bent holders (from the same cardboard)

Vertical slots are cut out of the cardboard next to each bottle. These parts are bent inward and create elastic clamps that press the bottle from the side. In this way, the bottles are fixed and cannot slide left and right.

- Narrowed bottle openings

The bottle openings can be slightly narrower than the widest part of the bottle so that the bottle is slightly “inserted” into the opening and cannot be easily moved.

Figure 3: Sketch of the second conceptual solution

Some further modifications were made to simplify the design, which was the idea at the beginning of the conceptual design process, to reduce material consumption and make it easier to manufacture. New ideas were also considered regarding the secure holding of the bottles in the packaging. These considerations still included the requirement that the packaging be made of a single piece of cardboard. The optimization of the conceptual design followed the following guidelines:

- Removal of redundant flaps

  Instead of complex internal holders, only side flaps that fold inwards and hold the bottles on the sides can be used. These flaps can be simple rectangular flaps instead of complex shapes.

- Using perforated cutouts instead of multiple layers

  Instead of adding additional layers of cardboard, the bottle openings can have elastic "wings" that fold inward when the bottle is inserted, providing enough friction to keep the bottles stable. This means that additional top and bottom flaps do not need to be constructed, saving material.

- Using a simple sheet of cardboard with minimal folds

  The design can be a simple rectangular sheet with cutouts, folded once and sealed at the sides. This means that the box uses only one line of glue or can even be foldable without glue.

- Using friction and tension instead of additional supports

  If the bottle openings are slightly narrower, the bottles will "fall" into the intended cutouts themselves and will not move. This eliminates the need for additional internal support.

This new approach significantly reduces the amount of material, simplifies production and remains environmentally sustainable (Figure 4).

Figure 4: Sketch of the final conceptual solution

4. DISCUSSION

Advantages of the design of the final version of the conceptual solution:

- Less material consumption – no additional internal inserts, everything is cut from one piece.
- Simpler production – less bending, fewer cuts, easier assembly.
- Environmental sustainability – made from a single piece of recycled cardboard, it is easy to separate and recycle.
- Safety of the bottles - the cutouts are precisely shaped so that the bottles do not fall out or slide inside the packaging.

The stages of making the finished product have been elaborated to avoid possible problems. The process of making the finished product is divided into 3 stages as follows:

- Processes of making the packaging product on paper before assembly

  Three cutouts for bottles are cut on the sheet. Around each cutout, there are small perforations that allow the inner "wings" to fold. At the edges of the arch, there are side pages that will be folded later.
- Placement of bottles in packaging

  When the bottle is inserted into the cutout, the cardboard "wings" automatically fold inward, encompassing the bottle and securing it in place. This prevents bottles from sliding or falling out of the packaging, even if the box is tipped over.
- Folding the box

  The sides fold upwards to form a solid structure. The lid can be closed without the need for additional glue.

This research shows how the packaging designer plays a key role in the production of cardboard packaging, as his choices directly affect the sustainability of the product throughout its entire life cycle – from production to recycling. The designer determines the type and amount of cardboard needed for the packaging, which affects the consumption of raw materials. Choosing recycled cardboard and certified materials (e.g. FSC) significantly reduces the environmental footprint, and good construction can reduce excess material without compromising the strength of the packaging. Packaging design must be adapted to the machines in the production process to reduce waste and energy costs. Compact and foldable shapes reduce volume during transport, which reduces emissions of pollutants that contribute to L.A.-type smog. Adhesive-free closures (such as insertion and folding instead of glueing) also have positive environmental impacts, making it easier to manufacture and disassemble packaging after use. Well-designed packaging ensures product stability and protection, reducing the amount of damaged goods and waste. Furthermore, the design

must enable easy separation of materials (e.g. without unnecessary plastic inserts or multi-layer composites that make recycling difficult). When developing conceptual solutions, the designer should minimize the use of colours and laminations to contribute to an easier recycling process, better process efficiency and higher quality raw materials.

5. CONCLUSION

A packaging designer is not just the creator of the box's appearance – he makes key decisions that affect the ecological footprint of the product throughout its entire life cycle. Smart design means less waste, less resource consumption and greater sustainability, which is crucial in the packaging industry today. Cardboard packaging design should not be a static process, but a constant iteration and improvement to achieve the optimal balance between functionality, environmental sustainability and cost-effectiveness. Accepting the first solution without further refinement can result in excessive material consumption, difficult recycling or unnecessary complications in production and transport.
Through continuous design optimization, it is possible to achieve better material utilization, reduce the need for additional components such as glue and plastic, and ensure easier degradability and recycling of packaging. Adhesive-free design, with smart folding and closing systems, reduces the ecological footprint because it facilitates material separation and reuse in recycling processes.
A properly designed cardboard box should be functional, ensuring product protection with minimal resource consumption. Each improved version of the design should further reduce material waste, improve production economics, and extend the packaging life cycle following the principles of the circular economy.

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REVIEW PAPER

ENHANCING TEXT LEGIBILITY IN AUGMENTED REALITY: CHALLENGES AND DESIGN RECOMMENDATIONS

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ABSTRACT

Text legibility has been an important topic in printed, digital, and augmented reality (AR) environments. It refers to the reader's ability to successfully recognize individual letters, words, and whole text. Text legibility in AR involves several challenges that need to be addressed, such as text color and contrast with respect to the background, background complexity, depth perception, and hardware limitations. The aim of this paper is to summarize the key findings on text legibility for AR, where text is one of the important digital elements added to the real-world environment. Therefore, we conduct a review study on text legibility in AR. We note that most authors use Optical See-Through Head-Mounted Displays (OST HMDs) and investigate 2D text in a 3D environment. We focus on the most important parameters of text legibility in AR that are related to text presentation: font type, text style, color and contrast, background influence, and perception of depth. Among these parameters, the background influence and color and contrast have been studied most extensively, as they pose the greatest challenges to text legibility in AR. Studies repeatedly point to issues such as contrast problems in OST HMDs and text illegibility in the presence of complex backgrounds. Also, 3D text is not commonly researched. Based on these findings, we propose design recommendations for the studied parameters that should be followed by AR applications' developers.

Keywords: Augmented reality (AR), text legibility, 2D text, 3D text.

1. INTRODUCTION

The basic function of a written text is to transmit information, which can only be achieved if the letters are sufficiently legible. Legibility refers to the reader's ability to recognize individual letters and the word that certain letters compose. This ability depends on various factors such as the shape of the letters, size, spacing between the word letters, line spacing, contrast, and environment lighting.

With the development of technology, reading has spread from printed media to digital screens. Early CRT screens showed problems with sharpness and blurring of text due to low resolution. More modern LCD screens have improved these aspects, but research has shown that other factors, such as font size, spacing, and contrast, still have a significant impact on legibility. The advent of augmented reality (AR) in the early 2000s marked the beginning of a new type of technology, with its advantages and disadvantages. Augmented reality combines real and virtual worlds by adding digital elements such as image, audio, video, and touch to a real-world environment in real-time. Unlike virtual reality (VR), which completely immerses the user in the virtual world, AR complements reality without completely replacing it [1]. AR mainly uses head-mounted displays (HMDs) (such as smart glasses), but also smartphones and tablets to display information that integrates with the user's environment. The main challenge in an AR environment is to ensure text legibility despite changing conditions such as environment lighting, complex backgrounds, and the distance of the user.

According to [2], research by Park et al. (2008) and Kim et al. (2015) showed that legibility

on smartphones does not differ significantly between serif and sans serif fonts. However, font size and contrast with the background play an important role. Gabbard et al. (2007) [3] investigated the effects of 2D text color, style, and contrast in external conditions, while Vairinhos et al. (2016) [4] examined the estimation of 2D and 3D text distance in a 3D environment. Palm (2018) [5] focused on the design of 3D text in AR, in terms of font type and depth. As AR becomes more prevalent in various fields such as industry, education, medicine, and entertainment [6], [7], research on text legibility and its accompanying concept of readability (ease and pleasantness of reading) is becoming more common. However, not all legibility parameters have been sufficiently researched, nor have consistent recommendations for the design of AR applications been established.

In this paper, a literature review on the topic of text legibility in AR is presented. Due to the limited number of pages, the scope of this paper includes a focus only on the most basic parameters of legibility. The search for related work was done in Google Scholar, using keywords: "augmented reality", "text legibility in AR", "text readability in AR", "3D text in AR", "text legibility on screens", "3D text legibility on screens". Unlike some other review papers in this field, such as Cauz et al. (2024) [8] and Erickson et al. (2020) [9], we focus on two important aspects of the considered studies: design recommendations for the 5 most basic parameters of text legibility, and challenges for future research.

In Section 2, an overview of the conclusions reached by related studies on the 5 most basic parameters of text legibility: font type, text display style, text color and contrast, impact of background, and impact of text perception and distance, is presented. In Section 3, we first discuss the challenges for future research and then provide recommendations for text legibility design. Chapter 4 concludes the work.

2. REVIEW OF THE LITERATURE ON LEGIBILITY IN AUGMENTED REALITY

Optical See-Through Head-Mounted Display (OST HMD) is a type of augmented reality (AR) device that allows users to see the real world through one or two transparent lenses, while digital content (text, labels, holograms) is projected onto the surface of the lens. This mode of display allows the simultaneous integration of digital elements with the environment that the person perceives. However, OST HMD systems often suffer from contrast problems, as virtual content may be less visible on bright or complex backgrounds. Also, due to the way human eyes focus on real and virtual content, vergence-accommodation conflict can occur [10], [11], which can make it difficult to read for long periods of time in an AR environment.

A Video See-Through Head-Mounted Display (VST HMD) is a device with cameras that record the real world, then processes the image with software and combines it with digital elements before displaying it on a screen inside the device. This allows for more control over the contrast and visibility of the text, as digital and real content can be better adapted to make them more readable. That said, VST systems often have display lag issues due to the length of time the recording is processed, which can cause discomfort for users when used for long periods of time [12].

In both cases, these are devices that are worn on the head (HMD), while the user's hands are kept free. This makes these devices suitable for work and simultaneous interaction of the user with the environment. They are also most often used in legibility research. Their biggest drawbacks are the technical limitations, which is why HMD devices are not yet ready for widespread use [7].

In addition to being displayed on various HMD devices, AR is also used through the screens of mobile devices, tablets and similar portable devices for various applications [13], [14]. Table 1 compares the two types of HMD systems and on-screen AR.

Table 1: Comparison of HMD systems with mobile devices (screen AR)

Argument	OST HMD	VST HMD	Screen AR
Display mode	Transparent lenses with projected virtual content	The camera captures the world and combines it with virtual content	Digital content is displayed on the screen, regardless of the environment
Contrast and legibility	Low contrast issues (text may become invisible)	Better contrast control, but possible display lag	High legibility as the text is clearly displayed on the screen
Perception focus issues	Possible vergence-accommodation conflicts	Minor problems because the entire view is on the same focal plane	There is no problem because the user only focuses on the screen
Interaction with the real world	High (the user sees the real environment in real time)	Moderate (the camera captures the world, but the processing is slightly slower)	Limited (the user must look through the screen and adjust the position)
Representation in legibility research	The most frequently researched	Less researched	Often used for AR applications, but less researched in the context of AR text legibility

2.1. Review of research on font type

Font selection has historically been one of the first parameters to be taken into account when researching text legibility. The legibility of serif and sans-serif fonts was primarily investigated. Serif letters have small lines (serifs) at the ends of the letters, while sans-serif letters do not have serifs and appear simpler. For a long time, it was thought that serif letters were more suitable for printed materials, and sans serif for screens. However, studies have shown that legibility is primarily related to the quality of both the print and the screen, rather than the type of font [2]. This has been confirmed by research on font types in AR, although, based on the results of research on printed materials and screen displays, the number of studies related to the type of font in AR is relatively small. Palm (2018) [5] used 3D serif and sans serif fonts in her research and did not find a statistically significant difference between them, but users subjectively preferred sans-serif fonts in the AR environment. In a review paper, Cauz et al. (2024) [8] pointed out that fonts with too much detail should be avoided, while there is no clear consensus on the superiority of serif or sans-serif letters. However, their research also covered legibility in VR, not just augmented reality. It was generally established that Arial (sans-serif) is often used as a standard. Arefin et al. (2024) [15] developed the specialized AR font SharpView, which significantly improved the sharpness of out-of-focus text compared to Arial, with a 24–44% increase in legibility. Their results suggest the need for specially designed fonts for AR systems that have yet to be evaluated on real users.

2.2. Review of research on text display style

Different styles of text presentation can significantly affect legibility in AR and are a frequent subject of research. Research is mainly carried out on the comparison of plain text, billboard style, outline and drop shadow. The style will include both 2D and 3D representations of letters. Gabbard et al. (2007) [3] analyzed four 2D text display styles (plain, bill-

board, outline, and drop shadow) and concluded that the drop shadow and outline styles improved legibility, while the billboard style did not lead to good result. However, the biggest reason for this was that they did not take into account the relationship between the color of the text and the color of the billboard. Fiorentino et al. (2013) [16] tested different 2D text styles (plain, billboard, outline, and a combination of billboard and outline) and found that billboard improved legibility compared to the other representations, whereas its biggest problem is that it can obscure the background. Debernardis et al. (2014) [10] tested 2D plain text and billboarded text. The results showed that the billboard style significantly improves legibility, especially for complex backgrounds and VST HMD devices. Vairinhos et al. (2016) [4] used the Arial font in three styles (2D plain text, 3D embossed, 3D wireframe) and tested how different styles affect distance estimation. In addition to having the best distance estimated for the 2D style, the respondents also subjectively rated this style as the most readable. It is important to emphasize that the study was not focused on comparing the legibility of 2D and 3D text, but on the estimation of distance in relation to a reference point. Palm (2018) [5] tested 3D text in an indoor environment. Bold 3D text stands out better, and greater text depth improves visibility, but can make it difficult to read from certain viewing angles. A review by Erickson et al. (2020) [9] confirmed that the billboard text style improves legibility but can reduce user performance when combined with dynamic billboard color changes that align with real-world colors. Falk et al. (2021) [17] tested a solid and a transparent billboard (50% transparency) and concluded that the solid (opaque) billboard significantly improves legibility. Wysopal et al. (2023) [18] conducted a study using a Level-of-Detail AR system that dynamically adjusts the display of text depending on the distance, which improves legibility, with the billboard style predominantly used. A review by Cauz et al. (2024) [8] confirmed that the billboard style and the outline style generally increase the legibility of text. It was emphasized that there is no need to use both styles of text display together, but individually.

2.3. Review of research on text color and contrast

The color of the text and the contrast between the text and the background play an important role in the legibility of text in AR, especially on different types of devices such as OST HMD and VST HMD systems. In terms of color, Gabbard et al. (2007) [3] pointed out that white, cyan, and green were the most effective colors for legibility, while red was the least effective, possible due to the limitations of the tested OST HMD device, while again Gabbard et al. (2019) [11] investigated the legibility of red text displayed on a dark background in a dimly lit room. To ensure consistency in perception, the text color was matched between the screen and the AR display. However, the use of a laser-based AR display (Microvision Nomad) may have led to a speckle effect, a phenomenon where spot-to-spot intensity variations occur, potentially degrading text clarity. This effect became particularly problematic at greater viewing distances, further reducing legibility and making it harder for users to read the text accurately. Fiorentino et al. (2013) [16] analyzed four text colors: black, white, red, and green, with red proving to be inferior to others. Debernardis et al. (2014) [10] tested text colors on OST and VST HMD devices. On OST devices, dark colors become transparent, while light colors remain visible. With VST devices, having a high contrast is key. The most legible combination in most situations turned out to be white text on a blue, solid billboard background. Palm (2018) [5] concluded that color in itself is not decisive, but rather the contrast between the text and the background. Erickson et al. (2020) [9] concluded that red color most often results in poorer legibility, while blue, green, and white provide better results, depending on the context. Falk et al. (2021) [17] tested text polarity and found that negative polarity (light text on a dark background) improves legibility in AR environments. Arefin et al. (2024) [15] introduced the SharpView font, which uses contrast adjustment and precise edge processing to improve legibility in dynamic AR

environments. Cauz et al. (2024) [8] found that on OST HMD devices, light colors such as white, cyan, and green are more visible, while dark colors, such as black, become transparent. They also stated that with VST devices, high contrast improves legibility, but too strong contrast can cause discomfort when reading.

2.4. Review of research on the impact of background

The background of text in AR is constantly changing and poses a great challenge for legibility. Gabbard et al. (2007) [3] investigated four types of background: brick, building, sidewalk, and sky. A text on the brick background led to the most reading errors, while the building background gave the best results due to its consistent lighting. Fiorentino et al. (2013) [16] found that background had a significant impact on reading speed – a neutral background (e.g., motor block) allowed for the fastest processing of information compared to darker or lighter backgrounds. Debernardis et al. (2014) [10] stated that, in VST HMD devices, the background has a significant impact on the legibility of text without billboards, while a dark background improves legibility on OST HMD devices. With VST HMD devices, legibility depends on the contrast and exposure settings of the camera. Palm (2018) [5] emphasized that the weight and depth of the 3D letters combined with the size helped create a good contrast between the text and the background according to expert users. Gabbard et al. (2019) [11] displayed text on a dark background to avoid contrast issues. However, the AR text at a distance of 6 meters became blurry. That may be due to a combination of distance adjustment, lighting, and eye fatigue of the user during the experiment. Falk et al. (2021) [17] tested three types of background: white, black, and complex (abstract colorful). The results showed that complex backgrounds reduced legibility, while monochrome backgrounds were more effective. Cauz et al. (2024) [8] pointed out that background texture negatively affects legibility when contrast is low or when texture is complex.

2.5. Review of research on the impact of text perception and distance

Debernardis et al. (2014) [10] confirmed that the vergence-accommodation conflict remains one of the most significant challenges in AR related to text display. The recommended text distance depends on the specific usage scenario but is most commonly used in the range from 1 m to 10 m. Vairinhos et al. (2016) [4] tested 2D and 3D text and found that 2D text had the fewest errors when estimating the distance from a reference point, while 3D embossed text had the worst results. Contrary to their initial hypotheses, the 3D wireframe text was somewhat better than the embossed version, but still worse than the 2D representation. Users subjectively rated the 2D text as more legible, suggesting a possible correlation between legibility and distance estimation capabilities. Palm (2018) [5] found that greater depth of 3D text can improve legibility under certain conditions. Gabbard et al. (2019) [11] investigated the direct effects of vergence-accommodation conflict, where participants had to constantly adjust their focus between real and AR-added text. This process led to faster eye fatigue and reduced performance for more distant text. According to Cauz et al. (2024) [8], the vergence-accommodation conflict is a key problem when reading text in an AR environment. The recommended text distances vary between 1 m and 10 m, and the optimal distance depends on the text size and usage scenario.

3. CHALLENGES, DESIGN RECOMMENDATIONS AND DISCUSSION

3.1. Challenges for future research

After considering related work for inclusion in this review, significant studies (original

research and review papers) published in the last 10 years were included, with a few exceptions of relevant studies from earlier. The studies considered have shown that most research in this area is conducted with HMDs and 2D text, as shown in Table 2, while only a few studies are related to 3D text and mobile screens.

Table 2: Overview of the use of display and text types

HMD	Screen	2D text	3D text	Literature
x		x		Cauz et al. (2024) [8]
x		x		Arefin et al. (2024) [15]
x		x		Wysopal et al. (2023) [18]
x		x		Falk et al. (2021) [16]
x		x		Erickson et al. (2020) [9]
x		x		Gabbard et al. (2019) [11]
	x		x	Palm (2018) [5]
x		x	x	Vairinhos et al. (2016) [4]
x		x		Debernardis et al. (2014) [10]
x		x		Fiorentino et al. (2013) [16]
x		x		Gabbard et al. (2007) [3]

The analysis of text legibility parameters in augmented reality (AR) pointed to a number of technical and perceptual challenges that are primarily related to the use of HMD devices. Mekni and Lemieux [7] pointed out the problem of technical performance of HMD devices that have yet to be developed to the level of usability in everyday life. Although HMD devices enable deep immersion and hands-free interaction, their technical limitations significantly affect the quality of text display and its legibility. Among the limitations of HMDs, the limited resolution of the screen stands out, which reduces the clarity of smaller typographic elements, especially when displaying serif or decorative fonts [12]. Furthermore, the limited FOV (Field of View) and variable focal length make it difficult to achieve a consistent focus on the text, especially when the text is set in the depth of the scene or in dynamic contexts (e.g., when the text is moving with the user's gaze) [19]. There is also the problem of limited brightness and contrast in transparent displays (e.g., HoloLens), which further reduce legibility in conditions of strong environmental lighting [20]. The vergence-accommodation conflict stands out, where participants have to constantly adjust the focus between the real world and AR text, which leads to faster eye fatigue and degradation of performance for more distant text [11].

Unlike HMDs, devices with a screen (smartphones, tablets) offer a higher screen resolution, better controlled contrast and sharpness of the display, and a consistent focal plane because users focus on the flat surface of the screen. This greatly reduces the problem of depth perception in an AR environment because the text remains in the same plane of focus without the need for constant eye re-focusing. Although this way of displaying is less immersive, the advantage could be simpler standardization of the legibility of the text. However, despite the technical advantages, research on legibility in the AR context on screen devices is relatively rare. The focus of academic and industry research is primarily on HMD devices, probably because the user has free hands, which is especially useful in industry, medicine and entertainment [7]. We believe that expanding research into screen-based AR could provide a useful and practical contribution to optimizing typographic solutions and increasing the overall availability of AR content to a wider audience. This direction of research is supported by the study of Bang and Woo (2023) [21], which explores how the combination of a smartphone and AR glasses can improve the reading

experience in augmented reality. AR HMDs are characterized by the problems of low resolution and limited FOV, which makes it difficult to read long texts. The authors tested a concept in which a smartphone is used as an additional screen in addition to AR glasses for reading text. They examined how this hybrid combination affects user performance, mental effort, visual fatigue and readability. Although the hybrid system did not improve the speed or accuracy of completing tasks, users reported less mental and physical effort, visual fatigue was lower, and subjective readability was higher when using a smartphone, especially with longer texts.

3.2. Recommendations for optimizing the legibility of text in AR

Based on the related work and the challenges observed, we recommend the following guidelines for the design of text elements in an AR environment:

1. Font selection: It is advisable to use sans-serif fonts and avoid complex and ornate fonts.
2. Display style: It is recommended to use a billboard style of text display, with solid (opaque) backgrounds. If a slight background occlusion is required, an outline or shadow of plain text can be used. Using plain text alone in most cases does not give good legibility.
3. Contrast: Good contrast between the text and the background is more important than the text color itself, with light text on a dark background giving better results and reducing visual fatigue.
4. Impact of background: It is recommended to use simple, monochrome backgrounds with high contrast to text, with blue and neutral colors showing the best results. Complex and textured backgrounds should be avoided because they reduce the speed and accuracy of reading, especially at longer distances and with dynamic changes in the environment.
5. Adaptive design: Dynamically adjusting text size, color, and style in relation to detected environmental conditions can further improve real-time legibility. It is recommended to use the Level of Detail approach, where only basic information is displayed at longer distances, and more extensive information at shorter distances.

The ideal text for AR would be a simple sans-serif font, such as Arial or Verdana, with a bold style for added prominence. It should be displayed in an opaque billboard style or possibly plain text with an outline. The recommended color combination is white text on a dark, monochrome background, with automatic adjustment of the contrast to the ambient light.

4. CONCLUSION

In this paper, we have provided an overview of the most basic parameters that affect the legibility of text in augmented reality (AR), with special emphasis on the differences between the display on HMD devices and the screen of mobile devices. The parameters of font type, text display style, text color and contrast, impact of background, and impact of text perception and distance were analyzed. Most of the research has focused on HMD devices, which, while providing immersive experience, suffer from technical limitations. On the other hand, screen-based AR on mobile devices has been less researched in scientific literature. Also, the focus of the research is on 2D text, while the legibility of 3D text was investigated less well. The design recommendations highlight the need for adaptive text that adapts to environmental conditions and device type. Future research should cover a wider range of contextual factors, including lighting, anchoring, segmentation, environmental dynamics, and the impact of long-term use on user visual fatigue [8], [19], [22].
In our future work, we will focus on 3D text and the parameters and conditions that can lead to high quality of 3D text legibility. Given the technical limitations of HMD devices, they are not expected to be widely used anytime soon. At the same time, the vergence-ac-

comodation effect in HMD devices remains an intractable problem for the time being, which is why it is necessary to conduct more detailed research into the text that is projected in AR with the help of mobile and similar screen-based devices.

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BLAŽ BAROMIĆ
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PROFESSIONAL PAPER

APPLICATION OF LEAN METHODOLOGY IN 3D MODELING AND ANIMATION PROCESSES

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ABSTRACT

This paper analyses the application of the lean methodology in the creation of a 3D character sculpture intended for use in advertising or promotional video materials. The final output presents the sculpted model, its components, and assembly methods through animation and accompanying visual information, prepared for 3D printing or other virtual applications. The study evaluates the advantages, limitations, and potential applications of integrating a lean approach into the 3D modelling workflow. It provides a detailed overview of various 3D modelling techniques, primarily utilizing Blender, and explores the development of complementary static and animated 2D graphics in Adobe Illustrator and Adobe After Effects. Additionally, the paper offers theoretical explanations of key concepts related to 3D technology and computer graphics, alongside a practical analysis of shaping individual sculpture segments. It addresses animation and texturing processes using various 3D modelling methods, incorporating lean principles to optimize the workflow according to the specific modelling approach and the requirements for achieving the desired form. Finally, the paper compares the conventional and lean approaches to 3D modelling, analysing their respective advantages and disadvantages in terms of time efficiency, complexity of creation, and the overall quality of the 3D model within optimal constraints.

Keywords: 3D modelling, lean methodology, polygons, resolution, animation

1. INTRODUCTION

Along with the popularization of various 3D visualizations in modern media, 3D modelling is becoming an increasingly relevant branch of the graphics industry. As a result, it plays an important role in production, requiring more time, cognitive effort, and financial resources [1].

3D modelling encompasses a wide range of methods for creating three-dimensional objects in a virtual environment. It relies on various computer tools to manipulate different types of computer graphics. This technique is used for prototyping products and producing diverse promotional materials, including 3D prints, animations, sculptures, and figures. Additionally, it is essential for designing characters in video games and movies, as well as for architectural visualizations. Its versatility allows for detailed, adaptable, and thorough creation of a subject from any perspective, effectively simulating the desired characteristics of the product [1-3].

Significant benefits can be achieved by applying efficient production principles to the complex and resource-intensive processes involved in 3D modelling. Lean, a management approach focused on maximising customer value while minimising waste, provides strategies for improving workflow, reducing non-value-adding activities, and enhancing overall efficiency. Methods such as One-Piece Flow, where items are processed one at a time, and Poka-Yoke, an error-proofing technique that prevents or detects mistakes early, can help streamline digital production and ensure consistent quality in 3D modelling projects [4].

This paper explores the design, modelling, and animation of a 3D sculpture in the form of video content. Additionally, it analyses the potential implementation of the lean philoso-

phy and methodology in 3D modelling processes using Blender. Furthermore, it examines the practical application of these approaches to compare different 3D design methods and their effectiveness in creating various levels of complexity in the sculpture's form.
The lean approach to 3D modelling focuses on simplifying processes by eliminating unnecessary actions that do not add value to the workflow. It utilizes advanced modelling methods while considering the requirements needed to achieve the desired characteristics of an object [5-8].
The paper will determine which approach to 3D modelling is more efficient in terms of time investment, cognitive effort, and final quality. It will evaluate various tools and software solutions that enhance efficiency by accelerating workflows, eliminating unnecessary operations, and simplifying the design process. These findings will be compared to more intuitive and beginner-friendly approaches within the same methodology.

2. METHODS AND MATERIALS

The practical part of this study was based on the development of a 3D character sculpture using Blender as the main modelling tool, supported by Adobe Illustrator and After Effects for accompanying graphics and animation. The workflow was divided into several stages: concept sketching, digital sculpting, polygonal modelling, texturing, rigging, and animation.
The modelling process began with sketches and vector illustrations designed in Adobe Illustrator. These graphics were layered and prepared for animation by isolating each element into separate layers. This structure facilitated import into After Effects, where dynamic motion graphics were created as an introduction to the animated presentation.
In Blender, a base human model was sculpted using digital sculpting tools. Additional elements—such as armour, clothing, and accessories—were modelled using box modelling and subdivision surface techniques, depending on the desired level of detail [9]. Various modelling techniques, including procedural modelling and NURBS modelling, were tested but primarily excluded due to complexity or inefficiency in this specific project context.
Texturing was performed using shader nodes in Blender, with real-time previews provided by the Eevee render engine [10]. The entire animation was rendered in Full HD (1920×1080) at 30 frames per second. More than 6,000 frames were exported in PNG format and compiled into a 4-minute animation, using frame-by-frame rendering to allow easier error correction.
Post-production was completed in Adobe After Effects and Filmora Wondershare, where sound effects, background music, and final colour grading were applied [11]. This multilayered production allowed precise control over visual and auditory components, increasing the overall clarity and impact of the presentation.

3. RESULTS

The creation of the 3D sculpture based on the fictional character Red Hood included several structured modelling phases, each optimized using lean-inspired principles to ensure efficiency and technical clarity.

3.1. Sketching and Concept Design

The project began with pencil and marker sketches that defined the character's costume and posture (Figure 1). These drawings guided all later modelling steps and reflected the character's agility and strength through a combination of flexible and armoured costume parts.

Figure 1: Sketches and character design illustration

3.2. Modelling the Human Body Base

A rough human base was sculpted using primitive shapes (cubes, spheres) placed over anatomical references in orthographic view. Subdivision Surface modifiers were applied to improve polygon flow before merging elements via Remesh (Figure 2).

Figure 2: Human body base modelling workflow

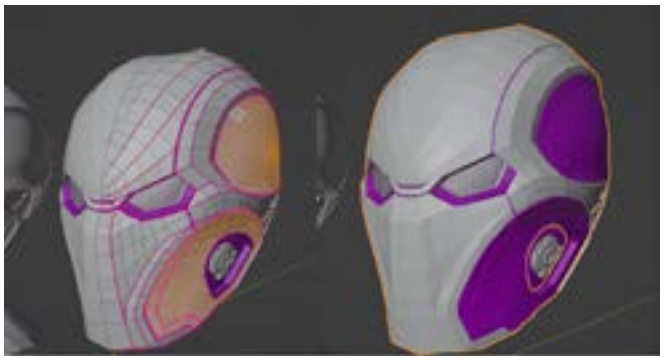
3.3. Armor and Costume Elements

Detailed modelling included chest armour (Figure 3), edge details, gloves, and boots. Hard-surface modelling techniques were used, along with retopology to reduce complexity without sacrificing detail.

Figure 3: Final shape of the secondary part of the suit

3.4. Helmet and Accessories

The red helmet was sculpted separately, ensuring symmetry and a smooth reflective surface (Figure 4). Additional elements like a stylized pistol and motorcycle were modelled using NURBS and polygonal tools.



.Figure 4: Material allocation and final helmet model

3.5. Texturing and Materials

Procedural texturing simulated fabric and metal materials, while material slots enabled separation of elements (Figure 5). Lean principles encouraged reuse and non-destructive workflows, reducing rework.

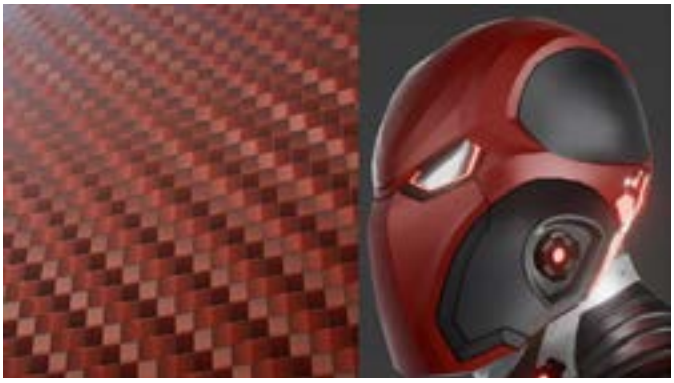


Figure 5: Carbon procedural material

3.6. Rigging and Animation

A skeleton rig was added for pose adjustments (Figure 6). The final character was animated to rotate and interact with lighting in a rendered scene, showcasing textures and detailing (Figure 7).

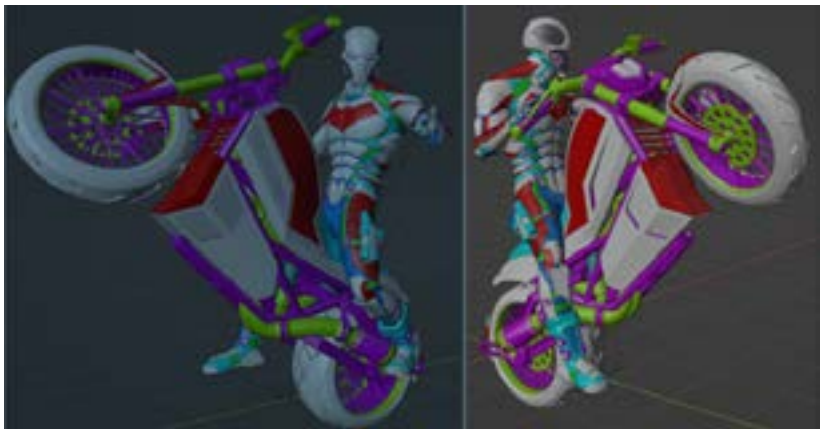


Figure 6: Sculpture's final pose

Figure 7: Render view of final sculpture, 4k, Cycles

4. DISCUSSION

The practical implementation of lean methodology in the 3D modelling and animation process yielded several measurable outcomes:
Time Reduction: The total time required to complete the 3D character model and accompanying animation was reduced by approximately 25% compared to a non-lean, exploratory approach used in a prior reference project of similar complexity.
Lower Error Rate: Early identification and prevention of common modelling and rigging errors significantly decreased the number of corrections needed during the rendering and post-production phases. Fewer than 5% of exported animation frames required re-rendering.
Output Quality: The final animated video was rendered in Full HD (1920×1080), consisting of over 6,000 frames. The visual consistency of both static and moving elements met quality expectations for promotional content and 3D printing preparation.
Modular Workflow: Tasks were segmented into clear units (e.g., base sculpt, armour, rigging, textures), allowing for parallel or iterative development, testing, and revisions. This structure also supported faster feedback cycles and version control.
The results indicate that integrating lean principles into the 3D modelling workflow can significantly enhance efficiency without compromising output quality. The use of lean techniques such as One-Piece Flow and Poka-Yoke helped streamline the process and

avoid unnecessary rework. Additionally, modular design and visual management practices made it easier to maintain consistency and reduce cognitive load throughout the project.
However, the lean approach also introduced certain limitations. Its structured nature reduced flexibility during the exploration or creative phases, where frequent iterations or spontaneous changes are typical. Moreover, initial planning stages required more time and precision, which may not be ideal for projects driven primarily by experimentation.
Nevertheless, for production-oriented 3D modelling—especially when the end use involves repeatability, quality assurance, or physical prototyping—lean methodology proved to be a valuable framework. It supported a balance between structured execution and creative flexibility, contributing to a professional and technically reliable outcome delivered within reasonable time and resource limits.

5. CONCLUSION

The integration of lean methodology into 3D modelling processes, particularly within the scope of animation and promotional content creation, provides notable benefits in optimizing workflow, ensuring quality, and maximizing resource efficiency. This approach reduces unnecessary steps and promotes ongoing improvement, resulting in consistent quality output and significant time savings.
While the lean methodology may not offer the same advantages in every modelling scenario—especially those requiring substantial artistic improvisation—it has proven highly effective in project-driven work focused on repeatability, collaboration, and the final product's readiness for digital distribution or 3D printing.
The comparison between lean and conventional workflows demonstrated that lean modelling enhances performance by simplifying tasks, increasing focus on value-added activities, and facilitating technical execution, particularly in the case of medium- to high-complexity 3D models.

6. SUPPLEMENT MATERIAL

The final animation is available at the link: https://youtu.be/u3OfCcvICuQ

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ORIGINAL SCIENTIFIC PAPER

ASSESSING THE COST-EFFECTIVENESS OF PREDICTIVE MAINTENANCE FOR GRAPHIC MACHINERY

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ABSTRACT

In today's rapidly evolving industrial environment, the demand for efficient plant maintenance is increasing. Traditional maintenance methods often lead to unexpected breakdowns, production downtime, and unnecessary repair costs. Given the complexity of graphic machinery, selecting an appropriate maintenance model is crucial for ensuring machine reliability and maintaining satisfactory product quality. Predictive maintenance utilizes data analysis and machine learning algorithms to anticipate failures before they occur. This paper explores its implementation alongside maintenance process reengineering in the graphic machinery industry, with the goal of improving reliability, reducing costs, and enhancing availability. The study highlights the importance of innovative maintenance strategies in ensuring competitiveness, sustainability, and production efficiency. Predictive maintenance-based reengineering can serve as a foundation for further research and applications across similar industrial sectors.

Keywords: maintenance, predictive maintenance, data analysis, graphic machinery

1. INTRODUCTION

In the printing industry, the availability and efficiency of machinery directly affect production performance, cost management, and delivery schedules. As printing technologies evolve, so do the complexities of machinery systems, which require advanced and more proactive approaches to maintenance. Traditional maintenance strategies, such as corrective and preventive maintenance, are often reactive and result in unplanned downtime, higher maintenance costs, and reduced machine reliability. Predictive maintenance (PdM) emerges as a data-driven approach that allows failures to be anticipated and prevented before they occur, thus improving overall equipment effectiveness (OEE) and reducing operational costs (Figure 1).

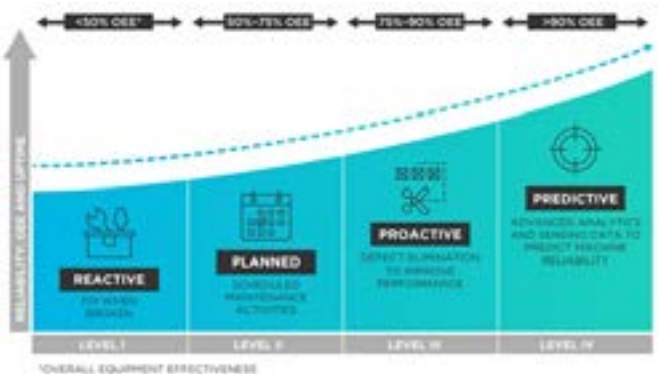

Figure 1: Maintenance Strategies and OEE Performance [4]

The importance of machinery maintenance in the graphic industry has been growing in parallel with the adoption of digital printing technologies, which demand greater pre-

cision, consistency, and uptime [5]. Unlike conventional offset systems, digital printing equipment integrates electronic, mechanical, and software-based components that must function in harmony [6]. A single unexpected failure—such as a clogged printhead or malfunctioning encoder—can halt production and cause significant delays or material waste. This environment necessitates a shift from reactive to predictive and intelligent maintenance systems.

Predictive maintenance relies on continuous condition monitoring, sensor integration, and advanced data analytics, including the application of machine learning algorithms to identify potential faults. It not only enhances machine reliability but also optimizes maintenance scheduling, reduces spare parts inventory, and improves the overall planning of production processes. Moreover, as sustainability becomes a strategic goal in the graphic industry, predictive maintenance contributes by minimizing waste, extending equipment lifespan, and improving energy efficiency [7-9].

This paper explores the potential of predictive maintenance as part of a reengineered maintenance process specifically applied to graphic machinery. Emphasis is placed on digital printing machines, where precise performance and minimal downtime are critical. The study combines theoretical insights and practical implementation by analyzing failure data from three different Roland printing systems and introducing a structured PdM approach based on data analytics and sensor technologies.

2. METHODS AND MATERIALS

The research was conducted using data collected from 100 service reports associated with three digital inkjet printers: Roland BN-20D, Roland LEF2-200, and Roland TrueVIS SG3-540. These printers are widely used in various sectors such as textiles, packaging, and promotional printing. Service records were examined to identify common failures and assess maintenance patterns. Technical specifications of selected digital inkjet printers are shown in Table 1 [10-12].

Table 1: Technical specifications of selected digital inkjet printers

Digital printers	Roland BN-20D	Roland LEF2-200	Roland TrueVIS SG3-540
Printing technology	Piezo inkjet	Piezo inkjet	Piezo inkjet
Print resolution	1440 dpi	1440 dpi	1200 dpi
Type of ink	ECO-SOL MAX	ECO-UV	TR2
Cutter speed	10 mm/s – 150 mm/s	-	10 – 300 mm/s
Print	CMYK + white	CMYK + white + varnish	CMYK
Connection	USB 2.0	Network cable	Network cable
Software	VersaWorks	VersaWorks	VersaWorks
Dimensions	1009x582x293 mm	1202x962x549 mm	2632 x 748 x 1320 mm
Weight	36 kg	110 kg	183 kg

Failure types were categorized into four groups: mechanical, electrical, software-related, and combined failures. The frequency of each failure was statistically analyzed using descriptive methods. The machine with the highest rate of failure, the Roland LEF2-200, was selected for the implementation of the predictive maintenance model.

The PdM approach consisted of the following phases:

Condition Monitoring: Sensors were used to track parameters such as vibration, temper-

ature, and electrical load to detect early signs of malfunction.
Data Collection and Integration: Historical and real-time data were gathered from machine sensors and operator logs.
Data Analysis: Exploratory Data Analysis (EDA) methods, including visualization (box plots, scatter plots) and descriptive statistics, were applied to reveal failure patterns.
Feature Selection: Key variables were selected, such as frequency of ink clogs, filter blockages, temperature fluctuations, and printhead errors.
Model Development: Predictive models were developed using supervised learning algorithms (e.g., decision trees, logistic regression).
Evaluation: Models were evaluated based on accuracy, precision, and recall using a test dataset.
Maintenance Planning: Maintenance actions were scheduled based on predictive indicators, aiming to reduce unscheduled downtimes and optimize resource allocation.

3. RESULTS

Analysis of the service records revealed that the most frequent failures included:
clogged printheads (15%),
clogged filters (12%),
encoder damage (10%),
print misalignment (9%),
air trapped in the ink system (8%).
These failures significantly affected print quality and machine availability.
Among the three machines, the Roland LEF2-200 showed the highest failure rate (38%) (Figure 2). This machine prints directly onto diverse materials using UV ink technology and has a flatbed system. Unique failure patterns were observed due to the reflective nature of certain substrates, which accelerated ink drying and contributed to printhead clogs.

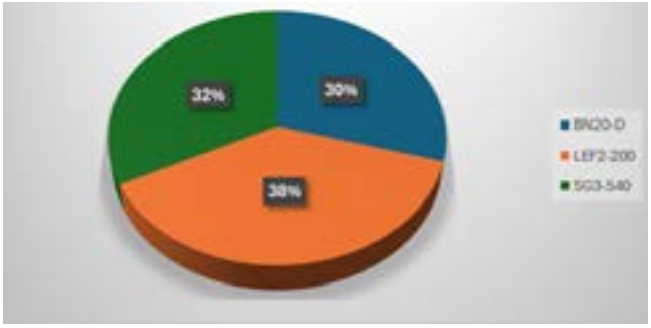

Figure 2: Failure distribution by selected digital inkjet printers (pie chart)

Implementation of the PdM system on the LEF2-200 involved continuous monitoring of ink flow, substrate reflectivity, and ambient temperature. The use of dark printing masks was introduced to reduce UV reflection and prevent ink drying inside the nozzles. Predictive alerts were generated when critical thresholds were approached, prompting preventive cleaning or replacement of components.
A comparison between pre- and post-implementation metrics showed a 35% reduction in unplanned downtime and a 28% reduction in total maintenance costs. The frequency of printhead clogs decreased by 40%, and the machine's availability improved by 12%.
In addition, qualitative feedback from machine operators indicated fewer interruptions in production and greater confidence in scheduling high-volume jobs. Data logs confirmed that timely interventions based on predictive insights successfully prevented at least five major failures over a two-month observation period. These results underscore the practi-

cal value of predictive maintenance in real-world production environments.

4. DISCUSSION

Maintaining printing machines and equipment is essential for ensuring continuous and efficient operation. Traditional maintenance approaches, such as preventive, corrective, and proactive maintenance, have been the industry standard for many years. However, with advancements in technology, a predictive maintenance model for printing machines has emerged. Comparing these different maintenance strategies provides valuable insights into their distinct approaches, benefits, and limitations, helping to select the most suitable strategy based on a facility's needs and resources (Table 2).

Table 2: Comparison of maintenance approaches

Aspect	Corrective Maintenance	Preventive Maintenance	Predictive Maintenance	Proactive
Timing of Maintenance	After the failure occurs	Scheduled	Data-Driven	Early Detection
Cost Efficiency	High, unplanned	Planned, frequent	Planned, optimized	Initially high, long-term lower
Downtime Reduction	Unplanned, extended	Scheduled, brief	Infrequent, brief	Scheduled and minimal
Equipment lifespan	Short	Extended	Extended	Maximally extended
Complexity	Low	Moderate	High	Very high
Required expertise	Basic	Basic to intermediate	Intermediate to high	High

The research indicates that predictive maintenance is a valuable strategy for graphic machinery, particularly in high-performance environments like digital printing. The reduction in failure rates and maintenance costs demonstrates its effectiveness over traditional maintenance approaches. Furthermore, by integrating condition monitoring and machine learning algorithms, PdM enhances the ability to detect early signs of failure, thereby improving decision-making and operational planning.

Challenges remain in terms of implementation. High initial investment in sensors and software, as well as the need for trained personnel, may be a barrier to smaller operations. Additionally, the effectiveness of PdM depends heavily on the quality of data collected, which underscores the importance of robust data acquisition systems and standardized logging procedures.

Despite these challenges, the scalability and adaptability of PdM make it suitable not only for the graphic industry but for other manufacturing sectors as well. The successful case of the LEF2-200 illustrates how even mid-range machinery can benefit from intelligent maintenance systems. With continued advances in AI and IoT technologies, predictive maintenance is expected to become a standard component of industrial asset management.

5. CONCLUSION

Predictive maintenance uses sensors and smart algorithms to monitor machine data, helping to predict failures and choose the best time for maintenance. The research confirms that predictive maintenance, when integrated within a reengineered maintenance framework, significantly improves the reliability and cost-effectiveness of graphic machinery

operations. The study of the Roland LEF2-200 printer exemplifies the potential benefits of PdM in reducing downtime, extending equipment lifespan, and optimizing maintenance practices.

Its implementation in the graphic industry could significantly reduce unplanned machine downtimes, enhance productivity, and lower the costs associated with emergency repairs. By adopting predictive maintenance models, companies can improve resource planning, reduce the need for maintaining large inventories of spare parts, and make more efficient use of technical personnel. While initial investment in technology and infrastructure can be substantial, the long-term benefits—such as reduced machine failures, minimized production delays, and optimized resource allocation—clearly outweigh the upfront costs. Machine stability and reliability have a direct impact on the quality of the final product, influencing both customer satisfaction and competitiveness in the marketplace. Predictive maintenance thus serves not only as a technical upgrade but as a strategic tool for improving operational excellence in the graphic industry.

The future of predictive maintenance lies in the integration of emerging technologies that will enable more proactive and precise resource management. To further expand its application, continuous research and development are needed—focused on tailored solutions that will optimize the process and support broader implementation within the graphic industry.

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BLAŽ BAROMIĆ
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REVIEW PAPER

RECORD OF THE BLACK COLOR

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ABSTRACT

Black, although present today in all aspects of visual and cultural communication, was not among the oldest colors used in human history. Its importance gradually grew with the development of dyeing technology and pigment production, making it an integral part of artistic and symbolic colour palettes. The key property of black is its greatest contrast with a light background, whether in pictorial or textual representations, which contributed to its widespread use in writing, art, and design.
Black is not just an optical or material phenomenon; it has deep cultural, psychological, and social connotations. In the humanistic context, it is associated with the concepts of death, mystery, and magic, but also with elegance, status, authority, and power. Historically, the use of black ink in literary works was the privilege of the educated and wealthy classes of society, making it a symbol of knowledge and intellectual dominance.
This paper analyzes the development and evolution of black throughout history, taking into account their technological progress, symbolic role, and influence on the shaping of civilization. Its application in civilized society is considered, to understand its multi-layered significance in different historical and cultural contexts.

Keywords: black dye, papyrus, parchment, paper, writing.

1. INTRODUCTION

The area of research has been described many times, but recent research has clarified some segments that have remained unnoticed or insufficiently explained throughout history. The paper explores and integrates old and new knowledge.
The colouring substances of ancient times are primarily of inorganic origin. However, there is research that shows that pigments of organic origin are about 1.1 billion years old in the subsoil of today's Sahara. At that time, there was no plant life or animal life. The colouring was presumably caused by bacteria with the help of solar energy. The colours ranged from green to blue, to purple and red, and according to some authors, pink. [1] [2]
The emergence of intelligent beings led to the need to record current events with the intention of informing future generations.
In order for a message to remain recorded for a long time, it was necessary to carry out the process of applying a coloured substance to a supporting base. This is where the conscious creation and use of colouring begins.

2. DEVELOPMENT OF COLORING

The substances that provide colour are called dyes or inks, and they must differ in their tonality, brightness, or saturation from the properties of the substrate.
The oldest paintings were found in caves and were painted with inorganic dyes (Figure 1). [3] [4] The dyes used to create cave paintings are today the bearers of information about the materials and technologies used to create Paleolithic works. [5]

Figure 1: Natural inorganic paint, source: Erd und Mineralpigmente - Kreidezeit Naturfarben[4]

The Maltravieso cave in Spain preserves figures painted red, dating back 64,000 years. Drawings between 44,000 and 40,000 years old have been found in several places around the world. Red, gray-red and brown were used. [6] The paintings mainly depict animals, but the painting of human hands and the image of a bull in Borneo on cave walls painted between 52,000 and 40,000 years ago, are also very well known. [7] [8] [9]
A combination of chalk, soil, animal fat and burnt charcoal was used to make dyes as early as 40,000 years ago. [6]
Most often, black was obtained from soot from burnt charcoal and manganese oxide. Yellow–ochre–brown from limonite, red from hematite from baked limonite, and white from kaolin, shells, calcite, gypsum, and calcium carbonate. [10] [11] Remains of plant material suitable for use as dyes have been found in Neolithic settlements. [12]
The composition of the dye depended on the area of discovery and the technological level of the region. Nowarla Gabarnmong – Australia has 28,000-year-old paintings of people, animals, and fish. Bright red, orange, white, and black pigments were used for painting. [13] Over time, the colour palette became increasingly rich.
The method of applying the dye to the surface was initially very simple. It was painted with hands and then with wooden brushes. The dye was also applied by spraying from the mouth or blowing through hollow bones. [10] [14]
The progress of civilization, which was based on oral tradition, took a major step forward with the introduction of pictures. The next major step was the introduction of writing. Some authors state that property was recorded on shells and ceramics in the Mediterranean as early as 8000 BC. [15] The first physical evidence of writing was found among the Sumerians around 4500 BC. [16] Initially, writing was done by carving into a writing surface.
Writing was also done on tree bark. Later, in Rome, scraping with a stylus on a board covered with wax was used. [17]
These were techniques without coloured writing. Later, with the discovery of different writing surfaces, writing with ink-dye, which was adapted for certain surfaces, began to be used. This was the development of writing on fabrics, papyrus, parchment and paper. The writing was visible, and the writing surface was not destroyed.
The oldest period of recording shows the use of both black and dark blue. From a humanistic perspective, black is not just a physical phenomenon but has a broader meaning. It has already depicted emotional thoughts and events in the author's environment in the distant past. [18]

3. SUBSTRATES FOR WRITING WITH COLORING INK

Papyrus is considered to be the oldest writing surface on which text and coloured images could be applied without destruction (Figure 2). The oldest known papyrus roll was found

in a tomb at Saqqara. It is believed to have been made around 2900 BC. [19]

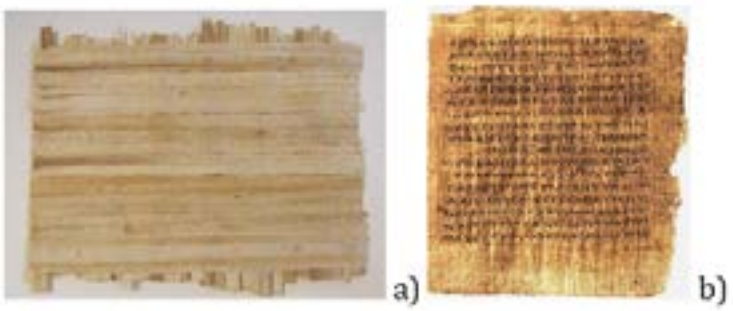

Figure 2: a) Sheet of papyrus for writing, b) Text on a papyrus writing pad [20]

The papyrus plant thrives primarily in the Nile Valley. The heart is cut from the trunk into thin strips, which are then stacked crosswise, kneaded to release the juice, and pressed. After that, the surface is ironed to make it suitable for writing. The entire manufacturing technological process takes about 10 days. [20] [21]
The next very important writing surface is parchment (Figure 3). [22].

Figure 3: Production of parchment [23]

The emergence of problems in the papyrus trade further stimulated the development of a new quality writing surface. [24] In the area of present-day Turkey, in the then-Greek city of Pergamon, a new process for making writing surfaces was developed around 200 BC. The basic material, called parchment, was goat and sheep skins, which were treated with a solution of lime. After removing the hair and remaining lime, the skins were stretched on wooden frames and dried. They were then sanded and polished and finally cut into the desired formats. [24] [25]
Parchment is an extremely durable material. Some of the oldest texts have been preserved on parchment. It is resistant to ageing and external influences. It is difficult to tear. It accepts dyes very well. It is possible to write on both sides. It is very durable and suitable for archiving. The downside is its high price. [23] [26]
Parchment was used for making all written and painted works, and even today it is used on special important occasions when the work needs to be immortalized.
A newer writing surface is paper. The oldest known written paper was found in China. A prayer is written on it. It is considered to be from the era of 200 BC. n. e. [27] [28]
It is recognized worldwide that Tsai Lun is the inventor of paper production. He was the first to describe the process of paper production and realized the production in 105 (Figure 4). [27] [29] The invention of paper is one of the turning points in human life. In the beginning, the recipe and technology of making paper was a Chinese state secret. [30]

Figure 4: Screens for manual initial paper production in China [31]

Paper production nevertheless spread to Korea and Japan (Figure 5), where it began around 610. The expansion of paper production continues in Arab countries. Baghdad 751 – 794, the first state paper production was opened. [29] [32] [33]

Figure 5: The spread of paper production from China to Japan, and via Asia and Africa to Europe [32]

The use and production of paper reached Europe via North Africa and the Mediterranean. The oldest European manuscripts on paper were found in present-day Spain, and date from 1036. They are the result of cultural contact between Islam and Western Christianity during the 11th century. Paper production in Europe began in the 12th century in Italy and Spain, then in France and Germany, and England in the 15th century. [29] [35] [36]
The production process was slow. It began with soaking rags and fabrics for up to 3 months, and these were the only raw materials. [27] Then the pulping was painstakingly done by hand. [35] As early as the 12th century, powered hammers were introduced into the pulping process, and in the 14th century, pulp mills were introduced, which significantly facilitated and accelerated the production process. The pulp is then poured into sieves and dried into the desired formats (Figure 6) [29] [37] [38]

Figure 6: a) Hydraulic hammers [34], b) Pulp mill[35]

Over time, the number of literate people grew, and so did the need for paper. Thus, in addition to rags, other fibrous materials such as cotton, flax, hemp, wood shavings, and more recently recycled paper began to be used as raw materials. [40]
However, the problem of spillage on the writing surface and the high absorption of dye-ink into the paper itself arose. To reduce these unwanted effects, the paper began to be coated with sizing obtained from animal gelatin. [29] Soon sizing was also added to the

paper mass, and various fillers were also added. The highest quality was obtained by using high-quality raw materials and certain coatings of the desired degree of whiteness, smoothness, and convenience for writing.

4. WRITING TOOL

The goal was to write down the text so that it could be read later as easily as possible. In the beginning, while writing in stone, wax, wood or some other material into which the text was engraved, they used metal or bone styluses. Most often, they were sharp at one end, and the other blunt side was used for wiping. [41]

Around 3000 years BC. n. e. in Egypt a brush was used for writing. [41] In China, it was written with a paintbrush on fabrics in the year 1000 BC. n. e. These were non-destructive procedures. The process of destroying the wax surface with a metal pen was used around 1300 in Rome, and then by the Anglo-Saxons. With the invention of papyrus and later paper, writing was done on their surface with special quills around 300 AD. Those pens were made of reeds. With these pens, ink was applied to the substrate without destruction (Figure 7). [42] [43]

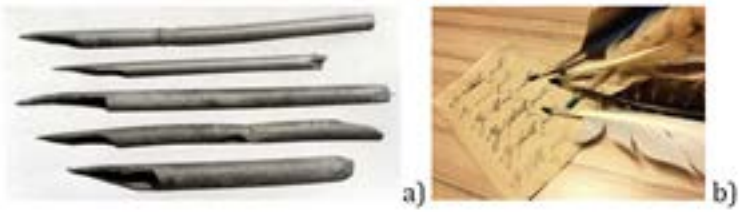

Figure 7: a) Reed pen, b) Goose quill used for writing[42]

The first use of the ink pen in Europe was in Spain. After 600 AD, this method of writing spread throughout Europe. Wooden quills were replaced by feathers from poultry. It was found that the way the quill was sharpened greatly affected the quantity and quality of production. [41]

Figure 8: a) Inkwell, Croatian Restoration Institute, b) Set of writing instruments[44]

Writing with a pen occupied a very high position in civilization. For wealthy citizens, writing pens decorated with expensive metalwork were hand-made (Figure 8). [45]

With the advent of printing, the value of hand-copying decreased considerably, as the reproduction of original manuscripts in large numbers was taken over by printing technology. This happened during the 15th century.

5. USING OF BLACK DYE

Black dye was used very early. For example, a significant use of black paint was established in the Lascaux cave in present-day France. Figure 9a shows a cattle, and the drawing is over 17,000 years old. The painting surface was rock. [46] The most common composition of black paint in caves was charcoal soot or carbon black and manganese oxide. [10] Over time, many writing surfaces were developed, such as clay, slate, ceramics, linen cloth, palm leaves, metals, stone, animal skin, wax, and paper. [47] For each of the surfaces, the dye –

the ink for writing or painting – had to be adapted. Unlike other colors, black completely absorbs all visible light that shines on it. [48] In doing so, not only the physical but also the humanitarian dimension should be taken into account, because painting and writing have also conveyed emotional states and opinions from the ancient past. Black is used in death, and magic, and also symbolizes elegance, wealth, privilege, and strength. [49]

Figure 9: a) Painting of a black ox from the Lascaux cave, circa 17,000 years old[50], b) Sumerians, circa 3,500 BC [51,]c) Egypt, circa 3,100 BC, d) Greece, 7th–6th century BC [52]

More than 40,000 years ago, paints of various compositions were used for painting, even organic raw materials found in nature. [53] Around 2,500 BC, Egypt used writing ink containing soot and glass (Figure 9). [54]
Over time, a combination of chalk, earth, animal fat, and burnt charcoal developed. The first colours were most often red and brown. [14] Later, a palette of 5 colours developed from such components: black, white, red, yellow, and brown. [6] At that time, black paint was made from charcoal soot, and from soot and manganese oxide. Yellow – ochre from limonite, red ochre from hematite or baked limonite, white from kaolin, shells, calcite, gypsum calcium carbonate, and other ingredients. [10]
With the development of civilization, dyes were created for writing-on-writing surfaces. Papyrus from the Nile Valley enabled the production of a writing surface with new, very favourable characteristics. Existing dyes had to be adapted to such a surface. The ink was created. These were liquids (usually aqueous solutions or suspensions) with which, using newly designed tools, it was possible to write well on sheets made of papyrus. [20]
The coloured substances in the ink were dispersed or dissolved in water (Aqua ink) [56]. Thus, in Egypt, 300 years BC, a mixture of soot or iron-rich earth, in water and vinegar, was used. The main binder was gum Arabic. 300 years BC In India, the so-called "adhesive ink" was formulated. It contained the revolutionary addition of iron gall compounds.
The Romans produced iron gall ink from iron and apple powder, with a binder of gum Arabic. Water was primarily used as a solvent, but beer, wine, and vinegar were also used. A disadvantage of such inks was that they sometimes released compounds that corroded paper writing surfaces and metal writing tools. [56]
Gallus solutions and gum Arabic were also often found in inks in the 19th century. However, acid-based inks were used for writing on parchment, because they penetrated and adhered to the surface more easily. [57] [58]
The composition of modern inks mainly includes: a dye, solvents or binders, a moisture regulator, resins, biocides, fungicides, and surfactants. [59]

6. LETTER PRINTING INK

The difficult, expensive and painstaking work of copying the required works resulted in the development of mechanical reproduction of the originals with the help of new technologies. Thus, a few decades after the appearance of woodcuts in the intaglio printing technique, engraving of the printing form in metal appeared. This was a more expensive process of higher quality prints, intended primarily for the aristocracy. The first records of intaglio printing, copper engravings, appeared around 1430. [60]
Printing was done in direct contact with paper, and ink, or a dye with a very low viscosity, was used for colouring. Such a dye easily remained in the recessed printing elements of the printing form in intaglio printing, while it was easily mechanically removed from free surfaces.
Such a printing technique did not meet the requirements of the then level of civilization for the fast and cheap production and distribution of books. These requirements were met by the invention of movable metal letters in the technique of letterpress printing, and book printing. This invention was made in 1440 by Johannes Gutenberg in the city of Mainz. The alloy used to cast Gutenberg's movable type contained lead, zinc, and antimony. The shape of the letters imitated Gothic calligraphy. [61] [62] [63] [64]

Figure 10: a) Cabinet with letters for letterpress printing b) Applying dye to a printing plate in letterpress printing [65]

The existing ink for writing, and possibly the one for intaglio printing, could not be satisfactorily accepted by the printing elements of letterpress printing, and the amount that was accepted was too small to achieve a high-quality print on paper. Therefore, it was necessary to formulate and produce a thick dye that, among other things, would not leak onto the free surfaces of the form between the raised printing elements. Additionally, the amount of dye transferred by the printing form to the printing substrate had to be sufficient to produce a satisfactory black print.
In addition to metal movable type and the printing press, Johannes Gutenberg also created a suitable dye (Figure 10). Before that, scribes and painters had used eggs as a binder, and printers also used oil as a binder for the dye. [66]
Gutenberg experimented with different compositions until he found a satisfactory composition: turpentine, linseed oil, resin, and carbon black. [67] Some authors also experimented with galläpfel, vitriol, etc. It was important to maintain the high viscosity and necessary adhesiveness of the dye. An important effect of such a dye was the good transfer of the dye to the paper, which resulted in black, permanently glossy prints, and their rapid drying. Also, the penetration of the dye into the printing substrate was not too great, so double-sided printing was possible. The aforementioned dye did not behave as an aggressive liquid. [68] [69]
From that day on, the development of industrial printing dyes began, whose quality satisfied the printing technology of many graphic printing techniques.

7. CONCLUSION

The development of world civilization largely depends on the possibility of recording events and the possibility of spreading what was recorded by duplicating the original. In this, writing surfaces and means that make the written visible play an important role.
Initially, painting was used, which is a certain improvement in the oral transmission of information from generation to generation. Then writing and writing down information appear, which significantly accelerates development.

- The oldest discovered colouring is about 1,100,000,000 years old.
- Discovered cave paintings in red, 64,000 years BC
- Discovered cave paintings in red, gray-red and brown, 44,000 years BC
- Cave paintings in black, white and colourful, colours 28,000 years BC
- Writing with the destruction of the substrate 8,000 or 4,500 years BC

The development of writing surfaces allowed for writing without damaging the writing surface.

- Papyrus 2900 BC
- Parchment 200 BC
- Written record on paper from around 200 BC discovered
- Firm date for paper production 105 AD
- Oldest manuscript on paper in Europe in the 11th century
- Industrial production of paper in Europe in the 12th century

The production and chemical and mechanical progress of dyes accompanied the development of writing surfaces. The consequence was the spread of knowledge and the growth of the civilization of mankind. This also entailed the development of writing tools. [70] [71]
A sudden, violent turning point in the development of society, science and culture occurred in 1440 with the invention of Johannes Gutenberg, his invention of metal movable type and the creation of industrial reproduction of all records. This is actually the first step in educating a wide range of people, thus beginning a rapid development in the direction of today's way of life.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

THERMAL PROPERTIES AND AIR PERMEABILITY OF COTTON KNITWEAR PRINTED WITH DIFFERENT TECHNIQUES

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ABSTRACT

Thermal properties and air permeability play a crucial role in the functionality of textile materials, particularly in apparel applications. This study investigates the impact of different printing techniques on these properties. Samples were produced using screen printing, screen transfer, direct transfer and direct to garment printing principle, with and without a white backing layer. It was assumed that the printing technique and the presence of a white backing layer alter the textile's microstructure, affecting its thermal resistance and air permeability. The results confirmed that the printed layer significantly reduces air permeability, and techniques that form thicker and denser ink layers lead to higher decrease. In contrast, direct to garment printing preserved the fabric structure, resulting in the highest air permeability. With thermal properties, denser printed layers exhibited lower thermal resistance, facilitating heat transfer through the material. Conversely, samples where the ink did not significantly alter the fiber structure retained more air within the textile, leading to higher thermal resistance. These findings highlight the importance of selecting an appropriate printing technique to optimize textile performance for applications requiring either thermal insulation or breathability.

Keywords: textile printing, thermal properties, air permeability.

1. INTRODUCTION

A garment functions as a dynamic barrier that regulates heat and moisture exchange between the human body and its environment. Its thermal performance is influenced by several factors, including the intrinsic properties of textile fibers, the air trapped between the fabric and the skin, and the static air layer on the garment's outer surface [1,2]. Together, these elements determine the garment's insulating capacity, breathability, and overall thermal comfort, highlighting the importance of understanding the interaction between textile structure and environmental conditions [1–3].

Among the key factors governing thermal regulation and comfort, thermal resistance (Rct) and air permeability play critical roles [3]. Thermal resistance refers to a fabric's ability to restrict heat transfer, directly influencing wearability in different climates. Higher thermal resistance provides better insulation by reducing heat loss in colder environments, while lower resistance enhances heat dissipation, improving comfort in warmer conditions [4]. The pore structure and air permeability of knitwear significantly affect its thermal resistance. Zhu et al. demonstrated that increasing the pore size and the ratio of pore area to the total fabric area leads to higher air permeability and reduced thermal resistance under convective conditions, due to greater heat exchange through airflow [5]. This suggests that, although thicker fabrics generally offer better insulation, highly porous structures may facilitate airflow and reduce heat retention. However, in still-air or low-convection conditions, porous knitwear may trap insulating air within its structure, thereby increasing thermal resistance [1,3].

In addition to structural factors, surface modifications such as coatings can also influ-

ence thermal behavior. Shayed et al. showed that specific coatings enhance thermal resistance by forming protective layers that reduce thermal energy loss without significantly increasing fabric weight [6].
Cotton, widely recognized for its breathability and moisture absorption, is a preferred substrate for various printing techniques, including screen printing, digital inkjet printing, and thermal transfer printing. Screen printing remains dominant due to its cost-efficiency and scalability, while digital inkjet printing has gained popularity for its precision and ability to reproduce detailed designs without significantly altering fabric characteristics [7,8]. The selected printing method can impact thermo-physiological comfort, as studies suggest that printing parameters affect perceived warmth and the fabric's ability to retain or dissipate heat [7]. Consequently, different printing techniques can alter the thermal resistance and air permeability of cotton substrates—two properties critical to wearer comfort and textile performance [8].
The printing technique influences fabric properties by modifying the surface structure, porosity, and ink coverage [8,9]. Techniques that produce dense ink layers tend to obstruct air pathways, reducing breathability and increasing thermal conductivity. Conversely, methods that allow ink to penetrate the fibers without forming a thick surface coating help preserve airflow and comfort. Understanding how printing technologies affect fabric performance is essential for optimizing design according to functional needs.
This relationship between printing methods and textile performance underscores the potential for optimizing fabric properties through thoughtful design. For instance, certain inkjet applications create a conformal coating that bonds closely to the fibers without significantly impacting the fabric's structure, as demonstrated by Shahariar et al. [10]. Such approaches preserve the textile's original comfort characteristics while adding functionality. Understanding these dynamics is vital for developing performance-oriented textile products that balance comfort and utility.
Although previous studies have explored the effects of individual printing techniques on textile properties, to the best of our knowledge, no previous study has systematically compared these four printing techniques under the same fabric and testing conditions in terms of both thermal resistance and air permeability. This study aims to fill that gap by systematically evaluating how each technique modifies the thermal and breathability properties of cotton knitwear, providing insights for optimizing textile performance based on the intended application.
Understanding how printing techniques influence fabric insulation and breathability is essential for designing functional textiles tailored to specific end-uses. For example, apparel for activewear may benefit from enhanced air permeability for improved moisture management and cooling, while thermally insulated garments are more suitable for cold-weather or protective applications. These insights contribute to the broader goal of optimizing printed textiles for high-performance and comfort-driven applications.

2. MATERIALS AND METHODS

2.1. Printing Techniques

This study examines four distinct textile printing techniques, commonly used for small- and medium-scale apparel production. The following methods are analyzed:

1. Direct-to-Film (DTF) Printing: This method utilizes aqueous inkjet technology to print an image onto a specialized transfer film. The printed film is then applied to the fabric using heat and pressure, allowing the ink to adhere and form a durable imprint on the textile [11].

2. Direct-to-Garment (DTG) Printing: DTG printing involves digital inkjet technology, where water-based inks are applied directly onto the textile surface without an intermediate film. This process enables high-resolution prints while maintaining the fabric's breathability [12].

3. Screen Printing (SD): Also known as silkscreen printing, this method involves forcing ink through the open areas of a mesh stencil onto the textile surface using a squeegee. It is widely used for printing on various materials, including fabrics, paper, plastics, and metals [11].

4. Screen Transfer (ST) Printing: This process combines screen printing and heat transfer technology. Initially, the image is screen-printed onto a specialized transfer film. The printed film is then placed on the fabric and transferred using high temperature and pressure, allowing for vibrant and durable prints.

2.2. Materials

Samples were printed on an identical cotton knit fabric (155 gsm) sourced from the same manufacturer and batch. The fabric pieces were cut to 30 × 30 cm, and on each sample was printed 25 × 25 cm patch, resulting in a total of 7 printed samples.
The DTF prints were produced using a Storm Jet printer, equipped with an Epson I3200-A1 printhead (CMYK+W). The DTG prints were created using an Epson SureColor F2000 DTG printer, which features an Epson PrecisionCore printhead (CMYK+W). SD and ST printing were carried out using a 100 threads/cm mesh, and Argon Texiplast inks were applied for both direct and transfer prints. This is standard mesh count that provides a balanced ink transfer suitable for cotton knitwear, ensuring adequate coverage without excessive pore blockage or loss of fabric flexibility.

2.3. Thermal properties

The thermal resistance (Rct) of the printed textile samples was determined according to GB/T 11048-2008 [13]. Measurements were conducted using a YG606D Thermal Guarded Hotplate.
For the analysis, printed textile samples were cut to 25 × 25 cm and conditioned under standardized atmospheric conditions (20 ± 2 °C, 65 ± 5% RH) before testing. This ensured environmental stability prior to thermal and air permeability measurements.
The sample was then placed on the test plate, preheated to 35°C, ensuring uniform thermal exposure. The test parameters were set using the instrument's control panel, including plate temperature (T_m = 35 °C), preheat of 15 minutes, sample thickness (d) and standard ambient air temperature (T_a). Thermal resistance (R_{ct}) was calculated using the Equation 1:

$$R_{ct} = \frac{(T_m - T_a) \cdot A}{H - \Delta H_c} - R_{ct0} \quad (1)$$

where:
T_m – test plate temperature (°C);
T_a – ambient temperature in the climate chamber (°C);
A – surface area of the hotplate (m^2);
H – heating power of the test plate (W);
ΔH_c – correction factor for heating power (W);

R_{ct0} – thermal resistance of the empty test plate (m^2K/W).

The heat transfer coefficient (K) and thermal conductivity (λ) were derived using Equation 2 and Equation 3:

$$K = \frac{1}{R_{ct}} \quad (2)$$

$$\lambda = \frac{10^{-3} \cdot d}{R_{ct}} \quad (3)$$

where:
λ – thermal conductivity (W/mK);
d – sample thickness (m).
These calculations allow detailed evaluation of how different printing techniques influence the thermal insulation properties of the fabric.

2.4. Air permeability

Air permeability was determined in accordance with SIST EN ISO 9237 (1995) [14], which specifies the methodology for assessing the air permeability of textile materials. Before testing, all samples were conditioned under standardized atmospheric conditions (20 ± 2 °C, 65 ± 5% RH). The analysis was performed using a SKYLINE Air Permeability Tester, applying a differential pressure of 100 Pa through an area of 20 cm^2. A total of 20 measurements were conducted for each sample at randomly selected locations, and the average air permeability was calculated.
The air permeability Q ($m^3/min \cdot m^2$) was determined using the Equation 4 [15]:

$$Q = \frac{q}{6 \cdot F} \quad (4)$$

where:
Q – volume of air passing through the fabric per minute at 100 Pa ($m^3/min \cdot m^2$);
q – volume of air passing through the specimen (dm^3/h);
F – test area (cm^2).
By measuring air permeability, this study evaluates how fabric composition, structural properties, and printing techniques influence breathability in printed cotton textiles.

3. RESULTS AND DISCUSSION

An overview of used printing techniques and sample labels can be seen below (Table 1).

Table 1: Sample overview

Sample	Printing technique
SD-WB	Direct screen printing. Black over White. Curing with hot air.
SD-B	Direct screen printing. Black only. Curing with hot air.
DTF-WB	Digital inkjet printing on film. Black over White. Transfer and drying with a heated press.
DTF-B	Digital inkjet printing on film. Black only. Transfer and drying with a heated press.

ST-WB	Screen printing on film. Black over white. Transfer and drying with a heated press.
ST-B	Screen printing on film. Black only. Transfer and drying with a heated press.
DTG-B	Direct digital inkjet printing. Black only. Drying with a heated press.

3.1. Thermal properties

Thermal properties, including thermal resistance (R_{ct}), thermal conductivity (λ), and heat transfer coefficient (K), were analyzed to evaluate how different printing techniques influence heat retention in cotton textiles. Results are presented in Table 2. Based on sample thickness it can be noted that the thickness increased by adding printed layers.

Table 2: Thermal properties of printed knitwear (Rct0 = 0.08292 m2·K/W)

Sample	d (mm)	Rct (m^2·K/W)	λ (W/m·K)	K (W/m^2·K)
Cotton knitwear	0.38	0.03239	0.01173	30.878
SD-WB	0.47	0.02185	0.02151	45.762
SD-B	0.46	0.02465	0.01866	40.571
DTF-WB	0.46	0.02496	0.01843	40.070
DTF-B	0.44	0.02814	0.01564	35.536
ST-WB	0.46	0.01793	0.02565	55.759
ST-B	0.44	0.02556	0.01722	39.125
DTG-B	0.42	0.03234	0.01299	30.921

Unprinted cotton knitwear had the highest thermal resistance, as expected for a fabric with high porosity and unrestricted air pockets. DTG-B sample exhibited a similar high thermal resistance, reinforcing the idea that ink printed with direct to garment technique penetrates the fibers rather than forming a surface barrier, allowing for more air retention and increased insulation. ST-WB sample had the lowest thermal resistance, indicating reduced insulation due to a thick ink layer blocking fabric pores and promoting heat conduction.

ST-WB sample had the highest thermal conductivity and heat transfer coefficient, meaning that it facilitates heat transfer more than any other sample, likely due to dense ink coverage. Unprinted cotton knitwear and DTG-B sample had the lowest thermal conductivity, confirming that their structure retains more air and reduces heat flow.

Air permeability results are presented in Table 3.

Table 3: Air permeability of printed knitwear (Area: 20 cm^2; Pressure: 100 Pa)

Sample label	Air permeability q (l/m^2·s)
Cotton knitwear	595.431 ± 21.71
SD-WB	0.603 ± 0.21
SD-B	1.992 ± 0.68
DTF-WB	0.825 ± 0.08
DTF-B	0.980 ± 0.11
ST-WB	1.009 ± 0.02
ST-B	0.944 ± 0.08
DTG-B	617.303 ± 8.22

Table 3 shows a significant variation in air permeability depending on the printing technique and the presence of a white backing layer. The unprinted cotton knitwear exhibited the highest air permeability, as expected due to its porous structure. Printed samples showed a substantial reduction in air permeability, with variations based on the printing method. DTG-B maintained high air permeability, nearly identical to unprinted fabric. This indicates that in direct to garment print, ink penetrates the fibers without forming a thick surface layer, preserving breathability. SD-WB had the lowest air permeability, confirming that a thick ink layer significantly blocks airflow. DTF-WB showed slightly higher permeability but remained much lower than DTG-B. DTF-B, ST-WB, and ST-B had similar values, indicating that transfer-based methods similarly reduce breathability. SD-B had better airflow than SD-WB, showing that the absence of a white backing layer improves permeability. Standard deviation values indicate measurement consistency across repeated samples, supporting the reliability of observed trends.

Figure 1. reveals a clear correlation between ink layer thickness, printing technique, air permeability, and thermal properties. As the ink layer thickness increases, air permeability decreases, confirming that denser ink applications obstruct airflow through the fabric structure. However, printing technique also plays a crucial role, as DTG-B maintains high air permeability despite having a similar thickness to some transfer-printed samples. A strong relationship is also observed between thermal resistance and air permeability—samples with higher air permeability, such as unprinted cotton and DTG-B, exhibit greater thermal resistance due to the presence of insulating air pockets. In contrast, samples with thick ink layers, particularly those with a white backing, show lower thermal resistance and increased heat transfer coefficients, indicating that blocked pores facilitate heat conduction. Additionally, materials with lower heat transfer coefficients (better insulators) tend to have higher air permeability, while those with higher heat transfer coefficients exhibit reduced breathability. These findings emphasize the interplay between fabric porosity, ink coverage, and heat transfer properties, highlighting the importance of selecting appropriate printing techniques based on the desired balance between insulation and breathability.

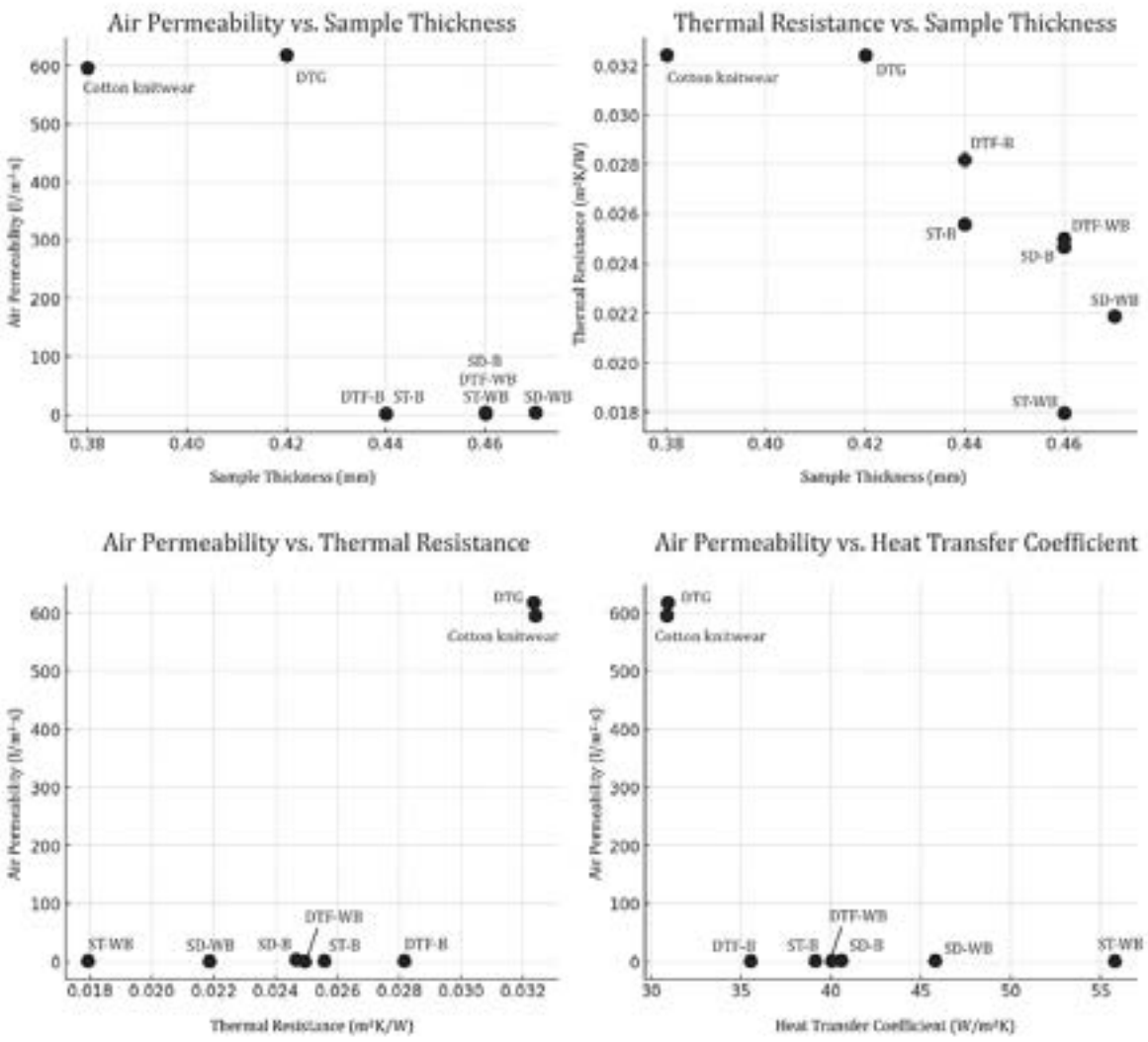

Figure 1: Correlation between tested parameters

4. CONCLUSION

Printing techniques that create a thick, surface-bound ink layer, such as screen printing and transfer printing, significantly reduce air permeability by obstructing airflow through fabric pores, which also increases thermal conductivity. In contrast, direct to garment printing, where ink penetrates the fibers rather than forming a surface layer, better preserves the fabric's breathability while minimally affecting thermal resistance. The findings demonstrate that both the printing technique and ink layer thickness play a crucial role in air permeability. Direct to garment printing maintains breathability, making it ideal for applications requiring airflow, such as sportswear, whereas screen and transfer printing, especially with a white backing, drastically reduce permeability, enhancing suitability for thermal insulation.

Understanding the interaction between printing methods and fabric properties is essential for optimizing textile performance for specific comfort and functionality needs. The direct to garment print on cotton knitwear exhibited both high air permeability and high thermal resistance, suggesting that more breathable fabrics retain more heat due to trapped air pockets. This study confirms that printing methods and ink layer character-

istics significantly impact the thermal and air permeability properties of cotton knitwear. Direct to garment printing, which allows ink to integrate into the fibers without forming a surface barrier, effectively preserves both breathability and thermal resistance, making it ideal for sportswear and activewear. In contrast, screen and transfer printing, particularly with a white backing layer, considerably reduce air permeability, making them more suitable for thermal insulation applications. These insights contribute to the optimization of printed textiles, balancing breathability and insulation to enhance wearability in different environmental conditions.

In further studies, a larger number of samples will be included to improve the statistical reliability of the results and to provide a more comprehensive analysis of the observed trends. Special attention will be given to the repeatability and reproducibility of thermal and air permeability measurements. In addition to the current macroscopic evaluations, future research will incorporate the assessment of micro-level surface characteristics, such as print mottle and micro-nonuniformity, using image analysis and digital evaluation tools. Correlation with other textile performance parameters, including moisture management, tactile properties, and durability under repeated washing, will also be explored to develop a more holistic understanding of how printing techniques affect functional comfort in cotton knitwear.

Acknowledgement:

This research was financially supported by the Ministry of Scientific and Technological Development, Higher Education and Information Society of the Republic of Srpska under project No. 19.032/961-60/24, titled "Critical Assessment of Color Quality Control in the Printing Industry in Accordance with the Recommendations of ISO 12647, ISO 15311, and ISO 13655 Standards."

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BLAŽ BAROMIĆ
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PROFESSIONAL PAPER

ADVANCEMENTS IN PDF STANDARDS: EMBRACING PDF 2.0 AND PDF/X-6 FOR MODERN PRINT WORKFLOWS

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ABSTRACT

The Portable Document Format is inevitable in the graphic arts industry. The PDF (Portable Document Format) format enables secure and easy document exchange and print production. The release of PDF 2.0 and the PDF/X-6 standard introduced significant advances in addressing contemporary workflow requirements. These standards are incorporated to improve transparency handling, colour management, metadata capabilities, and security measures. This way significantly impacts modern printing and digital workflows. PDF 2.0, developed entirely within the ISO framework, has provided a more robust and future-proof standard that caters to the diverse needs of various industries. Predictability in professional printing environments is enhanced by PDF/X-6, which supports advanced characteristics and some integration of processing steps. The paper explores the evolution of PDF standards, emphasizing the advancements in PDF 2.0 and PDF/X-6. Discussing their implications for modern print workflows and highlighting emerging trends shaping the future of PDF technology. Some world case studies and industry use cases are presented to demonstrate the practical impact of these standards. Primary challenges associated with adopting these standards are examined to provide a comprehensive overview of their implementation in the printing industry.

Keywords: PDF, standard, print workflow

1. INTRODUCTION

Digital document formats have significantly transformed how information is stored, processed and shared across industries. Among all these formats, the Portable Document Format (PDF) has become a standard for document exchange due to its ability to keep document integrity, layout consistency and compatibility across different platforms. Adobe Systems initially developed it in the early 1990s; PDF has since evolved into a globally recognized standard governed by the International Organisation for Standardisation (ISO) [1]. The last few years brought many structural iterations of PDF standards, and it has emerged to cater to specific industry needs, emphasizing the print and publishing sectors.
Since its inception, the PDF format has undergone numerous revisions to meet the needs of the graphic arts industry. PDF 2.0 made a significant moment since ISO 32000-1 (PDF 1.7) was published in 2008. The first version developed entirely within the ISO framework was PDF 2.0, independent of Adobe's direct oversight. This update incorporates features which ensure compatibility, security, and enhanced graphical fidelity. The increased support for colour fidelity and transparency handling has made it a significant improvement for print professionals [2].

Some of the commercial print shops that switched to PDF 2.0 have reported a reduction in prepress errors. The flexibility of PDF 2.0 has proven particularly beneficial in the packag-

ing industry to enhance and make more precise colour reproduction an essential part [3].

2. EVOLUTION OF PDF STANDARDS

Standardizing PDF formats has ensured reliability and consistency across digital and print workflows. Since its early days, PDF has been accepted as the de facto format for document sharing. Nowadays, it is adaptable to different industry needs achieved through specific subsets of standards. The PDF/X family, in particular, was developed to meet the rigorous requirements of professional printing workflows.
The PDF/X family of standards has been instrumental in ensuring predictable and reliable PDF work. Older versions, such as PDF/X-1a, mandated the flattening of transparencies and the conversion of all colours to CMYK (Cyan, Magenta, Yellow, Black), limiting flexibility. Upgrades in printing technology and increasing demands for complexity and novelty of design elements brought a pressing need for standards. This appearance could accommodate features like live transparencies and expanded colour spaces. That led to the development of PDF/X-4 and PDF/X-6 [4].
Furthermore, PDF/X standards continue to evolve to accommodate new printing technologies. That also includes digital and hybrid printing methods. Today, more and more companies are shifting to on-demand and short-run printing, and the role of these standards is to ensure consistency, which must remain crucial.

3. INTRODUCTION TO PDF 2.0

The current development of the PDF 2.0 version represents an expressive breakthrough in the progression of digital document standards. Released in 2017, it was the first update entirely governed by ISO, ensuring greater neutrality and industry-wide collaboration in its development. PDF 2.0 incorporates feedback and contributions from multiple industry stakeholders, resulting in a more robust and future-proof standard compared to previous versions that Adobe primarily influenced [5].

PDF 2.0 introduced several enhancements applicable to the graphic arts sector:

- **Improvements of Transparency:** Embellished handling of transparent objects, reducing the need for flattening and preserving design intent, which has been particularly useful in fine art reproduction and photo book printing.
- **Color Management:** Progressive support for complex colour profiles, assisting accurate reproduction of colour across different devices. For example, automotive manufacturers have leveraged PDF 2.0's expanded colour management capabilities to standardize digital proofs for vehicle wraps..
- **Metadata Enhancements:** Advanced metadata capabilities, improving better document management and searchability, primarily for automation of large-scale print workflows.
- **Security Features:** Strengthened encryption and security measures to protect document integrity, critical for government and legal document processing [2].

Despite these preferences, the adoption of PDF 2.0 has been a gradual process. Factors contributing to this include the inertia of established workflows and the time required for software vendors to implement full support for the new standard.

4. EMERGENCE OF PDF/X-6

Specifically, PDF/X-6 was improved to meet the evolving needs of print professionals by integrating improvements found in PDF 2.0. The increasing complexity of digital and hybrid printing workflows necessitates a more flexible standard that supports modern pro-

duction techniques without compromising efficiency [6].
PDF/X-6 was made to manage the limitations of its predecessors based on the foundation of PDF 2.0,:

- **Live Transparency Support:** PDF/X-6 allows for live transparency, preserving the visual integrity of complex designs in comparison to PDF/X-1a, which requires transparency flattening,
- **Expanded Color Spaces:** Support for color spaces beyond CMYK, including RGB (Red, Green, Blue) and spot colors, enabling more vibrant outputs.
- **Processing Steps Integration:** Inclusion of non-printing elements, such as die lines and varnish areas, standardized through ISO 19593-1, ensuring consistent handling across different workflows [6].

PDF/X-6 has improved document predictability. Some of the previous cases, such as the risk of rendering errors across different print devices, have been decreased. This standard offers flexibility for industries that rely on intricate details, such as packaging and textile printing.

5. CONCLUSION

The advancements encapsulated in PDF 2.0 and PDF/X-6 represent significant strides in addressing the complexities of modern print workflows. By embracing these standards, the graphic arts industry can achieve greater flexibility through design, workflow and output consistency. These standards hold promise for a promising future despite the challenges associated with their adoption, including software compatibility, training needs, and the coexistence of legacy systems.
Future trends such as artificial intelligence-driven automation, sustainability initiatives, and extended reality applications will continue to shape the evolution of PDF technology, with PDF 2.0 and PDF/X-6 at the forefront of these advancements. Their potential to revolutionize print workflows is inspiring, paving the way for a more efficient and innovative industry.
Standardized PDF workflows secure seamless document exchange and high-quality print production as industries adapt to these innovations. The industry's transition to PDF 2.0 and PDF/X-6 is not just an investment in the future of print and digital communication but a necessary step to ensure the sector remains competitive and efficient.

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

INVESTIGATION OF THE RHEOLOGY OF PRINTING INKS USED IN WATERLESS OFFSET PRINTING TECHNOLOGY

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ABSTRACT

We investigated the rheological properties of printing inks used in waterless offset printing (Toray-technology), paying particular attention to the variation of viscosity and tack values. The aim of our research is to understand the printing differences between the inks used during printing, with a particular focus on the problems of fading in iris printing. Studies have shown that the viscosity and tack of inks are closely related to the UV pigment ratio in addition to temperature. While an increase in pigment concentration in one ink resulted in a significant increase in viscosity, contributing to print defects, the viscosity of the other ink remained stable. The research has succeeded in determining the pigment ratio at which the viscosity and tack of the inks are close to each other, thus reducing printing errors. Reducing the pigment ratio of the inks we tested from 25% to 12-13% led to the elimination of printing problems. Further research is also planned to test alternative UV pigments to improve printing and optical properties. The research could contribute to technological advances in wetting fluid-free offset printing and to improving the efficiency of printing processes.

Keywords: Toray-technology, waterless offset printing, ink viscosity, tack of the ink, UV pigment, iridescent ink

1.INTRODUCTION

The development of waterless offset printing technology has brought significant advances to the printing industry, particularly with the use of Toray's innovative plates. [1] However, challenges remain, particularly in maintaining print quality under changing conditions. This research investigates the rheological properties of inks used in waterless offset printing, with particular attention to their viscosity and tack variations and how these factors affect print quality. Specifically, the research addresses the problem of fading in iris printing and aims to optimise ink formulation by analysing the effect of UV pigment ratios. By determining the optimal pigment concentration, the research will contribute to reducing printing errors and improving printing efficiency.

2. PRESENTATION OF THE TORAY PLATES USED

Toray Industries, Inc. is a Japanese multinational company founded in 1926. It started as a manufacturer of rayon and gradually expanded its activities. Today, it has become a major player in carbon fiber composites, electronics and information technology, and water treatment solutions. The company's strategic goals include promoting sustainable development. [2]
In the printing industry, Toray is a leader in the development of waterless offset printing technologies.

It offers the following products:

- TORELIEF™ photopolymer embossing plates - provide precise printing, their durability makes them suitable for high-volume production.
- RESOLUCIA™ flexographic plates - enable higher resolution printing with faster makeready and greater efficiency.
- IMPRIMA™ wetting fluid-free offset plates - provide an environmentally friendly solution with reduced carbon dioxide and VOC emissions.

Toray is actively engaged in research and development to contribute innovative technologies to the advancement of printing solutions. It focuses on sustainability, reducing environmental impact and improving print quality.

3. VISCOSITY AND RHEOLOGICAL PROPERTIES OF INKS

The aim of the tests is to analyze the rheological properties of inks used in waterless offset printing. Viscosity is a measure of the internal resistance of liquids, which depends on temperature and ink composition. The Arrhenius-Andrade equation (Equation 1) shows that viscosity decreases exponentially with increasing temperature. [3]

$$\eta = Ae^{\frac{E}{RT}} \quad (1)$$

Temperature control of printing units is a key factor in the practice of security printing, as print quality is sensitive to temperature changes. Due to the common temperature control of the inking units, rheological variations of different inks can only be controlled at the ink mixing stage.
Another important area of investigation is the effect of the UV pigment ratio on the viscosity and tack of the ink. The pigmented inks are produced in a three-roller mill. The pigment mixing ratio has a significant effect on the rheological properties of the inks. Experience shows that as the pigment content increases, printability deteriorates.
The aim of our research was to explore these relationships, reduce printing errors and determine the optimal composition of the inks.
The investigation of the rheological properties of printing inks is a key issue in the process of waterless offset printing. To determine viscosity and tack, special measuring instruments are used to accurately explore the behavioral properties of the inks.

3.1. Viscosity test

The viscosity of the inks was measured using the Haake RheoWin IQ1 viscometer, which is suitable for viscosity measurements in the temperature range 20-100 °C. [4] The instrument is rotary and the ink sample can be tempered by placing it in the machine. The viscometer can only be used in predetermined setting modes. According to the internal regulations of the security printing plant, the program cannot be modified.
The tests have shown that the amount of ink is crucial for accurate measurement. The amount of ink sample was gradually increased until the optimum range of 1.3-1.5 g was determined, which ensures accurate measurement results. The measuring instrument performs measurements at 40 °C, but tests were also performed at 25 °C to get a more accurate picture of the temperature dependence of the viscosity of the inks.
The results of the measurements confirmed the applicability of the Arrhenius-Andrade equation to the variation of the viscosity of inks with temperature. [5] [6]

3.2. Tack value test

The tack value indicates the adhesion of the ink. This is an important factor for print qual-

ity. The tack value is measured in N/m, which expresses the surface adhesion strength of the ink. In the security printing laboratory, the Inkometer Model 2006U was used for tack measurements. [7]
The tests compared the tack values – (Ta), maximum tack (Tmax), time to reach maximum tack (Ttime) and tack units (TU) – of the inks tested at different UV pigment ratios.
Tack measurements were performed in a standardised environment at 25 °C using 0.40 g ink sample. A special set of cylinders was used for UV drying inks and changed before each measurement to ensure accurate results.
It was found that higher pigment content leads to an increase in tack value. This can also affect the quality of the print. With a high tack value, the ink adheres more strongly to the print substrate, which increases the stability of the print, but can cause problems with ink uniformity. At low tack, the ink is less "sticky", which can be advantageous for quick ink release, but can reduce adhesion quality. [1]
Studies have shown that viscosity and tack are very important factors in the quality of the print. The viscosity of the ink can be significantly influenced by controlling the temperature. The tack value can be helped by optimising the pigment content. [1]

3.3. Methods of testing inks

The viscosity and tack of selected offset inks were tested at different temperatures and UV pigment ratios. The inks were prepared in the Trias 300 mill of the security printing company and the effects of pigment content and temperature were analysed.
The mixing ratio of the pigments was determined on the basis of printability experience. The maximum pigment content was 25% for the PJ005 ink (Table 1) and 22% for the PJ982 ink (Table 2).
Curves were fitted to the data using MATLAB software.

Table 1: UV pigment mixing ratios of PJ005 ink samples

name of ink	Pigment percentage [%]					
PJ005	0	3	9	15	21	25

Table 2: UV pigment mixing ratios of PJ982 ink samples

name of ink	Pigment percentage [%]						
PJ982	0	3	9	10	15	20	22

Since the printability of ink PJ982 was problematic, its rheological properties were investigated at different pigment ratios. Fitting curves were generated based on the points measured during the test. Using MATLAB software, we calculated RMS (root mean square error) values, which show how much the fitted values deviate from the original data. The smaller the RMS value, the more accurate the fit.
The results showed that an increase in pigment content significantly affects the viscosity and tack of the ink, which plays a key role in determining print quality. Our studies contribute to the determination of the optimal composition of printing inks, improving the stability of the printing process.

4. DESCRIPTION OF THE MEASUREMENT RESULTS

4.1. Composition of the inks tested

The inks used in our tests contain varying proportions of yellow (Y), cyan (C), translucent white and UV-sensitive pigment components. The mixing ratios are given below (Table 3).

Table 3: Composition of the tested offset inks

Ingredients	Mixing ratio [%]	
	PJ005	PJ982
Yellow	8.70	10.31
Cyan	2.50	3.40
Transparent white	63.80	64.29
UV sensitive pigment	25.00	22.00

4.2. Tested Viscosity and tack values

The viscosity and tack values of the inks were measured in the laboratory of the security printing company. According to the data in the table below (Table 4), the viscosity of PJ982 ink is more than twice (54.36 Pa·s) that of PJ005 (23.81 Pa·s), which may result in a significant difference in printability. Significant differences were also found when tack values were examined (Table 5), particularly for the Ttime parameter, which shows the rate of change of tack of the ink. This value is 163.8 s for the ink PJ0055 and only 69.8 s for the ink PJ982.

Table 4: Viscosity data for the tested offset inks , spring 2024

Viscosity		
Tested ink sample	Sample quantity [g]	Test value [Pa·s]
PJ005	5	23.81
PJ982	5	54.36

Table 5: Tack data of the tested offset inks, spring 2024

Tack					
Tested ink sample	Sample quantity [g]	Measured value			
		Ta [N/m^2]	T_{max} [N/m^2]	T_{time} [s]	TU [N/m^2]
PJ005	5	548	614	163.8	260
PJ982	5	461	467	69.8	310

4.3 Testing inks without pigment and with different pigment ratios

In order to better understand the effect of pigments, the viscosity of inks without pigments was also investigated. The results showed that the presence of pigment significantly increases the viscosity (Table 6). We also examined the effect of different types of UV pigments on viscosity. During the study, we did not change the C, M, Y pigment concentration, but only the UV pigment concentration. The results showed that both pigment type and concentration affect the rheological properties of the inks.

Table 6: Viscosity data for UV pigment free offset inks

Viscosity		
Tested ink sample	Sample quantity [g]	Test value [Pa·s]
PJ005	10	9.904
PJ982	10	6.520

4.4. Viscosity as a function of temperature and the calculation methods

The temperature dependence of the viscosity of the inks at 19.5 °C, 25 °C and 40 °C (Table 7), (Table 8) were determined. The results were used to model the variation of viscosity using the Arrhenius-Andrade equation and to determine the material constants (A and B) for each ink. By applying the equations, it was possible to predict the viscosity at different temperatures.

Table 7: Viscosity data for PJ005 containing different proportions of its own pigment at 25 and 40 °C

Tested ink sample	Pigment ratio [%]	$\eta_{25\,°C}$ [Pa*s]	$\eta_{40\,°C}$ [Pa*s]
PJ005	0	81.44	21.57
	3	94.12	21.78
	9	96.45	21.99
	15	90.72	20.44
	21	91.25	20.46
	25	89.91	21.89

Table 8: Viscosity data for PJ892 containing different proportions of its own pigment at 25 and 40 °C

Tested ink sample	Pigment ratio [%]	η 25 °C [Pa*s]	η 40 °C [Pa*s]
PJ982	0	76.97	22.66
	3	72.09	26.46
	9	96.32	32.66
	15	100.09	34.53
	20	113.80	37.97
	22	141.55	50.23

In the following, the viscosity of the inks at the production temperature (19.5 °C) is determined using equations (Equation 2) and (Equation 3):

$$B = \frac{T_1 T_2}{T_2 - T_1} ln \frac{\eta_1}{\eta_2} \quad (2)$$

$$A = \eta_1 e^{\frac{-B}{T_1}} \quad (3)$$

The viscosity of the inks (PJ005 and PJ982) was measured at two known temperatures (25 °C and 40 °C) (Table 9). Using Equation 1, the viscosity at any other temperature can be calculated using this data by using Equation 2 and Equation 3 to determine the constants A and B.

Table 9: Viscosity data for inks containing different proportions of their own pigment at 19.5 °C

Tested ink sample	Pigment ratio [%]	η19,5°C [Pa*s]	Tested ink sample	Pigment ratio [%]	η19,5°C [Pa*s]

PJ005	0	221.2	PJ982	0	193.0
	3	282.9		3	153.2
	9	293.3		9	217.3
	15	278.3		15	259.8
	21	280.9		20	308.5
	25	260.2		22	369.1

4.5. Results of the viscosity measurement and conclusions drawn

It was found that the viscosity of inks is significantly dependent on pigment content and temperature. For the ink PJ982, viscosity increases steeply with increasing pigment content (Figure 1). For the ink PJ005, the change in viscosity is less significant (Figure 2). Optimizing viscosity and tack values is key to improving print quality. The results can help to fine-tune the formulation of printing inks and increase the stability of the printing process.

The aim of the study was to determine the viscosity and temperature dependence of offset inks PJ005 and PJ982 at different UV pigment ratios. The measurements were carried out at 19.5 °C, 25 °C and 40 °C. The data obtained were analyzed for modelling. [8]

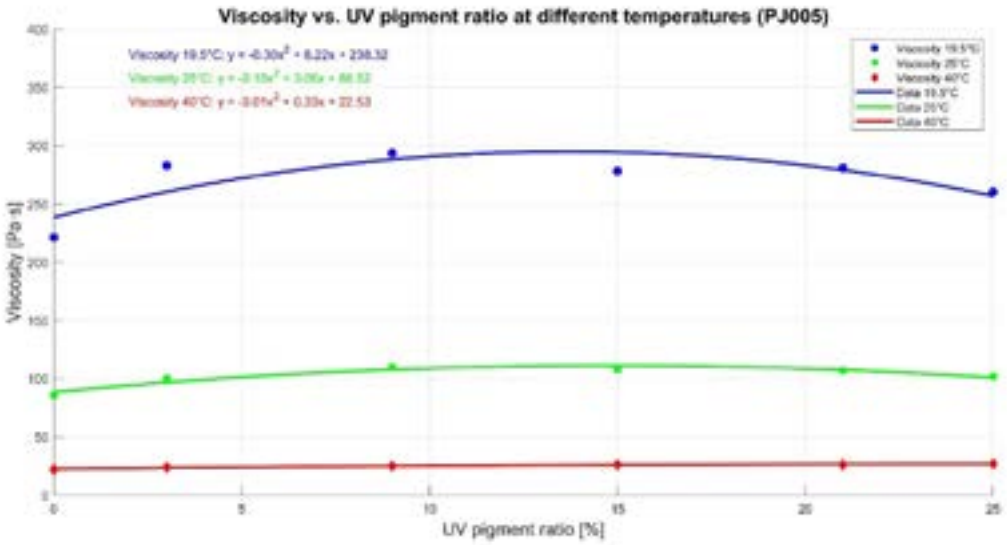

Figure 1: Temperature dependence of PJ005 pigment ratio viscosity, fitted curves

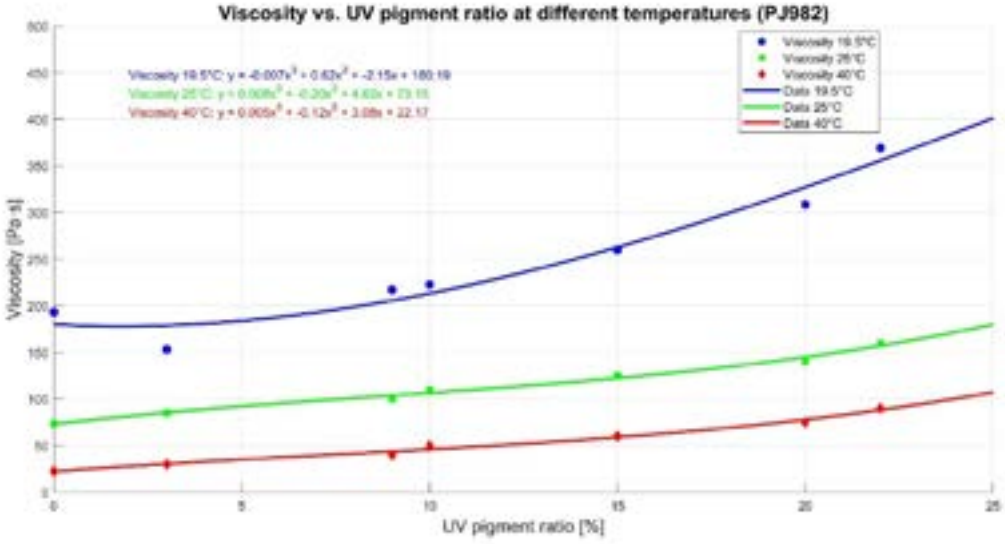

Figure 2: Temperature dependence of PJ982 pigment ratio viscosity, fitted curves

Tests at 19.5 °C show that the viscosity of PJ005 stabilises around a certain value, while the viscosity of PJ982 increases steadily with increasing pigment ratio. This trend was observed at all three temperatures tested. At a pigment ratio of 10-14% the viscosities of the two inks were still similar, but at higher pigment ratios the viscosity of PJ982 increased dramatically.

The relationship between viscosity and pigment ratio was described using different mathematical models. For the PJ005 ink, the quadratic function gave the best fit, whereas for the PJ982 ink, the third degree polynomial gave the best fit. The results also show that the temperature dependence of viscosity is a significant factor and that the selection of the right pigment ratio is a key factor for printability.

The tests were complemented by a numerical analysis using Matlab, which allowed the determination of the equivalence point of the viscosities. The results showed that the viscosities of the two inks are equal at a pigment ratio of 15.2%, while the range of ±10% deviation is between 13.5% and 17.5%. This pigment ratio may ensure optimum printability of the two inks. This is therefore the pigment range sought for ink PJ982 (Equation 4):

$$13{,}5\% < p < 17{,}5\% \tag{4}$$

With such a pigmented ink PJ982, it is expected that the printability of the inks that make up the iris pair will be close to the same.

4.6. Analysis of the tack values of the inks

The tack tests were carried out using Inkomenter Model 2006U equipment, which measured four main parameters – initial tack (Ta), maximum tack (Tmax), time to reach maximum tack (Ttime) and tack units (TU).

The results show that the tack values of the PJ982 ink are significantly different from those of the PJ005 ink above a certain pigment ratio, which may also indicate printing problems. Numerical analysis of the fitted curves was used to determine the pigment ratio at which the viscosity and tack of the two inks are nearly equal, thus optimizing printabil-

ity (Figure 3), (Figure 4).

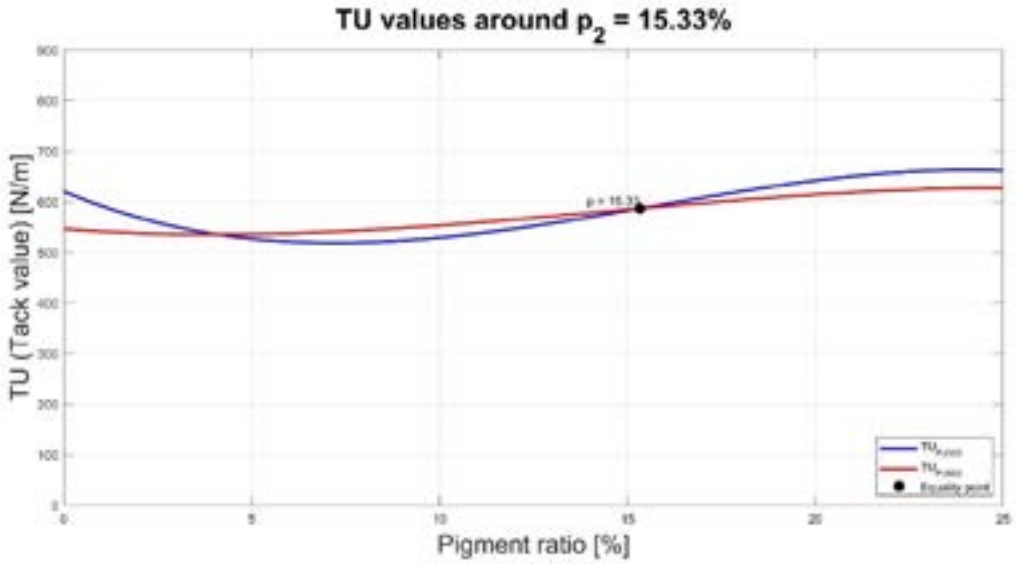

Figure 3: Variation of TU values of PJ005 and PJ982 inks as a function of pigment ratio

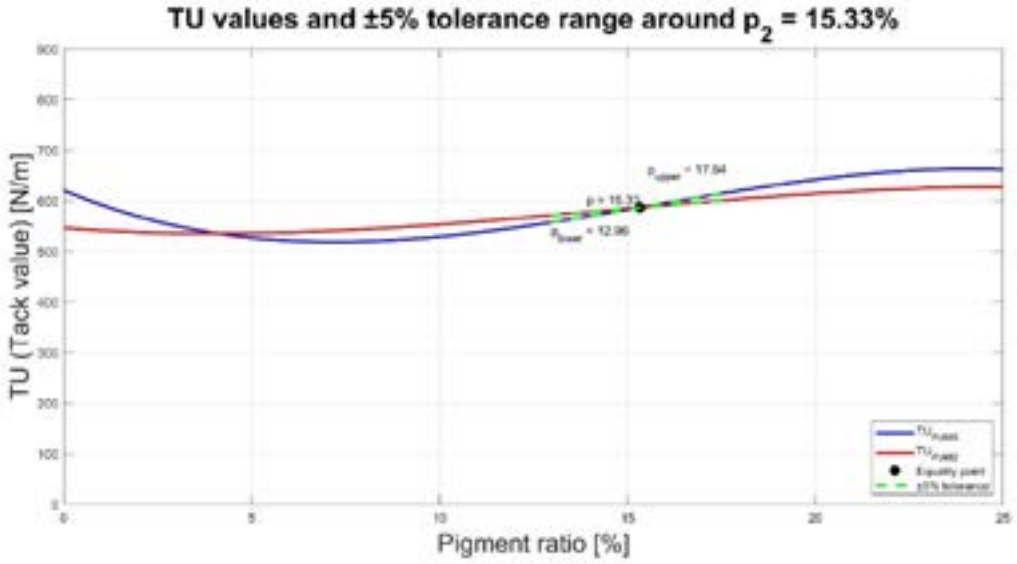

Figure 4: Variation of TU values of PJ005 and PJ982 inks as a function of pigment ratio ± 10%

The results show that the printability of ink PJ982 can be improved by optimizing the pigment ratio, the ideal range of which has been determined by numerical calculations to be between 13.5 and 17.5%. Within this range, the viscosity and tack values are sufficiently close to those of the printable PJ005 ink, thus reducing errors during printing.

4.7. Test printing

Photographs of the print load strips we were taken in the security printing laboratory. The following figure (Figure 5) shows how the print's load strip "glows" in yellow and red light when exposed to UV radiation at 254 and 365 nm. The ink PJ982 emitted yellow light when exposed to UV radiation in the UV-C range. The PJ005 ink was irradiated with UV-A

and emitted red light. The ink PJ982 has a print streak that clearly shows the printing problem that caused the print to streak. The aim was to eliminate this phenomenon.

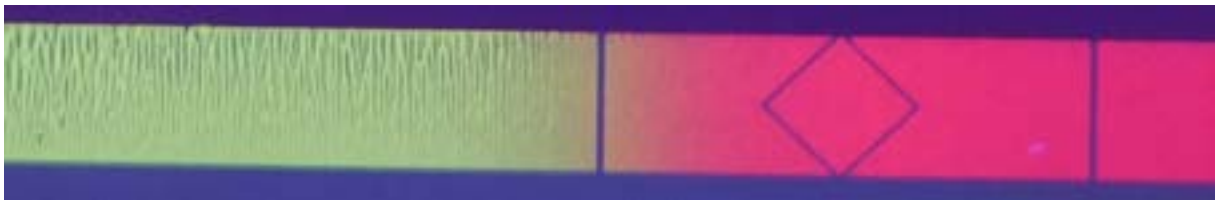

Figure 5: PJ982 and PJ005 inks under 254 and 365 nm UV radiation

Figure 6 shows a version of PJ982 in which the UV pigment content has been reduced from the original 25% to 11%. The previously observable streaks are no longer visible.

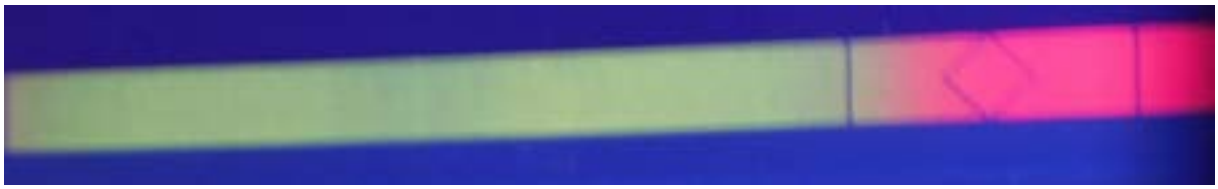

Figure 6: PJ982 (11% pigment ratio) and PJ005 inks under 254 and 365 nm UV radiation

Figure 7 shows the version of PJ982 in which the UV pigment percentage has been reduced from the original 25% to 12%. In this case, the streaks had also disappeared.

Figure 7: PJ982 (12% pigment ratio) and PJ005 inks under 254 and 365 nm UV radiation

Figure 8 shows the version of PJ982 in which the UV pigment percentage has been reduced from the original 25% to 13%. The streaks seen in Figure 5 are no longer present.

Figure 8: PJ982 (13% pigment) and PJ005 inks under 254 and 365 nm UV radiation

Figure 9 shows a version of PJ982 in which the UV pigment percentage has been reduced from the original 25% to 14%. At this point, although the streaks observed in Figure 5 are not visible, it is possible to observe that the print defect associated with pigment bleeding is beginning to develop.

Figure 9: PJ982 (14% pigment) and PJ005 inks under 254 and 365 nm UV radiation

5. CONCLUSION

We investigated the rheological properties of different inks used in dry offset printing. The dry offset printing process uses silicone coated printing plates. Therefore, no conventional wetting fluid is required during printing. The plates produced by Toray are widely used. The research is related to the production of a security printing product on a polycarbonate substrate. The prints were made on a Heidelberg Speedmaster 52 printing press. During the iris printing, the following problem was encountered - one of the inks (marked PJ005) printed well, but the other (marked PJ982) showed pigment bleeding, deteriorating the quality of the print. Our aim was to investigate the effect of the viscosity of the inks and its temperature dependence on the UV pigment ratio on the print quality. After evaluating the results, we proposed solutions to overcome the printing difficulties. The analyses concluded that the viscosity of the problematic ink PJ982 is strongly dependent on the proportion of UV pigment applied. Therefore, experiments and test production were carried out with different UV pigment ratios.
In summary, the ink will print well at a pigment content of 11 - 13%.
It is recommended to reduce the UV pigment ratio to the indicated range and to further investigate other UV pigments with more appropriate behaviour.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

PROFESSIONAL PAPER

CUSTOMER SATISFACTION WITH THE SERVICES OF THE OBITUARY DEPARTMENT OF THE NEWSPAPER SLOBODNA DALMACIJA – SPLIT

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ABSTRACT

Slobodna Dalmacija is one of the oldest and most influential Croatian daily newspapers. Through its sections and announcements, it has significantly shaped public opinion. One of the most well-known sections is the obituary column. With the introduction of daily obituary publications, the volume of newspaper pages increased, consequently leading to a growing demand for greater system automation. "StoryEditor" is a modular software designed for managing, processing, and laying out graphic, marketing, and web media content. It significantly accelerates the process of creating finalized obituaries based on the WYSIWYG (What You See Is What You Get) principle for end users. For the purposes of this study, a survey was conducted among users from four Croatian counties (Split-Dalmatia, Zadar, Dubrovnik-Neretva, and Zagreb counties) to assess their satisfaction with the obituary department services of Slobodna Dalmacija.

Keywords: newspapers, obituaries, service, StoryEditor, modules

1. INTRODUCTION

Obituaries represent notices of an individual's death, typically published in newspapers. They often include details such as the date and place of death, the cause of death, funeral arrangements, as well as personal information like the deceased's name, age, family members, and notable achievements [1, 2].

The precursors to modern obituaries were books containing brief biographies, which bore significant resemblance to contemporary obituaries. In 1731, newspapers began publishing the first modern obituaries in The Gentleman's Magazine, a London-based periodical [3].

Following this development, obituaries evolved into commemorative pieces with a particular emphasis on the public life of the deceased. Over subsequent centuries, more modern obituaries began to encompass both public and private aspects of an individual's life. During the 19th century, obituaries frequently described scenes of death in vivid detail. Consequently, death notices often included phrasing such as: "For a brief part of the year she was young, a beloved wife and companion, a mother, a corpse!" [4].

In Yugoslavia during the 1970s, obituaries omitted details regarding both the public and private lives of the deceased unless they held a significant societal position. Standardised notices were commonly published merely to inform the public of an individual's passing. The content and style of obituaries reflect societal norms and have evolved in tandem with social changes. They not only differ in terms of their content and tone but also signify broader cultural and social transformations.

Slobodna Dalmacija, one of Croatia's oldest and most influential daily newspapers, has played a key role in shaping public opinion through its various sections, including obituaries. These notices constitute an essential segment of newspaper announcements [5].

The publication of such notices began sporadically in Slobodna Dalmacija during the 1950s. By the 1960s, announcements regarding family members' deaths or expressions

of gratitude from organisations within the former state became more frequent [6]. Initially consisting of simple two-sentence acknowledgements following advertisements, these notices later incorporated introductory paragraphs spanning column widths, followed by the deceased's name and a brief note of gratitude. As daily publications became standard practice, newspaper page counts increased significantly, resulting in higher circulation volumes and printing costs. The editorial team viewed this expansion as an opportunity to diversify offerings alongside traditional commercial advertisements and classified ads—a format that remains integral to this day.
The system "StoryEditor" [7], featuring the Obituaries and CRM modules with their respective subdivisions, is utilised for the reception and technical processing of obituaries in the editorial office of Slobodna Dalmacija.
Since its implementation in Slobodna Dalmacija, the "StoryEditor" editorial system has undergone significant changes in both functionality and design. Key upgrades have been introduced through modules that enhanced performance, although not all modules are employed in daily operations. The system, developed by the Zagreb-based company "Domena.com," was designed to meet high automation demands across all segments of publishing [8]. This includes not only standard features such as text and image input but also full integration of plug-ins for user data analysis, performance metrics, and editorial evaluations of article quality, whether informative or investigative in nature.

1.1. Obituaries Modul

In the "Obituaries" panel (Figure 1), each advertisement intended for publication is entered.
The primary categories of announcements include:

- Notices of death / deceased individuals
- Condolences
- Expressions of gratitude
- Remembrances

The advertisement entry management system is structured around these categories, utilising the following input divisions:

- Group
- Category
- Format
- City
- Add-ons
- Link type
- Status

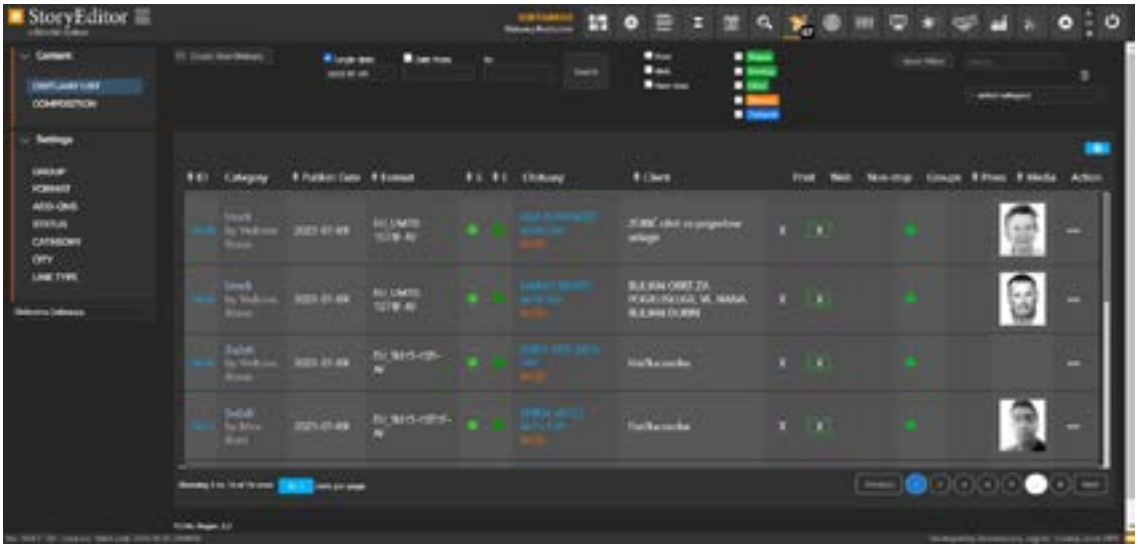

Figure 1: Layout of the Obituaries Panel

Group– Division based on primary columns (width and ongoing advertisements). The fundamental element of this type of announcement is a column of a specific width, which is filled as advertisements are received (continuous flow/AutoFlow). A column with double width (medium), along with a frame, requires a specialised payment system and position determination due to the selection of the frame and advertisement layout.
Format– Advertisement space formats (Figure 2) serve not only to define the size of the advertisement based on input but also to enable the application to export entries later in XML format [9] for layout processing in graphic applications. Each emblem has its format defined by these settings, which also apply to photographs. Therefore, for formats featuring photographs, emblems, or without emblems, numerous distinct formats are required. These formats subsequently appear in menus from which employees select options according to customer preferences.

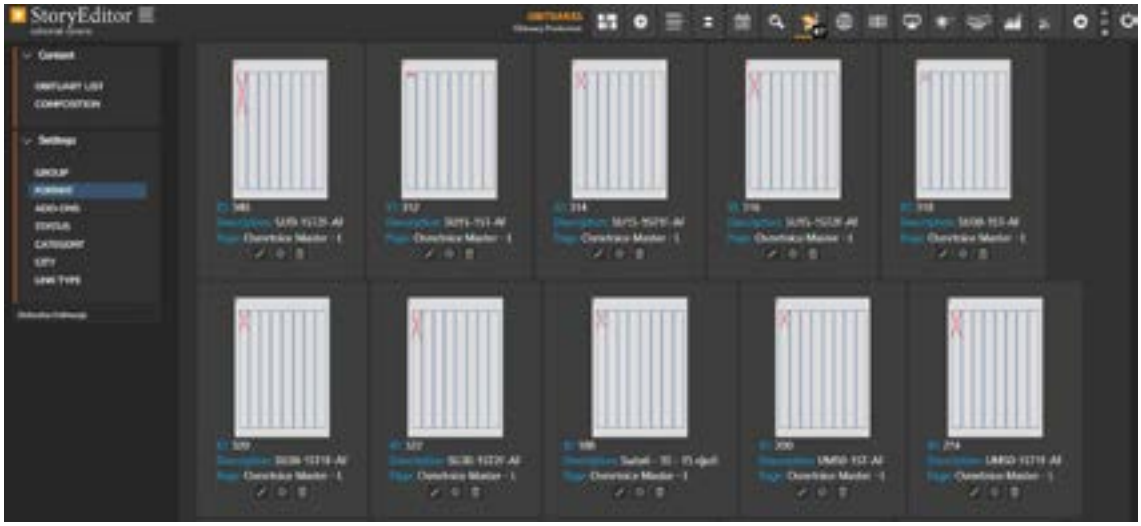

Figure 2: Advertisement Space Formats

Add-ons – The feature formats accompany all types of advertisement dimension widths.

It is also important to emphasise that for each feature format, there is a connection to column formats. The widths of the features are created in the graphic application "InDesign," into which the final advertisement is exported at the end of the workflow. The naming of features is designated by the type of semiotic marker, width (AF, 2ST, 3ST), length ranging from 5 to 15 cm, and paid formats from 1/18 to 1/1 page size. Figure 3 illustrates one type of feature, the semiotic marker.

Figure 3: Formati obilježja i vrste semiozoma (semiotika)

Status – These notifications serve to indicate the current state of the advertisement within the process. The statuses include creation (entry), entry of web advertisements (for online advertising only), finalisation of advertisement creation, and the initiation of the payment process within the system. The colour and appearance of statuses are illustrated in Figure 4.

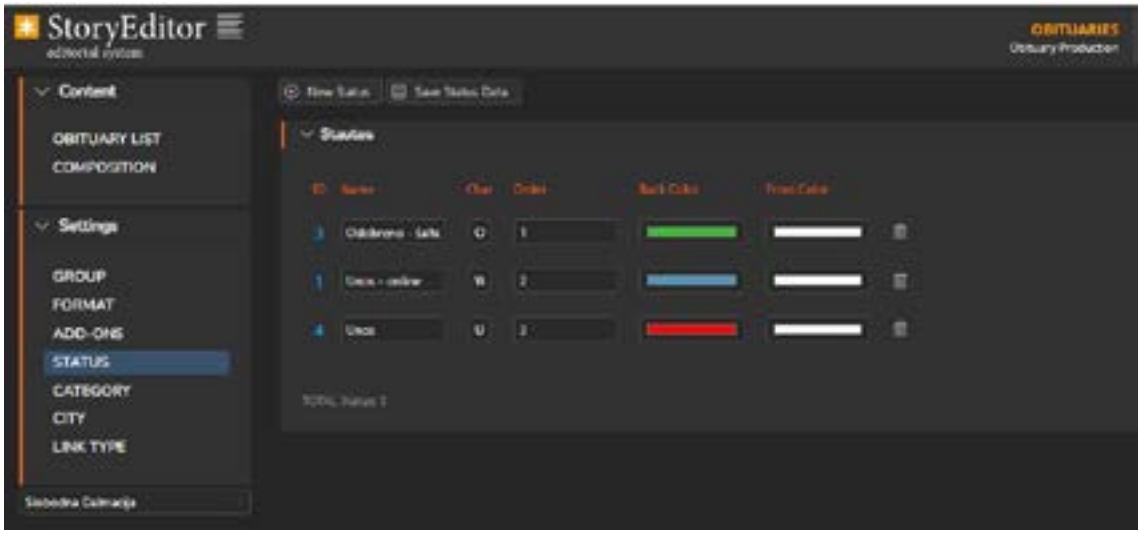

Figure 4: Feature Formats and Types of Semiotic Markers (Semiotics)

Category – The primary division of advertisement space (Figure 5) includes Notices of death / deceased individuals, Condolences, Expressions of gratitude, and Remembrances.

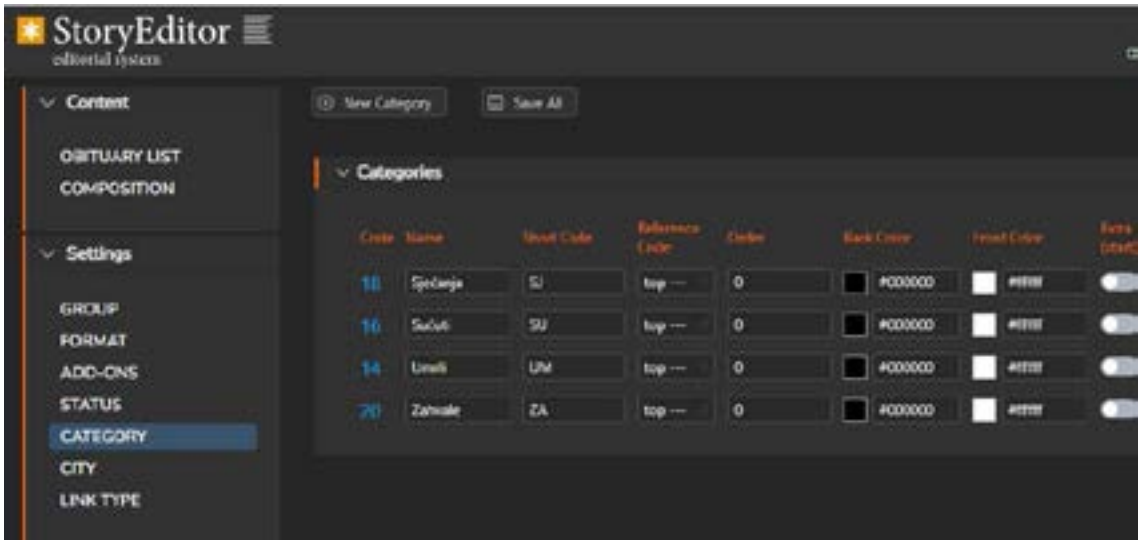

Figure 5: Categories of Offerings within this Advertisement Segment

City – The "City" column (cities), shown in Figure 6, includes not only city names but also systematically retrieved geographical latitudes and longitudes. These data are intended to facilitate, in addition to the advertisement segment, future interactivity on digital maps to indicate sales locations across the country.

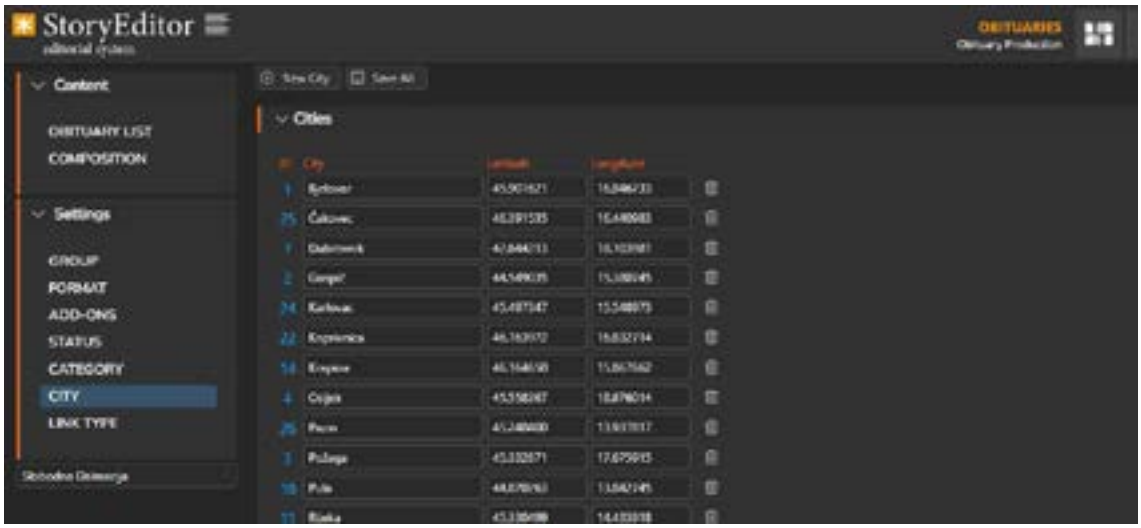

Figure 6: Panel Displaying the Entry of Location Coordinates for Cities

To enable the addition of events, particularly in the tourism sector, these locations are essential. They provide precise location services through digital maps. These locations are exclusively created via manual input. Current solutions such as Google Maps, Bing Maps, Nokia Maps, etc., do not offer sufficient precision due to the nature of handling vast amounts of data and the extended time required for data modification, often resulting in inaccurately marked object locations (e.g., location adjustments within less than 30 metres of a sales point). Manual entry and modification of geographical locations, in coordination and agreement with the respective partner, has proven to be the most effective solution.

Link type – Extensions related to future services for commercial advertisements offered alongside online solutions.

1.2. CRM Module

The "CRM" module enables the entry of all necessary data for creating invoices, orders, and offers. Within its settings, items for cost centres are defined, specifying the department responsible for preparing offers—in this case, the obituaries department. Additionally, it allows for the input of company details, including their VAT identification numbers (OIB), tax obligations, and the printing of JIR and ZIR tax invoice numbers. The module provides options for determining price ranges based on advertisement size, as well as the possibility of subsequent additions or surcharges to offers.
The display of entries for companies and agencies collaborating with the department facilitates the monitoring and control of each order item for individual companies through the order history linked to an ID number.
Figure 7 illustrates the module and an example of creating an obituary with multiple photographs from the offer. The figure shows the structure of required information inputs, including the publication in which the advertisement will appear, the required format, advertisement category, publication and end dates, names of the deceased, selection of web or print editions, column information markers, frames, or "medium" advertisement formats.
After data entry and offer preparation, a preview of the future advertisement is created for the client—in this case, a remembrance of the deceased. The system is programmed to accommodate one or more photographs by selecting an emblem at the top of the advertisement and arranging names or dates at the bottom of the photograph. This is made possible by a flexible XML [10] (eXtensible Markup Language) solution.
Once the client approves the proposed advertisement layout, a final invoice is generated containing all necessary elements: publisher details, quantity, tax base, invoice number, issuer's name, and an associated QR code. The invoice is then forwarded for entry into the layout preparation programme.

Figure 7: Final Layout of an Entered Obituary with Two Images and an Emblem

2. EXPERIMENTAL PART

For the purpose of assessing customer satisfaction with the quality of external services, a survey was conducted. It involved 43 satisfied clients who evaluated the quality of service provided by the Obituaries department.

The survey was based on the relationship between the client and the quality of the offer, specifically focusing on the modules and their functionalities directly related to the client's selection of services and purchase satisfaction. The modules supporting this process are the "Obituaries" and "CRM" modules.

The sample of respondents was drawn from four counties: Split-Dalmatia County, Zadar County, Dubrovnik-Neretva County, and Zagreb County. The age range of respondents spanned from 18 to 78 years, including both men and women.

3. RESULTS

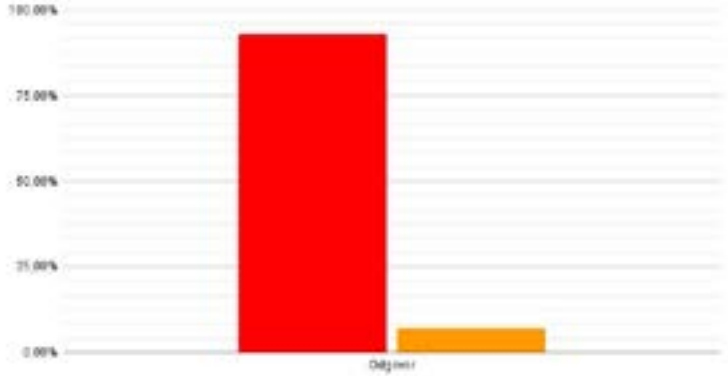

Figure 8: Responses to the Question: Do You Consider It Important to Publish a Death Notice for a Deceased Family Member in Public Media?

The diagram (Figure 8) reveals a significant disparity: 97% of clients expressed support for publishing such notices, while only 7% were opposed. This result highlights a traditional approach to this form of advertising but also reflects a conservative attitude towards the subject, which may influence the final outcome. The respondents were predominantly of Dalmatian origin, with various occupations across Croatia.

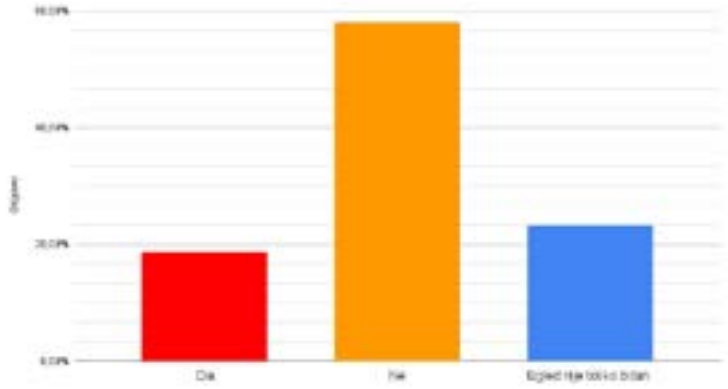

Figure 9: Responses to the Question: Would You Change the Design of Obituaries in the Print Edition of Slobodna Dalmacija?

The second question addressed the design of obituaries, as shown in the diagram (Figure 9), examining its influence on service selection and whether clients desire changes to the long-standing design. In response, 18.6% of respondents expressed a positive opinion regarding changes to the design, 58.1% supported maintaining the traditional design, while 23.3% considered the appearance of such notices less important compared to their content or message.

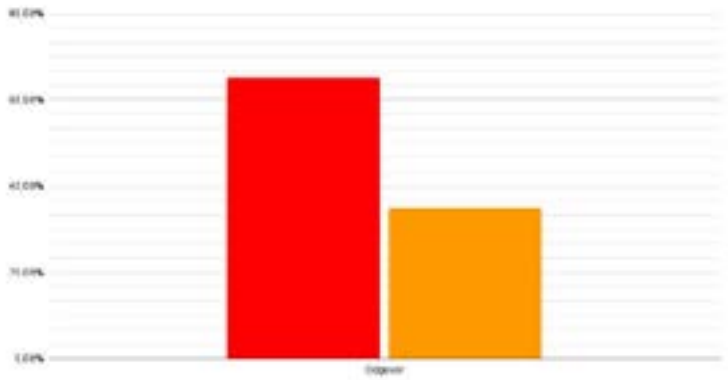

Figure 10: Responses to the Question: Do You Consider It Important to Supplement a Death Notice with a Photograph of the Deceased?

The subsequent question, visible in the diagram (Figure 10), also pertains to the announcement itself but focuses on the design concept of obituaries where a photograph of the deceased is included. It examines whether clients consider such supplementation with a photograph to be informative. Most respondents, 65.1%, indicated that they do, while 34.9% stated that it is not as important as the announcement itself.

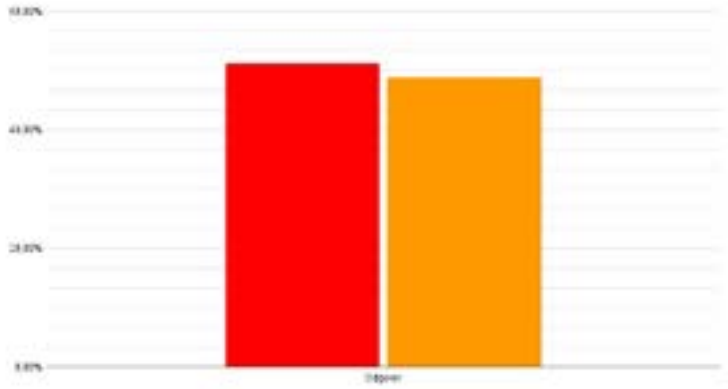

Figure 11: Responses to the Question: Do You Believe It Is Sufficient to Include Only the Name, Surname, and Date of Death in a Death Notice?

The next question, concerning the necessity of additional information in death notices beyond the basic announcement of death, is illustrated in the diagram (Figure 11). It examines whether supplementary accompanying text is needed. A narrow margin was observed, with 51.2% of respondents expressing a positive opinion on including additional text, while 48.8% believed that such text is unnecessary.
This response may have been influenced by regional differences, as local newspapers in certain areas do not include such advertisements or additional information beyond the basic death notice. For instance, in regions such as Zagorje and Zadar, there is less adherence to the traditional practice of including supplementary text in death notices. Typically, this text may consist of a biblical excerpt (in cases of Catholic faith) or details about the place and date of burial, along with obligatory mentions of family members.

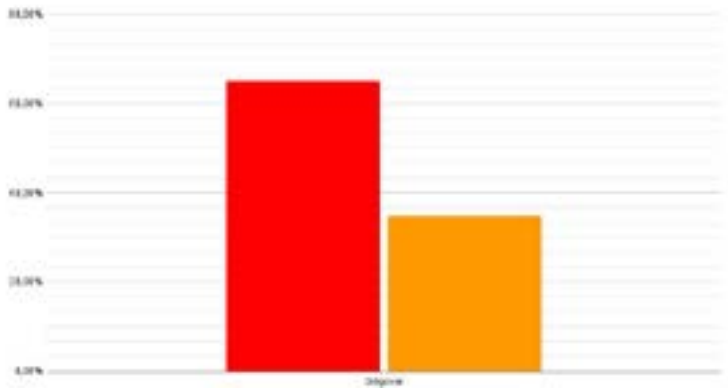

Figure 12: Responses to the Question: Do You Support a Standardised Design/Format for Death Notices as Well as Other Announcements, Such as Condolences, Remembrances, and Expressions of Gratitude?

The question regarding the design of death notices, specifically how the visual impression affects their appearance and content, is illustrated in the diagram (Figure 12). It explores whether respondents prefer only essential and concise information or would rather read more details about the deceased and their family. Such preferences do not allow for a fully standardized format for death notices, as seen in publications like Jutarnji list. Additionally, these notices require special processing and manual adjustments due to the wide range of single-column, double-column, and multi-column obituary formats.

Condolences, remembrances, and expressions of gratitude are relatively standardised in terms of text length, with only minor differences such as the inclusion of a photograph of the deceased. Respondents expressed 65.1% support for a standardised format, while 34.9% preferred a more flexible style for obituary design. This difference can also be attributed to regional affiliations.

The current modern design of the print edition organised into blocks, as well as the web-based obituary solutions in Slobodna Dalmacija, subconsciously present respondents with a block-like (rectangular or square) format that is easier to adopt, read, or browse.

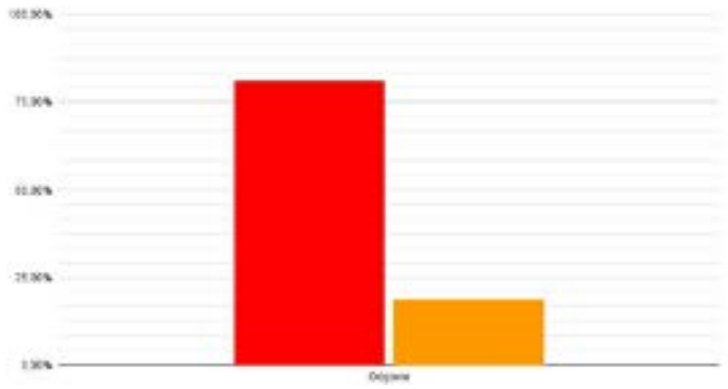

Figure 13: Responses to the Question: Do You Consider the Price of a Death Notice Advertisement Too High?

This question, which remains a relevant topic, examines how much is paid for the service and whether such advertisements are financially accessible to the general public. Respondents indicated that 81.4% consider the price of advertisements too high, while

18.6% believe the price aligns with current living costs.
The increase in living expenses influences consumer choices even for this traditional form of advertising, which can be characterised in Dalmatia as a necessity. The rising costs of energy, paper, and dyes have significantly exceeded those of previous years. This justifies an increase in advertisement pricing, not solely attributable to publisher monopolies. The diagram (Figure 13) illustrates the results of this question.

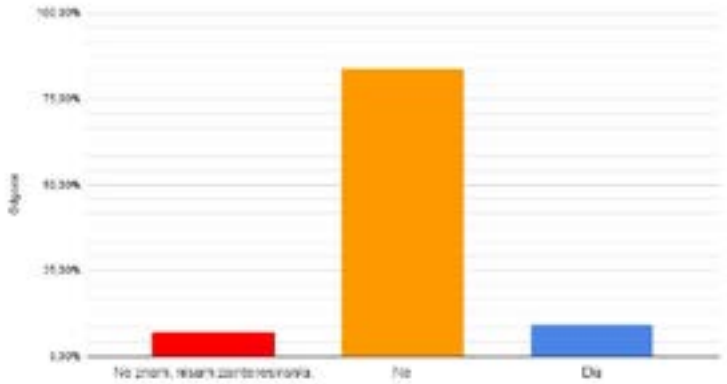

Figure 14: Responses to the Question: Do You Support Not Publishing Death Notices?

Regarding overall interest in publishing death notices, 83.7% of respondents expressed support for such publications, 9.3% were uninterested or opposed to any form of announcement, while 7% were either indifferent or uncertain about this type of advertising. From these results, it can be inferred that pricing models for advertisements may pose a barrier for certain individuals, as highlighted in the diagram (Figure 14).
The subsequent series of questions, illustrated in the diagram (Figure 15), addresses the qualitative services and client support provided by Slobodna Dalmacija as a publisher. A key factor motivating customers to choose this form of advertising is the client support offered across various service models.
When identifying errors, it is crucial—particularly in this segment—to rectify mistakes promptly. This type of advertising does not tolerate even minor errors, requiring a team of individuals involved in quality control from the receipt of the obituary to its layout and final review. Support for this segment is provided across all shifts by graphic designers during the submission of pages for printing.

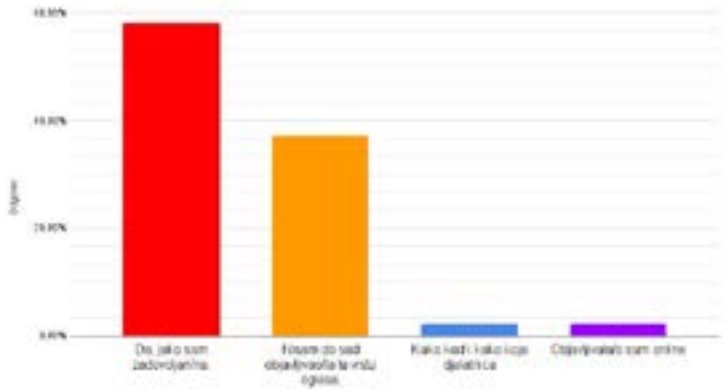

Figure 15: Responses to the Question: Are You Satisfied with the Service Provided by Employees in the "Obituaries" Department of Slobodna Dalmacija?

The question regarding respondents' satisfaction with the support provided by employees in the Slobodna Dalmacija Obituaries department revealed that 58.1% expressed satisfaction with the publication process and control through direct interaction at the counter. Meanwhile, 37% of respondents indicated they had not previously published such advertisements at the counter or had done so exclusively through agencies. Additionally, 1% of clients reported experiences with individual employees, and another 1% stated they utilised online services without direct contact with employees or corrections.
This diagram demonstrates a high level of satisfaction among clients who have previously used this type of advertisement service.

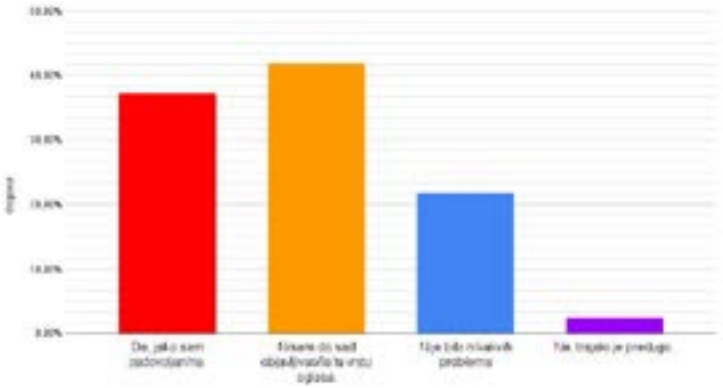

Figure 16: Responses to the Question: If an Error Occurs, Are You Satisfied with the Speed of Corrections by Employees in the Obituaries Department?

For respondents, the reaction time of employees in the event of errors—such as inaccuracies in the provided content, changes to burial times, or other essential details like family members' names—was of great importance. Such errors are not uncommon within the total number of submitted obituaries.
Respondents expressed satisfaction with the responsiveness and efficiency of employees, as shown in the diagram (Figure 16). Specifically, 37% were satisfied with direct corrections made at the counter, 41% had not published notices directly at the counter but rather through contracted agencies or online services, 21% stated that no issues arose during subsequent corrections, and 1% reported that corrections took too long without specifying reasons.
This diagram and the high percentage of satisfied clients suggest that the department is well-organised and capable of resolving most issues in communication with clients and contracted agencies across Dalmatia. The diagram also highlights a very minor percentage of dissatisfaction among clients, with no clear reasons for the problems provided. This suggests that misunderstandings may be a factor—a situation that can be tolerated given the volume of advertisements processed during working hours.
The following diagram illustrates complaints regarding online payment options for obituary advertisements (Figure 17). Respondents indicated that 1% experienced issues with payment. However, details about these problems remain unavailable due to various factors, such as communication errors between payment servers, interruptions between clients and servers, or insufficient user education. Nevertheless, 76% of respondents were satisfied with online payment outcomes, indicating a reliable and secure payment system with minimal issues. Additionally, 23% of respondents stated they had not used the online service.

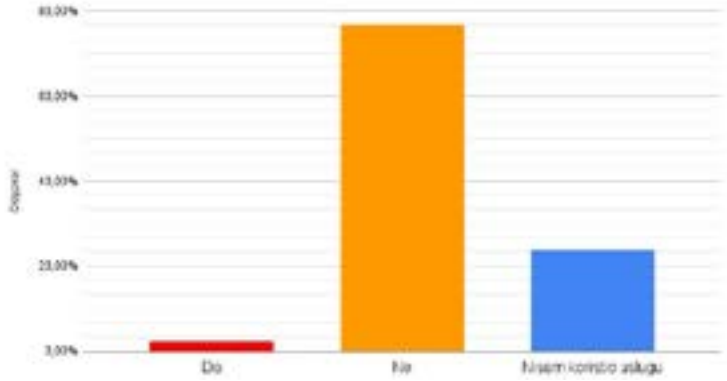

Figure 17: Responses to the Question: Do You Have Complaints About Online Payment for Death Notice Advertisement Services?

With the integration of the new "Obituaries" and "CRM" modules into the editorial system "StoryEditor," it became possible to manage not only offers and invoices in one place but also to display a formatted and finalised advertisement upon request. Previously, formatted advertisements were only visible after graphic designer intervention. This module bridges the gap between clients and graphic designers, allowing clients to immediately view the final state, make changes, if necessary, calculate word counts for pricing, and switch from single column to multi-column formats upon request, directly with an employee.

As shown in the diagram (Figure 18), 86% of respondents expressed satisfaction with the on-demand service, 1% reported dissatisfaction, and 13.7% stated they had not published advertisements at the counter. This suggests that contracted agencies sometimes act as intermediaries, handling material submission and advertisement publication without involving the client directly.

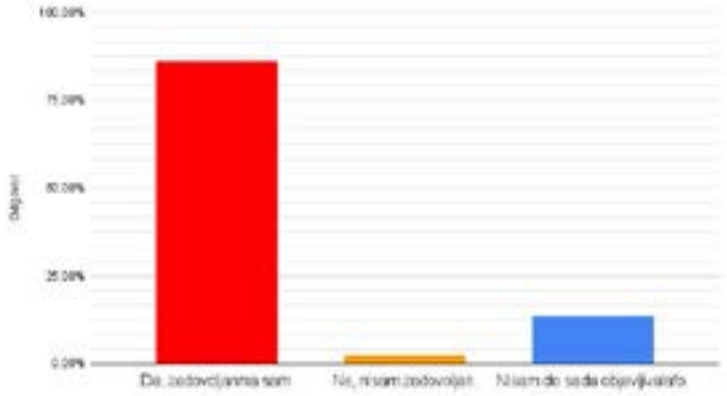

Figure 18: Responses to the Question: After Requesting an Advertisement (Death Notice, Condolences, Expressions of Gratitude, Remembrances), Are You Satisfied with the Future Obituary Design as WYSIWYG (What You See Is What You Get), Meaning What You See in the Offer Will Be Reflected in Print?

The overall rating of services provided by the Obituaries department of Slobodna Dalmacija, on a scale from 1 to 5, reflects both subjective and objective assessments of service quality. Users rated the service as excellent with a high percentage of 58.1%, very good at

32.6%, good at 7%, and poor at 2.3%.
This distribution of ratings demonstrates overall satisfaction across all service segments, including the offer process, problem resolution, employee responsiveness, minor errors, collaboration with agencies, issues related to online display and payment, and the implementation of new technologies in the workflow.
Finally, the survey proposed an evaluation of pricing aspects, as illustrated in the diagram (Figure 19), where all costs associated with death notices, condolences, expressions of gratitude, and remembrances were assessed as part of the department's offerings.

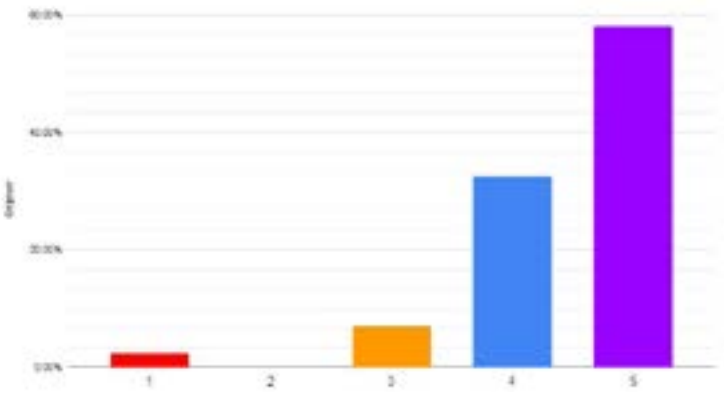

Figure 19: Answer the question: Your rating of the overall service provided

In further analysis, user satisfaction is influenced not only by the material value of the offer but also by the scalable ability to adjust costs on-site through the selection of advertisement size and the quantity of offers, allowing each client to purchase advertisement space within their financial means.
The overall rating of services provided by the Obituaries department of Slobodna Dalmacija, based on a scale from 1 to 5 and focusing on service pricing and rental costs, revealed the following distribution: 18.6% of respondents rated the service as 1, sufficient ratings (2) were also at 18.6%, good ratings (3) accounted for 34.9%, very good ratings (4) were at 18.6%, and excellent ratings (5) were given by 9.3% of respondents.
A subjective approach was applied to this evaluation due to a range of factors that cannot be easily organised into a table. Factors affecting cost evaluations include the clients' financial circumstances, as seen in columns with ratings of 1 and 2, which show minor support for perceived cost levels, as well as residence outside the Dalmatian region. Clients may not be aware of the actual business costs involved, which can increase negativity during evaluations.
The column with a rating of 3 reflects a realistic perspective in which clients recognised the value of advertisements despite their cost, with 34.9% showing appreciation for the service provided. The analysis of rating 4, in contrast to ratings 1 and 2, demonstrates an opposite trend where respondents acknowledged the balance between real advertising costs and rental expenses for advertisement space. Finally, respondents who rated the service as 5 were those with longer-term experience in this type of advertising. These respondents predominantly come from Dalmatian regions, where traditional values are deeply rooted, and they understand the significance of this form of advertising.
One notable factor is the value of online visibility for this type of advertisement, which allows relatives abroad to learn about their loved ones' circumstances through such notices—an important consideration given that over two million Dalmatian expatriates are scattered across the globe.

The overall survey analysis, illustrated in the diagram (Figure 20), demonstrated a positive attitude towards all services related to this type of advertising provided by Slobodna Dalmacija. This trend continues steadily alongside secure and high-quality advancements across all service areas.

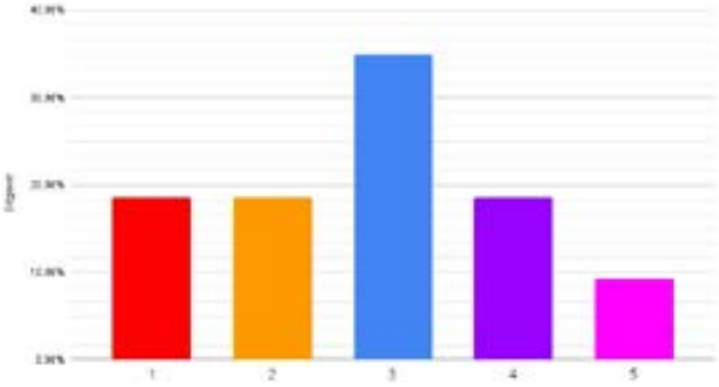

Figure 20: Responses to the Question: Your Rating of the Cost of Advertising Services

4. CONCLUSION

With the development of StoryEditor, particularly its Advertisement and Obituaries modules, combined with experience and new technologies, it has become possible to create fully formatted obituaries based on the WYSIWYG (What You See Is What You Get) principle for end users. This module resolves longstanding issues related to integrating multiple applications that process text input, photographs, export to file systems via XML-structured data, and pricing model/space calculations through a third application. Its implementation eliminates subscription rights and usage fees for these applications, contributing to significant cost savings.

Today, Slobodna Dalmacija is the leading daily newspaper in terms of the number of obituaries published daily. Consequently, a substantial portion of the newspaper's revenue originates from this segment, making client satisfaction crucial.

The overall results in the obituary sales segment, as outlined in the survey, demonstrate that these new modules offer users speed, the ability to modify advertisements on-site, selection of pricing models based on individual financial capacities, and a negligible amount of negative feedback, as evidenced by the findings.

A particularly positive response was noted across surveyed regions (Split-Dalmatia County, Zadar County, Dubrovnik-Neretva County, and Zagreb County), where users identified their preferred obituary display model. However, one aspect remains universally agreed upon: the quality of offerings and customer support in resolving errors are decisive factors in choosing this type of advertising and the target company.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

REDESIGN OF THE VISUAL IDENTITY OF SECOND-HAND CLOTHING STORE CHAINS

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ABSTRACT

Visual identity is a crucial aspect of corporate branding. Effective visual identity systems enhance a company's identity by reinforcing desired perceptions while bringing customers closer to the brand's characteristics. A well-developed brand personality helps establish an emotional connection with customers. When a brand exhibits traits that resonate with its target audience, it can evoke feelings of credibility and affiliation. By analysing the current visual identity design of Textile House and the results of conducted research, insights into customer perceptions of the store will be formed. Considering the opinions of research participants, a redesign has been developed that best aligns with existing customers while attracting new ones. Following the redesign, a new survey was conducted to measure the success of the new design in terms of both its aesthetic function and its emotional impact on customers.

Keywords: visual identity, branding, logo, typography, visual element

1. INTRODUCTION

Each individual is characterized by a set of attributes that make them authentic and recognizable to people and society as a whole. Developing and defining identity gives human beings a sense of belonging and purpose in their social environment. Identity and ownership are useful because people consider their identities when making decisions; thus, these identities are situated, pragmatic, and aligned with the possibilities and limitations of the immediate context. [1] Having a strongly defined identity is also essential for companies and product brands. A well-developed visual identity should be a priority in every business strategy because its primary task is to create an image of the brand among consumers. Many company choices are made with low involvement and minimal information processing, largely influenced by brand awareness, image, and/or the overall reputation of the company selling the products. [2]

Brand identity includes defining the purpose or greater reason why the brand exists and what its mission is. Branding is understood as a comprehensive process of defining, creating, and establishing a unique identity for a product, service, or company. Corporate identity, in addition to the organization's stance, behaviour, and communication with the environment, constitutes one of the essential pillars of an institution's identity [3]. A strong brand identity will help build brand value by increasing customer recognition, awareness, and loyalty, which in turn helps the company be more successful. [4] Brand strategy is one of the most demanding areas of marketing, but also one of the most important. It is a complex framework that includes strategic methodologies and thoughtful moves that harmoniously combine the company's values, aspirations, market insights, and competitive positioning. The main goal of branding strategy can be achieved by correctly understanding product characteristics. [5] The operation and successful execution of strategy tasks will bring greater connection with clients and improve brand perception in the market. [6] Brand architecture determines the scope and depth of the brand, offering clarity on how products/services are organized and how consumers perceive them. Furthermore,

it influences consumer behaviour by optimizing the transfer of credibility between different brands and their sub-brands. [7] Positioning is the most important phase in brand asset management strategy. Brand positioning is the process of creating a unique image, distinctive features, positive associations, and values in the minds of consumers to create a sustainable brand image and ensure consumer loyalty to the brand. [8] It should also be noted that a brand with a recognizable narrative has greater value both symbolically and concretely. [9]

Visual elements in design are fundamental components that designers use to create convincing and effective visual compositions especially colours. These elements play a crucial role in conveying information, directing the audience's focus, and evoking emotions. [10, 11] Key visual elements in design include logos, colour palettes, typography, shapes, and space (or its absence). [12] A logo is a symbol, a graphic and visual sign that plays a vital role in the company's communication structure. The logo functions as the most critical quality in the promotional environment, enabling companies to differentiate themselves. Creating a logo is not an event but a result of very precise analyses of geometric shapes, colours, various signs, and symbols, all blended into a harmonious mixture that is forced to "catch" and become part of people's consciousness. [13] A logo must have certain properties to be effective: simplicity, relevance, recognizability, memorability, adaptability, reproducibility, readability, and coherence. [14] Typography is a crucial element of graphic design as it expresses feelings, conveys meanings, creates contrast, highlights ideas, and adds visual interest to the content being designed. [15] The three main elements—typeface, spacing, and arrangement—are included in the concept of typography. [16]

1.1. Visual Identity of Textile House

The visual identity of Textile House lies in its recognizable logo, slogan, and primarily colours and typography, which extend virtually through social media and in stores, creating visual support for the identity through posters and clothing labels. The logo consists of flat compositions, a circle that is the starting point of the design, and a rectangle that emphasizes the brand name (Figure 1). The used typography is simple and sans-serif, with bold weight in the upper part of the solution and regular weight in the lower part of the text, where the purpose of the brand is described. The most striking part and the part by which they are recognizable is the leading colour of the logo. Vibrant, energetic red displays the primary red colour in the RGB system (255,0,0) and extends from the colour of the surface to the colour in typography. The logo predominantly features the principle of contrast in colour value, as well as line thickness, creating a strong and striking logo.

Figure 1: Textile House Logo

2. EXPERIMENTAL PART

In the experimental part, the goals of the redesign will be set, as well as two hypotheses that will be confirmed or refuted using surveys. The hypotheses are as follows: The existing visual identity does not communicate the company's message effectively; current customers want a change and the identity does not attract enough new customers. A more modern design suitable for the target group works better with existing customers, but also attracts new customers. The first survey is conducted to bring the customer closer to the store and determine the stance and emotions of customers towards Textile House. Using the results from the first survey, a redesign will be conducted based on the responses received, where a subsequent survey will determine the credibility of the two hypotheses and the success of the redesign. The survey, conducted through Google Forms, included 25 respondents. Respondents are divided into two groups: existing customers and potential new customers of Textile House. The first survey consisted of 18 questions, while the second survey after the redesign consisted of 16 carefully selected questions that largely introduce the feelings and opinions of current and future Textile House customers.

3. RESULTS

3.1. Results of the First Survey

The questionnaire was completed by 25 people, of whom 68%, or 17 participants, were of younger age (18-25 years), 28% or 7 respondents were of middle age (26-35 years), and 4%, or one respondent, was under 18 years old. The most represented respondents had high professional qualifications (36%, 9 people), while others included higher professional qualifications (24%, 6 people), medium professional qualifications (16%, 4 people), students (12%, 3 people), and master's/doctoral degrees (12%, 3 people). The largest portion of respondents, 36% or 9 people, do not visit Textile House. Another 10 people, 20% and 20%, visit Textile House once a month or once a year. Twelve percent of respondents visit Textile House once a week, while 8% or two people visit Textile House once a year or, conversely, as 4% or one respondent visits daily. When asked how important visual identity is to them when choosing a second-hand store (Figure 3), 36% of respondents replied that visual identity is important. Twenty-eight percent of respondents said it has medium importance, while another 28% expressed that visual identity is very important. Only 8% of respondents claimed that visual identity is not important when choosing a logo. None of the respondents thought that visual identity was less important when choosing a store.

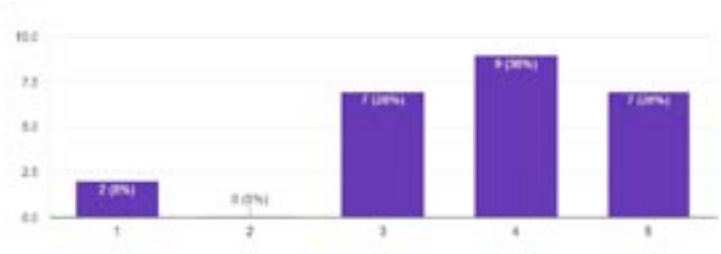

Figure 3: Response to the question: On a scale of 1-5, how important is visual identity (especially the logo) when choosing a second-hand store?

When respondents were shown the current Textile House logo (Figure 2) and asked to rate its visual appeal on a scale of 1-10 (Figure 4). A score of 1 represents no attractiveness at all, a score of 2 represents no attractiveness, a score of 3 represents quite a bit of

unattractiveness, a score of 4 represents a little unattractiveness, a score of 5 represents neither attractive nor unattractive. A score of 6 represents a little attractiveness, a score of 7 represents attractiveness, a score of 8 represents higher attractiveness, a score of 9 represents very attractiveness, while a score of 10 represents an extremely attractive logo. A large majority, 52% of respondents, stated that the current logo is not at all appealing and rated it with a 1. A rating of 2 was given by another 32% of respondents, as well as ratings of 3 and 4, which were given by 4% of respondents each. Ratings above 5, specifically 6 and 8, were given by 4% of total respondents each.

Figure 4: Response to the question: On a scale of 1-10, how visually appealing is the logo?

When asked to rate the logo as traditional or modern on a scale of 1-5, where 1 represents traditional, 2 represents slightly traditional, 3 represents neither traditional nor modern, 4 represents slightly modern, and 5 represents modern (Figure 5), a total of 36% of respondents rated the Textile House logo as traditional with a rating of 1. A rating of 2 was given by 32% of respondents. For a rating of 3, stating that the logo is neither traditional nor modern, 24% of respondents agreed, and 8% of respondents considered the logo more modern than traditional.

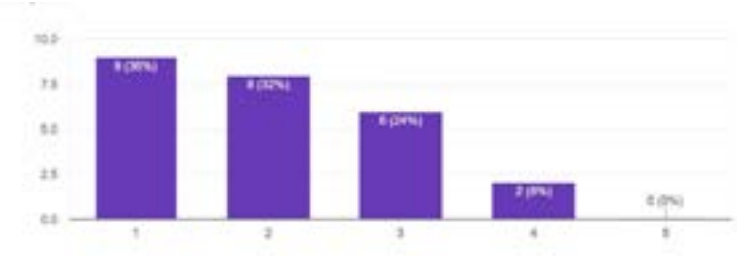

Figure 5: Response to the question: On a scale of 1-5, do you consider the logo traditional or modern?

Similarly, when asked to rate the logo as ordinary or impressive on a scale of 1-5, where a rating of 1 represents ordinariness, 2 represents slight ordinariness, 3 represents neither ordinary nor impressive, 4 represents slightly impressive, and 5 represents an impressive logo (Figure 6), a large majority, 64% of respondents, considered the logo ordinary and gave a rating of 1. A rating of 2 was given by the remaining 32%, with only 4% of respondents rating the logo as slightly impressive.

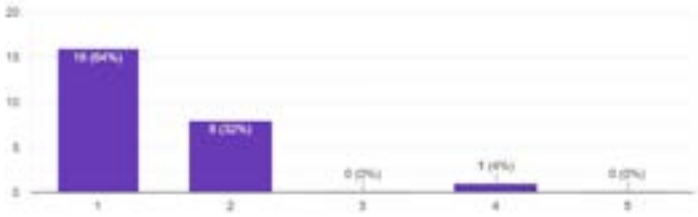

Figure 6: Response to the question: On a scale of 1-5, do you consider the logo ordinary or impressive?

When asked if they liked the colour of the logo, a large majority, 84% or 21 respondents, replied that they did not like the colour, while only 16% or 4 people responded positively to the colour of the logo (Figure 7). Similarly, when asked the same question about typography, 72% or 18 respondents replied negatively about the font in the logo, while only 28% or 7 respondents liked the typography used in the logo (Figure 8).

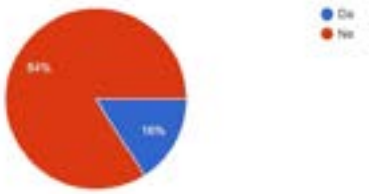

Figure 7: Response to the question: Do you like the colour in the logo?

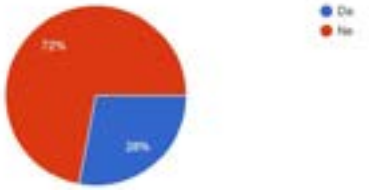

Figure 8: Response to the question: Do you like the typography (font) in the logo?

A large majority, 52% or 13 respondents, considered the logo unrecognizable, while 48% or 12 respondents recognized the logo. Also, when asked what makes the logo recognizable, the most common answer was the colour, which accounted for 72% of responses. Regarding what respondents liked about the logo, the most common answer was “nothing” with 28% or 7 respondents, while the rest of the respondent’s mentioned simplicity and strikingness of the letters. When asked a similar question about what they did not like about the logo, the answers varied from a lack of creativity and interest in the logo to colour, typography, and composition. Many respondents also highlighted the brightness of the red colour as a negative aspect of the logo. When asked to estimate which age group the logo relates to (Figure 9), a large majority believed that the logo relates to people over 50 years old (60%, 15 respondents), while other responses included 35-50 years old (32%, 8 respondents) and 25-35 and 18-25 with equal 4% or one respondent each

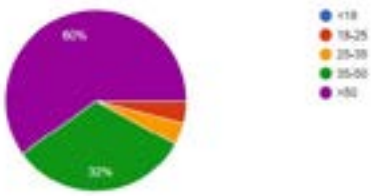

Figure 9: Response to the question: Based solely on the logo's appearance, which age group do you think it relates to?

A large majority, 60% of respondents, believe that the logo relates to people over 50 years old, while other responses included 35-50 years old (32%, 8 respondents) and 25-35 and 18-25 with equal 4% or one respondent each (Figure 10)

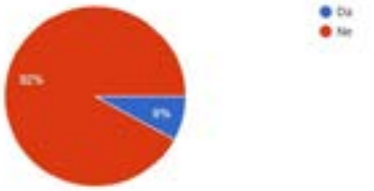

Figure 10: Response to the question: Based solely on the logo's appearance, would you like to shop at this store?

Surprisingly, a large majority of 92% or 23 respondents would not shop at the store based on the logo's appearance, while only 8% or 2 respondents would continue to shop there (Figure 11). A surprising number of respondents (92% or 23 people) believe that a redesign of Textile House's visual identity would positively affect their shopping experience. Also, 92% of respondents believe they would shop at Textile House more frequently if a redesign of the visual identity were implemented. (Figure 12). On the question of whether a redesign of the visual identity would attract new customers, 100% of respondents answered positively (Figure 13).

Figure 11: Response to the question: Do you think a redesign of Textile House's visual identity (logo, posters, labels) would positively affect your shopping experience?

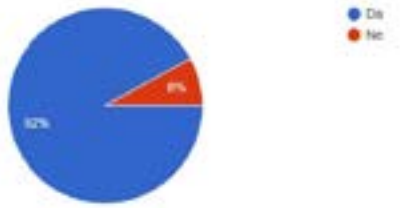

Figure 12: Response to the question: Do you think a redesign of Textile House's visual identity (logo, posters, labels) would make you shop there more frequently?

Figure 13: Response to the question: Do you think a redesign of Textile House's visual identity (logo, posters, labels) would attract new customers?

The survey results confirm the hypothesis that the existing visual identity does not match the company's image. Customers are eager for change and believe that a redesign would positively affect their shopping experience and increase the frequency of purchases but would definitely attract new customers as well. In the redesign process, the responses from the survey will be considered, replacing aspects that customers dislike while retaining those they like.

Based on the analysed survey results and the guidelines derived from it, the visual identity of Textile House was redesigned. The logo was created using a combination of typography and symbols. The symbol in the logo represents houses in a row hung from a clothes hanger, playing on the abstraction of the store's name (Figure 14). The symbol is executed in a line style with thicker weight that aesthetically matches the thickness of the used typography. In terms of typography, it is important to mention the connection between the letter's "t" and "h," which create a continuous line, serving both an aesthetic function and a symbolic representation indicating strong foundations, stability, and strength. For primary typography, Nordlig Regular was chosen, and for secondary typography, Engravers Gothic Regular, a simple sans-serif font. When selecting the main colours for the visual identity, the existing colours were retained: red (RGB (62, 62, 63)), black (RGB (174, 32, 39)), and white (RGB (251, 248, 237)).

Figure 14: Final Textile House Logo

3.2. Results of the Second Survey and Discussion

The questionnaire was completed by the same respondents who completed the first survey to maintain consistent responses. The questionnaire was completed by 25 people.
On the question of how attractive the new logo is on a scale of 1-10, a rating of 1 represents no attractiveness, a rating of 2 represents unattractiveness, a rating of 3 represents moderate unattractiveness, a rating of 4 indicates slight unattractiveness, and a rating of 5 indicates neither attractive nor unattractive. A rating of 6 represents slight attractiveness, a rating of 7 indicates attractiveness, a rating of 8 represents higher attractiveness, a rating of 9 indicates great attractiveness, and a rating of 10 indicates an exceptionally attractive logo (Figure 15). A total of 56% or 14 respondents rated the new logo as attractive.

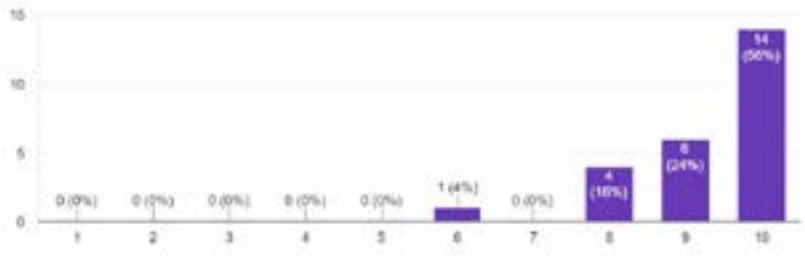

Figure 15: Response to the question: On a scale of 0-10, how visually attractive is the logo?

When respondents were shown the logo and asked to categorize it as traditional or modern on a scale of 1-5, where 1 represents traditional, 2 represents slightly traditional, 3 represents neither traditional nor modern, 4 represents slightly modern, and 5 represents modern, 40% or 10 respondents considered the logo very modern with a rating of 5, 36% or 9 respondents considered it moderately modern with a rating of 4, and 24% or 6 respondents considered it between traditional and modern with a rating of 3.
Similarly, when asked to categorize the logo as ordinary or impressive on a scale of 1-5, where a rating of 1 represents ordinariness, 2 represents slight ordinariness, 3 represents neither ordinary nor impressive, 4 represents slightly impressive, and 5 represents an impressive logo, 76% or 19 respondents considered the logo very impressive with a rating of 5, 20% or 5 respondents considered it moderately impressive with a rating of 4, and

4% or 1 respondent gave the logo a rating of 3, indicating it was between impressive and ordinary.
On the question of whether they liked the colour of the new logo, a surprising 96% or 24 respondents voted positively for the colour, while only 4% or 1 respondent did not like the new colour (Figure 16). Similarly, on the question of typography, identical responses were obtained; 96% of respondents liked the typography, while 4% did not like the new typography (Figure 17).

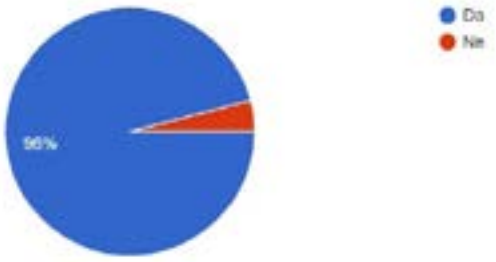

Figure 16: Response to the question: Do you like the color in the logo?

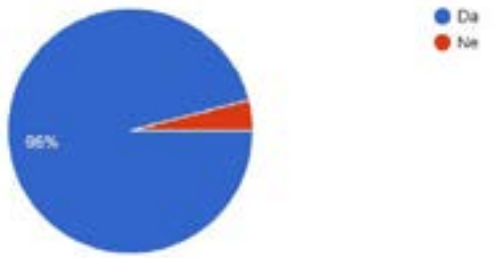

Figure 17: Response to the question: Do you like the typography (font) in the logo?

When respondents were asked what they liked about the logo, the most common response was the color and creativity of the design, followed by typography.
On the question of what they did not like about the logo, 4% or one respondent voted for the seriousness of the logo and typography, while another 4% of respondents voted for the color. The remaining 92% or 24 respondents stated that they liked everything about the logo.
When asked to estimate which age group the logo relates to (Figure 18), 60% or 15 respondents voted for the middle age group of 25 to 35 years, 24% or 6 respondents voted for the age group of 18 to 25 years, and 16% or 4 respondents voted for the age group of 35 to 50 years.

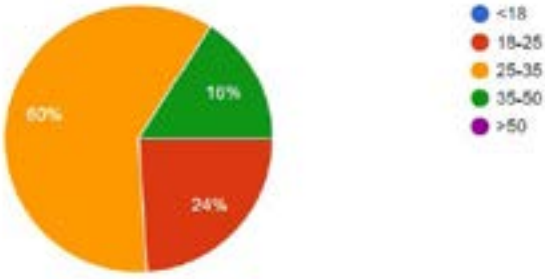

Figure 18: Response to the question: Based solely on the logo's appearance, which age group do you think it relates to?

On the question "Based solely on the logo's appearance, would you like to shop at this store?" (Figure 19), a surprising majority of 96% or 24 respondents would like to shop at the store, while 4% or one respondent would not want to shop there regardless of the redesign.

Figure 19: Response to the question: Based solely on the logo's appearance, would you like to shop at this store?

In the subsequent questions, both logos of Textile House were presented: the current logo and the redesigned logo. When respondents were asked to choose the more attractive logo, a surprising 100% of respondents chose the redesigned logo (Figure 20). Additionally, on the question of which logo would have a more positive impact on their purchases at Textile House, 100% of respondents again answered with the redesigned logo (Figure 21). The redesigned logo would also encourage customers to shop more frequently at Textile House, with 100% of respondents (Figure 22). On the final comparison question, which logo would attract new customers, a surprising 100% of respondents again answered with the redesigned logo (Figure 23).

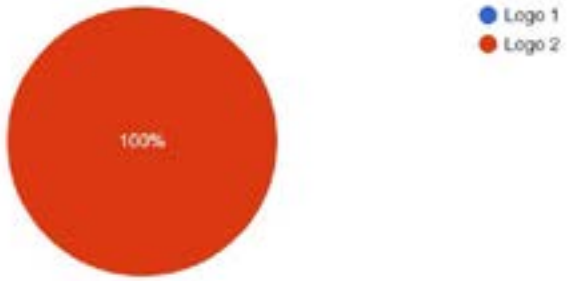

Figure 20: Response to the question: Which logo is more visually appealing to you?

Figure 21: Response to the question: Which logo would have a positive impact on your purchases?

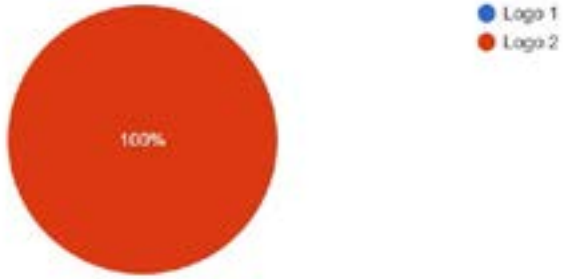

Figure 22: Response to the question: Which logo would encourage you to shop more frequently at Textile House?

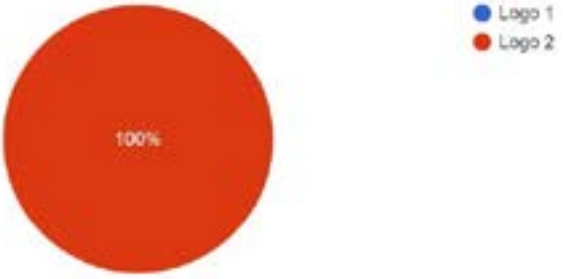

Figure 23: Response to the question: Which logo would attract more new customers?

4. CONCLUSION

Strong branding and a consistent, well-developed visual identity are essential for every company. By using consistent visual elements during the redesign process, associations and positive opinions about the company were created among customers. The new visual identity of Textile House is significantly more acceptable on the market than the current design. Additionally, the new visual identity attracts new customers, while encouraging existing ones to shop more frequently. As mentioned, companies today are as strong as their visual identity and the messages they convey through it.

The existing logo, typography, posters, and labels do not effectively communicate their values, do not adequately connect with customers, and do not establish a strong brand presence in the market. Visual identity is often the first thing people notice about a brand. If visual elements are unattractive or poorly designed, they can create a negative first im-

pression, potentially deterring potential customers or clients. Moreover, a poorly designed visual identity can convey a lack of professionalism. This can lead people to question the quality of products or services, making it difficult to build public trust.
During the redesign, credibility, consistency, and first impressions were considered. Consistent visual branding helps establish brand recognition, promoting consistency and credibility. A professional and cohesive visual identity instils trust and credibility in the minds of consumers. When a brand appears polished and well-presented, it signals to customers that the company is reliable and committed to quality. Visual elements have the power to evoke emotions and connect with the target audience on a deeper level. Colours, images, and design choices can convey the personality and values of a brand, fostering a strong emotional connection with customers.
When designing a logo for a second-hand shop, it is essential to prioritize simplicity, clarity, and relevance to the target audience. Particular attention should be given to the choice of color and typography, as these elements had the strongest influence on perception and acceptance of the redesigned logo among respondents. The logo should be distinctive, emotionally appealing, and tailored to a younger demographic, thereby increasing the likelihood of attracting new customers and strengthening the loyalty of existing ones.
For future research, it is recommended to include a larger and more diverse sample of participants and to monitor the long-term impact of visual identity on customer behavior and business outcomes. It would also be valuable to explore how different visual elements of a logo affect perceptions of sustainability and environmental awareness, which are increasingly important in the second-hand retail sector.
The area of visual branding goes beyond the surface level of aesthetics, developing into a key strategic tool that shapes perceptions, builds connections, and fosters trust. This is an investment that pays off in the form of a resilient and influential brand, positioning the company for sustainable success in a crowded market.

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

TESTING THE EFFICIENCY OF ECOFONTS IN REDUCING TONER CONSUMPTION AND IMPROVING ENVIRONMENTAL PERFORMANCE

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ABSTRACT

Sustainable development presents advantages from both an environmental and economic perspective. Modern society relies significantly on printed graphic products, so the graphic industry plays an important role in terms of its environmental impact. Although typography is a relatively small factor, it is desirable to examine every part of the process to potentially achieve greater efficiency. Ecofonts are an interesting innovation that potentially allows for reduced toner consumption without sacrificing readability. The aim of this research was to examine the effectiveness of ecofonts compared to conventional fonts in terms of toner consumption to determine the potential benefits of using such fonts. The results showed that significant savings in toner consumption can be achieved by using ecofonts.

Keywords: ecofont, typography, sustainability.

1. INTRODUCTION

Ecofont is a specially designed font aimed at achieving better economic and environmental efficiency compared to a conventional (regular) font. Eco font is intended to use less ink/toner during printing without compromising readability. This is achieved by incorporating empty spaces (holes or lines) within the characters, unlike conventional fonts [1]. These empty spaces should not be clearly visible on print at smaller font sizes due to the interaction between ink/toner and paper, which theoretically reduces the size of the empty spaces, making them less noticeable.
An ecofont can either be originally conceived and designed as a new, more eco-efficient font or an existing conventional font can be modified to create empty spaces within the characters, thus transforming it into an ecofont. Figure 1 shows a comparison between a conventional font and an ecofont. As observed, two principles regarding empty space are used, one with holes and the other with lines.

Figure 1: Comparison of the conventional font Bitstream Vera Sans (left) with two ecofonts: Ecofont Vera Sans with dots (center) and Ryman Eco with lines (right).

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When searching online, two ecofonts are likely to stand out the most: Ecofont Vera Sans and Ryman Eco. The first is based on modifying an existing conventional font into an ecofont, while the second was designed as a completely new ecofont, with no official counterpart in a conventional font. Ecofont Vera Sans is a sans-serif font designed by the Dutch agency Spranq. It is essentially a modified version of Bitstream Vera Sans, differing from the original only in that its characters contain empty spaces (holes). Spranq claims that using the ecofont should result in approximately 20% ink/toner savings compared to the original font, depending on the font size [2]. This font is also usable in Croatia, as it includes diacritical characters (č, ć, đ, š, ž). However, closer look revealed that the letter "đ" (both uppercase and lowercase) does not contain empty spaces like the other characters, meaning there is no difference in ink/toner consumption for this letter compared to the original font. Additionally, unlike the original font, the ecofont lacks italic and bold variations, limiting its usability. The characters of the font can be seen in Figure 2.

Figure 2: Characters of the Eco Vera Sans font

Ryman Eco is a serif ecofont released by the British company Ryman. The manufacturer claims that it should use 33% less ink/toner on average compared to popular conventional fonts such as Arial, Times New Roman, Georgia, and Verdana. The font was designed by Dan Rhatigan in collaboration with the Grey London agency, with the goal of creating the world's most beautiful and sustainable font [4]. Eco-friendly design often involves compromises in aesthetics, and being aware of this, the font's creators sought to find an optimal balance between ink/toner savings, readability, and beauty. It is noted that the font has been positively received by both environmentalists and the design community. At smaller font sizes (between 10 and 14 pt), the lines of negative space within characters should not be clearly visible, while at larger sizes, they become an interesting feature of the font [4]. Figure 3 displays the font's characters.

Figure 3: Characters of the Ryman Eco font [4]

Thus, when examining the two most well-known ecofonts, their limited practical use becomes evident. However, one might ask: what if Ryman decided to correct these limitations - would Ryman Eco then become the ultimate solution? The font would certainly be more usable, but a true solution must consider human needs for variety. No single font, no matter how aesthetically pleasing, can be the best choice for every situation - different types of fonts exist for a reason. Font selection influences how text is perceived. Different typographic characteristics create different impressions for the reader, and not every font is suitable for every application. Sans-serif fonts may be perceived as neutral, while serif fonts are seen as stable, practical, mature, and formal. Script fonts can be perceived as youthful, joyful, creative, rebellious, feminine, casual, and charming. Modern display fonts may appear masculine, assertive, rough, sad, and harsh. Monospaced fonts may be considered dull, plain, unimaginative, and harmonious [5]. Therefore, choosing a single font, such as Ryman Eco, for all types of content is not suitable. In some cases, a serif typeface is preferable, while in others, a sans-serif typeface is more appropriate. Sometimes, it is necessary to adhere to specific standards and use a particular font. Additionally, there is often a need to stand out, and one way to achieve this is through unique typography. The challenge becomes even greater when considering regions of the world that do not use Latin-based characters. This highlights the need for a solution that provides significant ink/toner savings while allowing for broad applicability.

However, even if existing fonts are adapted, ecofonts have one potential drawback: their display on screens. Ecofonts are not primarily designed for digital use, so when displayed on screens, readability may be compromised. This means that for the best readability every text should first be typeset in a conventional font and then converted into an ecofont before printing to save ink/toner. This process is impractical and time-consuming, "time is money." Additionally, conversion may introduce errors, which no serious company can afford. Therefore, simply offering a wide range of ecofonts is not enough; a solution that works well for both print and digital environments must be found. In response to this challenge, the company Ecofont offers a solution in the form of a software driver that converts conventional fonts into ecofonts before printing. This means that although the document uses a conventional font, the driver will convert the characters into eco-friendly versions before printing, thereby enabling toner savings. The company claims that their

product can save up to 50% in ink/toner usage [6, 7]. This approach is likely the most logical one but is currently quite limited. At the time of writing, only five fonts are supported: Arial, Calibri, Tahoma, Times New Roman, and Verdana. Additionally, the driver is only compatible with the Windows operating system [6]. With the help of Artificial Intelligence, a better solution could be developed - one that automatically adapts all existing fonts into ecofonts before printing without user intervention. Furthermore, such technology could determine the optimal size of the empty spaces within characters to ensure ink/toner savings without sacrificing readability. Nevertheless, ecofonts have a long way to go, if they prove to be a viable solution at all. Two major challenges remain. First, ecofonts must demonstrate significantly greater efficiency in ink/toner savings compared to conventional fonts. Second, they must offer readability comparable to that of conventional fonts. The focus of this study is to examine the efficiency of ecofonts in terms of ink/toner consumption. Font selection affects ink/toner consumption [5, 8]. However, manufacturer claims should always be verified, as independent research may sometimes challenge their assertions, as was the case in the comparison between Ryman Eco and Times New Roman [9]. Fonts differ in their characteristics, and evaluating the effectiveness of ecofonts requires comparing fonts with equivalent typographic characteristics. Actual character size, line thickness, and shape are some of the factors that significantly impact results. Therefore, just because a font has “eco” in its name does not necessarily mean it will save ink/toner compared to any conventional font. The characteristics of fonts must be taken into account [9].

Thus, an appropriate method for testing the efficiency of ecofonts is to compare them with a conventional font that has identical typographic characteristics. Previous studies using such comparisons agree that using ecofonts can lead to ink/toner savings [1, 10, 11]. However, further research is needed to determine the exact amount of savings that can be expected for various fonts. The aim of this study is to examine the efficiency of ecofonts in terms of toner consumption in laser printers. The efficiency of three ecofonts was compared to three conventional fonts in three different sizes. To eliminate the influence of different typographic characteristics on the results (such as line thickness and shape), the only difference between the fonts was that the ecofonts contained empty spaces (holes) within the characters.

2. MATERIALS AND METHODS

2.1. Toner Consumption Estimation

The efficiency of reducing toner consumption was tested for three ecofonts compared to three standard fonts. Toner consumption was assessed by measuring the weight of paper samples before and after printing. The difference in mass before and after printing represented the toner mass.

2.2. Fonts

The fonts used in the study were Arial and eco Arial, Times New Roman and eco Times New Roman, as well as Bitstream Vera Sans and Ecofont Vera Sans - all can be found on the internet. The only difference between the tested fonts was that the eco variant had holes in the characters, while the conventional variant did not. All fonts were tested in three different sizes (8 pt, 10 pt, and 12 pt) and only in their conventional variants.

2.3. Text Sample

For each font and font size, a Microsoft Office Word document was created containing a

single A4 page filled with randomly generated text (Lorem Ipsum) to ensure the entire page was covered with text. The characters, amount of text (word count), formatting, and all other parameters on the page were identical for both the ecofont and the conventional font—the only difference being that the ecofont characters contained empty spaces (holes).
First, a sample was printed using the ecofont, after which the font was changed to its identical conventional counterpart, and the page was printed again. This process was repeated for each font and font size.
The document settings for each font and font size is presented in Table 1.

Table 1: Microsoft Office Word document settings for printing of text samples.

Property	Value
Size	A4 (210 x 297 mm)
Margins	Normal (top: 25 mm, bottom: 25 mm, left: 25 mm, right: 25 mm)
Line spacing	1,5
Alignment	Justified

2.4. Printing Substrate

For this research, Navigator (The Navigator Company, Setúbal, Portugal) wood-free uncoated 80 g/m^2 A4 office paper (210 × 297 mm) was used as the printing substrate (Table 2). The paper was conditioned to room conditions (23 ± 1 °C and 50 ± 2%) for at least 24 hours before printing. Ten A4 paper samples were prepared for printing each font and font size.

Table 2: Navigator Universal paper specifications (given by the producer)

Property	Standard Used for Determination	Value
Whiteness CIE	ISO 11475	169
Opacity %	ISO 2471	95
Moisture %	ISO 287	4
Bendtsen Roughness ml/min	ISO 8791/2	120
Thickness µm	ISO 534	110
Bulk µm/g/m2	_	1.38

2.5. Printing Process

From the previously mentioned Microsoft Word document, 10 samples were first printed using the ecofont. Then, the font was changed to its identical conventional counterpart, and the page was printed again 10 times. This process was repeated for each font and font size.
The samples were printed using a Canon L11121E (Canon, Tokyo, Japan) laser printer. Throughout the entire test, a Topjet H-Q2612A/FX10/703 (Topjet, Zhuhai, China) black toner cartridge was used to ensure consistency. The print settings were kept at their default values.
During testing, the relative humidity in the room was measured at 59% ± 10%, and the temperature was measured at 23 °C ± 1 °C.

2.6. Weight Measurement of Printed Samples

The weight of each paper sample was measured before and after printing using an Acculab ALC-210.4 (Sartorius, Oakville, Canada) analytical balance. After weighing all the samples, printing was performed. Following the print, the weight of each individual sample was measured again using the same balance to determine toner consumption. Thus, the weight of each sample before and after printing was compared. The difference between the weight of the samples before and after printing represented the weight of the toner used. For each font and font size, the mean value and standard deviation were calculated based on the 10 samples. Based on the comparison of the mean sample masses using the standard font and the ecofont, an estimate of the ecofont's savings relative to the standard font was made.

2.7. Percentage of black pixels of Printed Samples

Additionally, to gain insight into the advantages and disadvantages of different measurement methods, an analysis of the coverage of the samples by black pixels was performed. For each font and font size, 5 printed samples were scanned using an Epson Perfection V750 Pro scanner. The scanning resolution was set to 600 dpi in 8-bit Grayscale mode, and the scanned images were saved in .tif format with a size of 4924 x 6957 px. After scanning, the digital samples were imported into the ImageJ tool, where they were converted into binary format - a black-and-white image (Figure 4). Then, using the same tool, the surface coverage of black pixels (area and area fraction) was measured for each sample.

Figure 4: Printed sample before (left) and after (right) conversion to binary format

2.8. Image Analysis

To create a better understanding of the impact of the size and shape of the empty spaces in ecofonts on the results, samples were photographed using an Olympus BX51 microscope and an Olympus DP72 microscope camera. For each font and font size, a piece was

cut from the printed sample containing the same word (the first word in the text), and an image analysis was performed on the last letter of the word (the letter "m"). All samples were magnified 50 times (50x).

3. RESULTS

3.1. The measurements of the mass of individual samples

The weight measurement of individual samples are presented in Tables 3, 4, and 5. The results showed that the use of ecofonts could lead to toner savings ranging from 14% to 62%, depending on the type and size of the font, as well as the method used to create the ecofont. Since the texts on the page varied depending on the selection and size of the font, it is only possible to compare the conventional font with its ecofont variant in the same font sizes (e.g., Arial 8 pt and Arial Eco 8 pt). In the following text, the conventional font and its ecofont variant will be referred to as a "set."

Table 3: Results for the Arial set

Font Type	Font Size (pt)	Savings (%)
Arial	8	-62
	10	-38
	12	-56

Table 4: Results for the Times New Roman set

Font Type	Font Size (pt)	Savings (%)
Times New Roman	8	-59
	10	-37
	12	-47

Table 5: Results for the Vera Sans set

Font Type	Font Size (pt)	Savings (%)
Vera Sans	8	-14
	10	-18
	12	-21

The results show that the greatest toner savings were achieved with the Arial set at a font size of 8 points (pt). Similar results were observed with the Times New Roman set. The smallest savings were noted for the Vera Sans set. It is important to note that the Vera Sans set also exhibited the smallest amount of empty space (holes) within the characters of the ecofont, which is consistent with the results of the mass measurements of individual samples. Interestingly, the results for the Arial and Times New Roman sets showed a decrease in efficiency at a size of 10 pt, followed by an increase at a size of 12 pt. For the Vera Sans set, an increase in efficiency was observed with the increase in font size.

3.2. Percentage of black pixels of Printed Samples

Percentage calculation of black pixels confirmed toner savings in the case of the Arial and Times New Roman sets, but not for the Vera Sans set. For each set, the savings according

to the image analysis were more modest than those observed in the mass measurements of individual samples. For the Arial set, the savings ranged from 10% to 15%, depending on the font size. For the Times New Roman set, the savings were slightly weaker, ranging from 7% to 9%.
In contrast to the mass measurement results, the image analysis showed the highest savings for the Arial set at a font size of 12 pt. In the case of the Times New Roman set, the greatest savings were visible at a font size of 10 pt. For the Vera Sans set, the image analysis did not show any savings at font sizes 8 and 10 pt, and only around 3% savings at 12 pt. For font sizes 8 and 10 pt, the percentage calculation of black pixels result was unusual, as the same text was used for both the conventional and ecofont, so a difference in favor of the ecofont should have been visible due to the empty spaces within the characters.
The data from the image analysis are presented in Tables 6, 7 and 8, expressed as the percentage of surface area covered by black pixels.

Table 6: Results for the Arial set

Font Type	Font Size (pt)	Savings (%)
Arial	8	-14
	10	-10
	12	-15

Table 7: Results for the Times New Roman set

Font Type	Font Size (pt)	Savings (%)
Times New Roman	8	-7
	10	-9
	12	-7

Table 8: Results for the Vera Sans set

Font Type	Font Size (pt)	Savings (%)
Vera Sans	8	/
	10	/
	12	-3

3.3. Image Analysis

To study the impact of the shape and size of the empty spaces on the results, image analysis was performed using a microscope. Figures 5 to 13 display a comparison between the conventional font and the ecofont across all tested sizes. For the Arial and Times New Roman sets, the holes are noticeable even at a font size of 8 pt. The Vera Sans set has the smallest hole size, at 8 pt (Figure 11), the toner dispersion effectively covers the empty space, making the holes barely visible. At 10 pt (Figure 12), the holes become slightly more pronounced, but still less than in the Arial and Times New Roman sets at 8 pt. At 12 pt (Figure 13), the holes become clearly visible in the Vera Sans font, but are still smaller than those in the Arial and Times New Roman sets. This aligns with the toner consumption measurements for the Arial and Times New Roman sets, a larger difference in toner usage is visible compared to the Vera Sans set. Only at 12 pt did the Vera Sans set show savings above 20%.

The microscopic image analysis shows that the holes are significantly larger in the Arial and Times New Roman sets, which is consistent with the efficiency results obtained from the weight measurements of individual samples. Additionally, due to the considerably smaller holes in the Vera Sans set, it can be inferred why the image analysis did not show savings. The holes are small, and when converted into a binary format, additional details were lost.

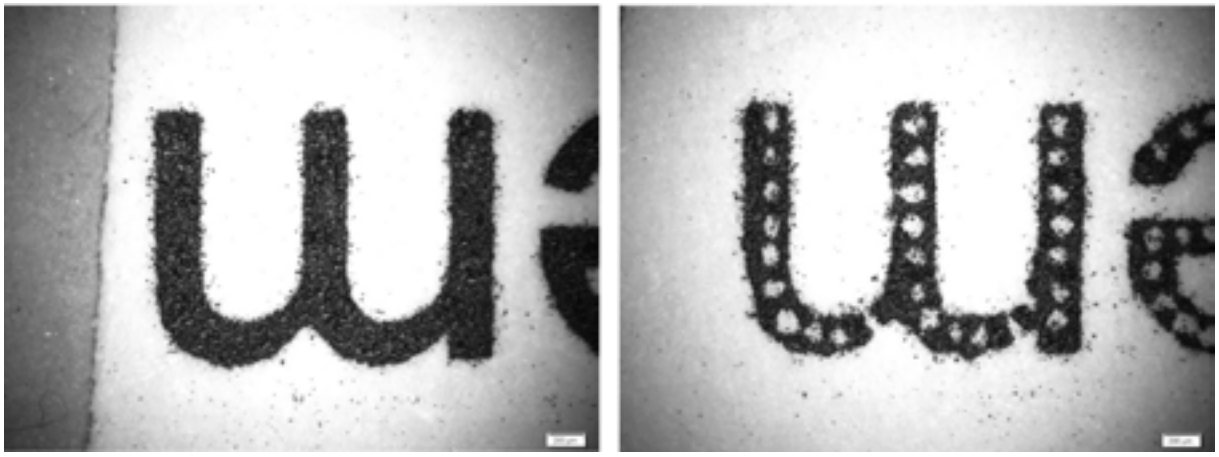

Figure 5: Comparison of the letter "m" for Arial set at a size of 8 pt

Figure 6: Comparison of the letter "m" for Arial set at a size of 10 pt

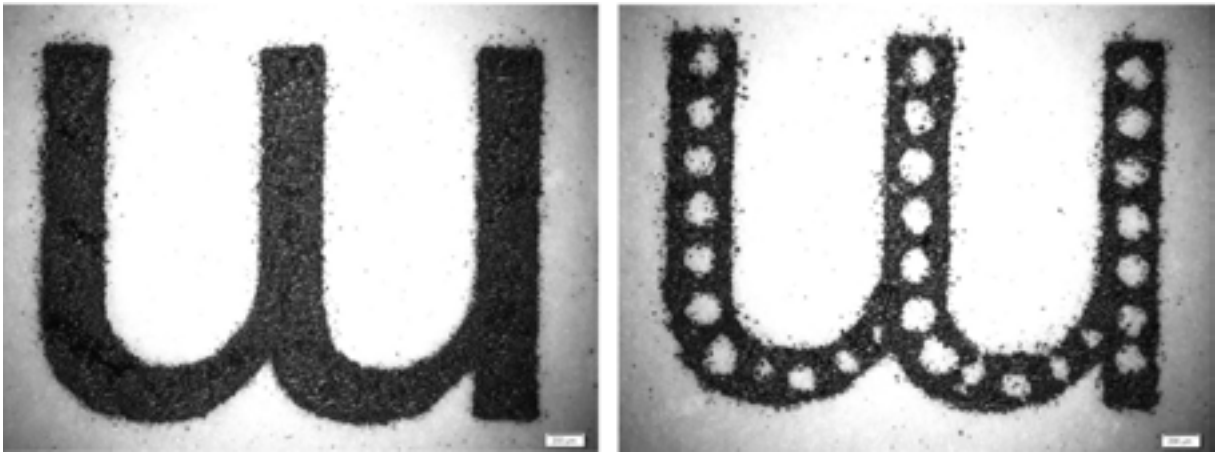

Figure 7: Comparison of the letter “m” for Arial set at a size of 12 pt

Figure 8: Comparison of the letter “m” for Times New Roman set at a size of 8 pt

Figure 9: Comparison of the letter “m” for Times New Roman set at a size of 10 pt

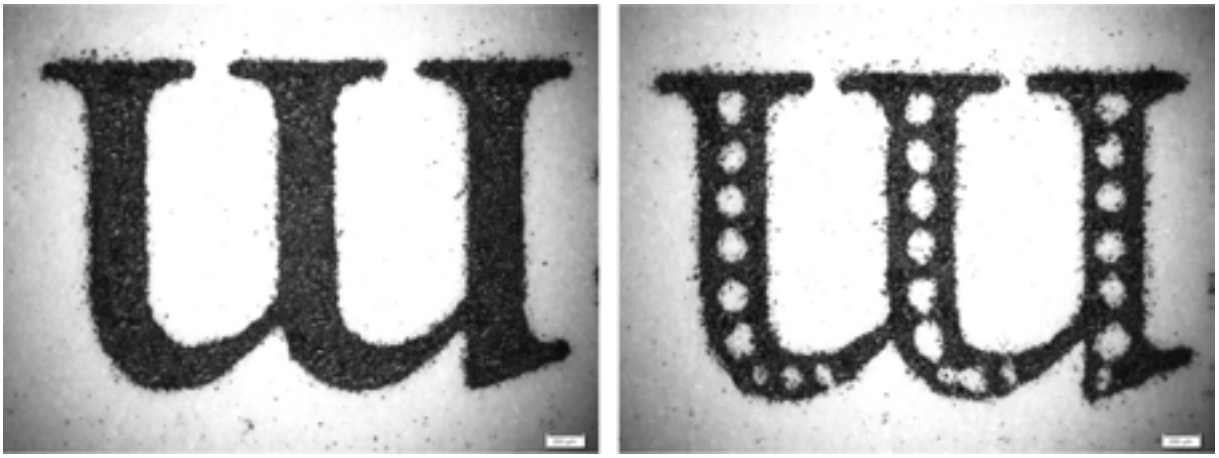

Figure 10: Comparison of the letter “m” for Times New Roman set at a size of 12 pt

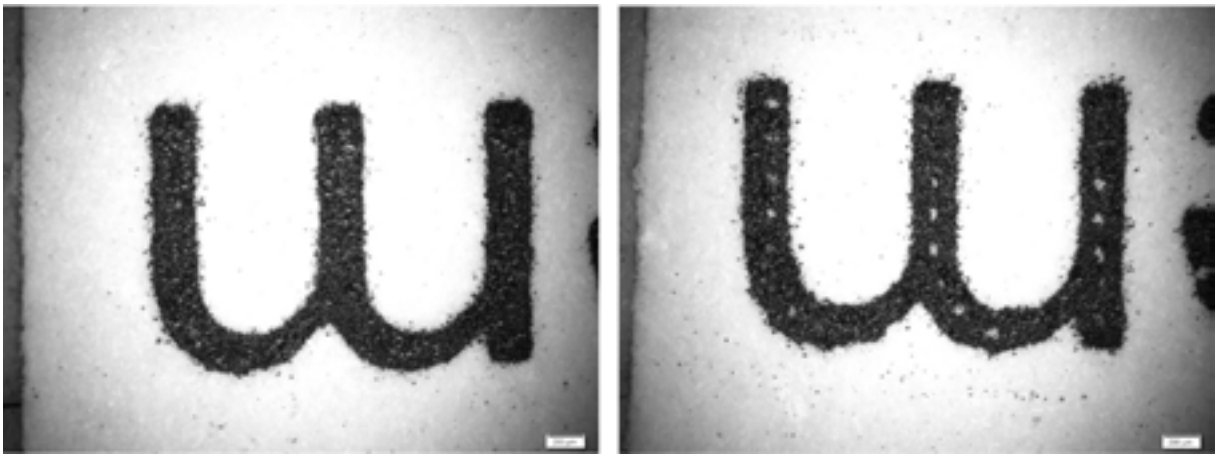

Figure 11: Comparison of the letter “m” for Vera Sans set at a size of 8 pt

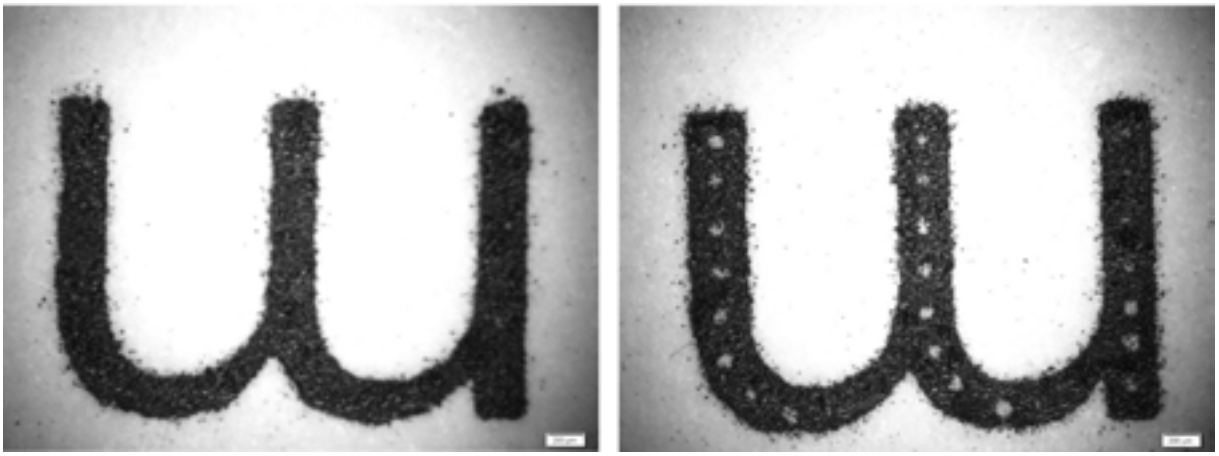

Figure 12: Comparison of the letter “m” for Vera Sans set at a size of 10 pt

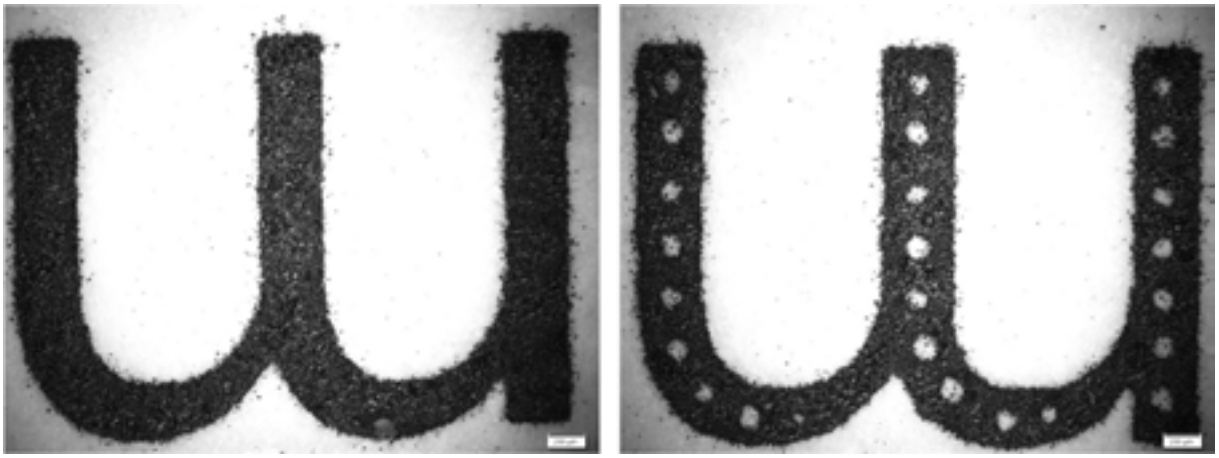

Figure 13: Comparison of the letter "m" for Vera Sans set at a size of 12 pt

4. DISSCUSSION

The research provided insight into the challenges of measuring the efficiency of ecofonts. It is evident that, depending on the measurement method, different assessments of efficiency can be made. Measuring the weight of individual paper samples is considered the most reliable of the methods used. It demonstrated toner savings of up to approximately 60%, which is a significant saving. The results align with previous studies that have shown that ecofonts can noticeably reduce toner consumption [10, 11]. For the Arial font set, the results confirmed earlier research on the effectiveness of the ecofont adjustment - savings of around 50% were recorded at a font size of 12 pt [6, 7]. In both the Arial and Times New Roman sets, a decrease in efficiency was observed at 10 pt, followed by an increase at 12 pt, which is unusual. The microscopic analysis did not provide an answer as to why this occurred. For the Eco Vera Sans set, the smallest savings were observed, but the results do confirm the manufacturer's claims of up to 20% savings compared to the original font [2]. The measurement of the number of black pixels showed that toner savings of up to 15% can be achieved by using ecofonts, which is a noticeably smaller estimate than that obtained through individual sample mass measurement. However, this method is considered unreliable, as the resolution of 600 dpi and the size of the scanned images are likely not high enough for a quality image analysis of the font details, considering the entire page was scanned and the font characters are relatively small. Additionally, the conversion to binary format likely caused further loss of detail.

The microscopic image analysis offered insight into the impact of the shape and size of the empty spaces in ecofonts on the research results. From the microscopic images it is evident that during printing, unwanted toner spread occurs beyond the edges of characters and holes in letter. This may result in text blurring and loss of sharpness. This problem occurs due to improper toner fixation, poor paper quality, or technical issues with the printer [12]. This problem negatively affects print legibility and can reduce the overall quality of the printed material [1].

Additionally, it can be observed that the larger the empty space (holes), the greater the toner savings. However, it is necessary to find the optimal size to achieve the best balance between savings and readability. Although readability of ecofonts was not the focus of the research, based on the image analysis, it can be assumed that the readability will be worse for fonts that perform better in terms of savings. The Vera Sans set shows the smallest toner savings, but the toner dispersion best covers the holes of the ecofont, making the difference the hardest to notice in the prints. For the Arial and Times New Roman sets,

the difference is more noticeable when comparing the conventional and ecofont prints. It was observed that the prints made with ecofonts were slightly more faded (washed out), the contrast between text and background was reduced for the ecofonts compared to those made with conventional fonts, which should be taken into account when applying ecofonts.

Although the research provides some insight into the effectiveness of ecofonts, the results are not sufficiently reliable and can only serve as a basis for further studies. Several limitations need to be considered. First, the effect of humidity on the samples is unknown. Second, only one printer was used. Third, there is measurement imprecision, a relatively small number of samples, and certain observed phenomena that need further investigation. Testing on a larger number of samples and printers would offer more precise results. Fourth, there is limited knowledge of the tools used for testing—the percentage calculation of black pixels could likely be done more precisely. Therefore, further research is required to obtain more reliable results.

However, it should be noted that the research did not attempt to determine effectiveness under strictly controlled conditions but rather aimed to provide results that can be expected under typical usage. This research is like a small piece of the puzzle - it may be small and with holes just like ecofonts, but it is still necessary to form the complete picture.

5. CONCLUSION

The study on ecofonts has provided valuable insights into their efficiency, highlighting the challenges associated with measuring their effectiveness. The most reliable method, mass weight measurement of paper samples, demonstrated significant toner savings of up to 60%. This aligns with previous research indicating that ecofonts can substantially reduce toner consumption. However, results varied depending on the font type and size, with Arial and Times New Roman showing unusual efficiency patterns at different font sizes. The Eco Vera Sans set confirmed manufacturer claims of up to 20% savings but showed the smallest overall savings. The analysis also underscored the importance of optimizing the size of empty spaces in ecofonts to balance savings with readability. While microscopic analysis revealed that larger empty spaces correlate with greater savings, it also suggested that fonts with better savings might compromise readability. For instance, prints from ecofonts appeared more faded compared to conventional fonts. Despite these findings, the study's limitations—such as measurement imprecision, limited sample size, and the use of a single printer—mean that the results are not definitive. Further research is necessary to address these limitations and provide more reliable data. Nonetheless, this study contributes to the broader understanding of ecofonts under typical usage conditions, serving as a foundational piece for future investigations aimed at refining ecofont technology and its applications. Ultimately, while ecofonts show promise in reducing toner consumption, ongoing research is crucial to fully realize their potential and address the trade-offs between savings and readability.

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

BENTONITE-ENRICHED ETHYLENE SCAVENGER ACTIVE PACKAGING FILMS TO EXTEND THE FRESHNESS OF CHERRY TOMATOES

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ABSTRACT

Ethylene is critical in the ripening and senescence of fruits and vegetables, ultimately reducing their shelf life. Consequently, its accumulation can hinder the marketability and availability of various horticultural products, contributing to significant post-harvest losses and food waste. In this study, ethylene-scavenging packaging films were developed to help preserve the freshness of fresh produce during distribution. These films were formulated by incorporating different amounts of bentonite into polylactic acid (PLA). Structural characterization was performed using FTIR spectroscopy, while thermal properties under an inert atmosphere were analyzed via TGA. Additional evaluations included surface energy, color, transparency, and gloss measurements. The films were also subjected to gravure printing to assess their printability. Finally, the effectiveness of PLA/bentonite films in maintaining the quality of packaged cherry tomatoes was examined regarding hardness, color retention, and weight loss. Results demonstrated that increasing the bentonite content improved the storage stability of the cherry tomatoes.

Keywords: Bentonite, polylactic acid, active packaging

1. INTRODUCTION

Scientific interest in food-contact packaging has been increasing significantly in recent years. The growing consumer demand for fresh products with extended shelf life and preserved quality has prompted producers to develop more advanced and safer packaging systems. Packaging technology is crucial for fresh produce, as quality can only be maintained after harvest, not enhanced. Therefore, packaging has the potential to improve the suitability, safety, and quality of food products while reducing the use of preservatives, food waste, and the incidence of foodborne illnesses. All these benefits can lead to substantial cost savings and economic advantages for food retailers and the food industry (1,2).

Active packaging is an innovative technology based on the mutual interaction between the packaging material, the product, and the surrounding environment. These systems actively modify the environmental conditions surrounding the packaged food, enhancing its sustainability, extending its shelf life, and ensuring the preservation of its quality. Unlike conventional packaging materials, active packaging systems interact with the atmosphere in direct contact with the food, prolonging shelf life and maintaining product quality. In this context, active packaging technology should be considered an effective and promising approach with significant potential for further development in food packaging. Active packaging refers to a method that involves the removal of components such as ethylene, moisture, and oxygen from the environment or integrating active agents into the packaging system to inhibit microbial growth. There is a growing demand for ethyl-

ene scavenger-based packaging for fruits and vegetables to control premature ripening by eliminating or absorbing ethylene gas from the packaging atmosphere (3,4,5).
Ethylene (C_2H_4) is a volatile phytohormone that regulates plant development and ripening. After harvest, excessive production of ethylene gas accelerates the ripening process and contributes to the degradation of fruit and vegetable quality. Therefore, managing ethylene levels is essential for prolonging the shelf life of perishable produce. Commercial ethylene scavengers are marketed in sachet formats or as polymer-coated papers, operating through adsorption mechanisms. Materials such as zeolite, clay, silica, activated carbon, and alumina are commonly integrated into packaging systems to remove ethylene from the storage atmosphere progressively. Recently, porous minerals like clay and zeolites have emerged as promising substitutes for conventional potassium permanganate-based scavengers, which pose potential risks to human health and the environment. Research findings have confirmed that these alternative ethylene scavenging materials are non-toxic, eco-friendly, and have been recognized as safe for food packaging use by the U.S. Food and Drug Administration (FDA) (5-7).
Poly(lactic acid) (PLA) is a well-known environmentally friendly polymer. One of the main advantages of this commercialized biopolymer is its ability to reduce the waste problem, particularly in packaging applications (8,9).
Due to certain limitations of biopolymers, such as poor thermal stability, low toughness, and a narrow processing window, reinforcement with suitable additives has become a popular research topic in recent years (10,11). Natural minerals are added to biopolymers as fillers due to their low cost and ease of processing. Bentonite minerals are typically obtained as ash particles resulting from volcanic eruptions. Bentonite ($Al_2H_2O_6Si$) is a clay composed of aluminum octahedral and silica tetrahedral layers, which is readily available, low-cost, and environmentally friendly. Due to its exchangeable cation content, it facilitates the physical adsorption of ethylene (12).
In this study, eco-friendly active packaging films has the ability to extend shelf life of cherry tomatoes were developed by incorporating bentonite clay, which is ethylene scavenging substance, into biobased and biodegradable PLA. The primary aim of paper is to estimate the ethylene adsorption capacity of bentonite during the storage period of cherry tomatoes. To investigate bentonite's ethylene gas adsorption effect, it was added into the PLA films at different concentrations (0, 2.5, and 5 wt.%), and its impact on degradation was examined.

2. MATERIAL AND METHOD

2.1. Material

Polylactic acid (Mw ~60,000) is a polymeric film material was supplied from Sigma-Aldrich. Sigma-Aldrich provided bentonite. Cherry tomatoes were sourced from Izmir, Türkiye.

2.2. Method

2.2.1. Preparation of PLA/Bentonite packaging films

Solvent casting, which requires less work, was used to create PLA/Bentonite packaging films. Before beginning the film preparation process, BNTs and PLA pellets were vacuum-dried in an oven set to 80°C for eight hours. 10 g of PLA pellets were dissolved in 100 ml of chloroform for four hours at 25°C while stirring at 1000 rpm with a magnetic stirrer to perform solvent casting. To create PLA/Bentonite packaging films, Bentonites

were dissolved in a PLA solution at a ratio of 0 (control film)–2.5–5 weight percent, with a total solid content of 10 weight percent. For 30 minutes, the film formulations containing bentonites were submerged in an ultrasonic bath to ensure that the bentonites were uniform. The mixtures were poured into 150 mm-diameter glass Petri plates and allowed to air dry. The other films intended for testing were preserved in a desiccator after the dry films were removed, and a cherry tomato was packed with each formulation. The loading rates of bentonites were used to code the samples. For example, the packaging film with 2.5 weight percent bentonites is denoted by PLA/2.5Bentonite. Figure 1 shows the PLA/Bentonite packaging film preparation process.

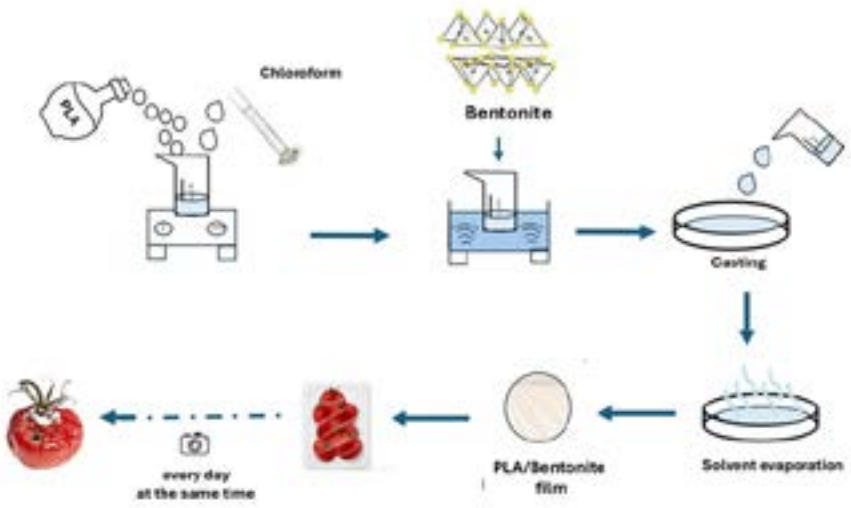

Figure 1: Production scheme of PLA/Bentonite active film

2.2.2. Characterization

Fourier-transform infrared (FTIR) spectroscopy was performed using a Bruker IFS 66/S spectrometer equipped with an attenuated total reflectance (ATR) accessory.
Thermogravimetric analysis (TGA) was carried out on a PerkinElmer STA6000 system, within the temperature range of 30°C to 750°C, under a nitrogen atmosphere. The heating rate during the measurements was set to 20°C per minute.
Color differences were determined using the CIELab 2000 (ΔE_{00}) method by ISO 11664-6:2014. The calculations were based on the mean of five independent measurements. In this method, ΔL*, Δa*, and Δb* denote the differences in lightness, red-green, and yellow-blue coordinates between the sample and the reference color. The L* axis represents brightness, ranging from black to white; the a* axis spans from green to red; and the b* axis extends from blue to yellow. Here, ΔL*, ΔC*, and ΔH* represent the differences in lightness, chroma, and hue between the standard and the sample. The ΔR term accounts for the interaction between chroma and hue differences. Weighting functions SL, SC, and SH adjust the contributions of lightness, chroma, and hue depending on the sample's position in the CIELab color space. The parametric coefficients kL, kC, and kH are applied for viewing conditions such as surface texture, background, and spatial separation.
Gloss measurements for all packaging films were conducted using a BYK-Gardner micro-gloss meter with 75° geometry, following the ISO 8254-1:2009 standard. The contact angles of produced films were found on Pocket Goniometer Model PG-X, version 3.4 (FIBRO Systems AB, Sweden). Surface-free energy was calculated according to the ASTM D5946 standard test method, depending on the water contact angle. The images of droplets were then recorded by using a CCD video camera.

The color characteristics of the produced packaging films were evaluated using an X-Rite eXact portable spectrophotometer in compliance with the ISO 13655:2017 standard. The device was operated under standardized measurement conditions, employing a 0/45° geometry with a polarization filter, a 2° standard observer angle, and a D50 illumination source. Measurements were performed within the 400–700 nm wavelength range across the visible spectrum.
Cherry tomatoes were purchased from the local agricultural center in Türkiye to investigate the use of packing films to store fresh cherry tomatoes. Fresh cherry tomatoes were distinguished by their red color, and only perfectly formed, rot-free cherry tomatoes were chosen. In the center of the dried wrapping paper, three distinct contents were chosen: cherry tomatoes and all of the same ripeness. Packaging films were used to wrap the cherry tomatoes tightly. Each specimen was visually and tactilely inspected daily while kept at ambient temperature and constant relative humidity.

3. RESULTS

3.1. Chemical characterization of the produced active films

Identifying functional groups in the packing films can be characterized using FTIR spectroscopy. The FTIR spectra of packaging films containing 2.5 and 5-weight percent bentonites and pure PLA are displayed in Figure 2. Representative bands were found at 2800-3000 cm^{-1} for CH_2 asymmetric stretching, at 3400-3000 cm^{-1} for the O–H stretch, and at 1750 and 1180 cm^{-1} for the C=O stretching and the C–O–C stretching for both pure PLA films and active packaging films containing 2.5 and 5 weight percent bentonites. The $–CH_2$ rocking modes are represented by the 794 and 779 cm^{-1} doublets in the spectra of pure bentonite (14,15).
According to Zhu et al. (2005) and Karaca et al. (2013), the intermolecular contact between the two neighboring hydrocarbon chains in a perpendicular orthorhombic subcell causes the splitting of the $–CH_2$ rocking bands, which also necessitates an all-trans-conformation for detection (15-17). According to Banik et al. (2015), the band in the 950–1100 cm^{-1} range that corresponds to the stretching vibration of the Si–O group divides into a sharp band at 1033 cm^{-1} with a shoulder of about 1088 cm^{-1} that is due to perpendicular Si–O stretching.

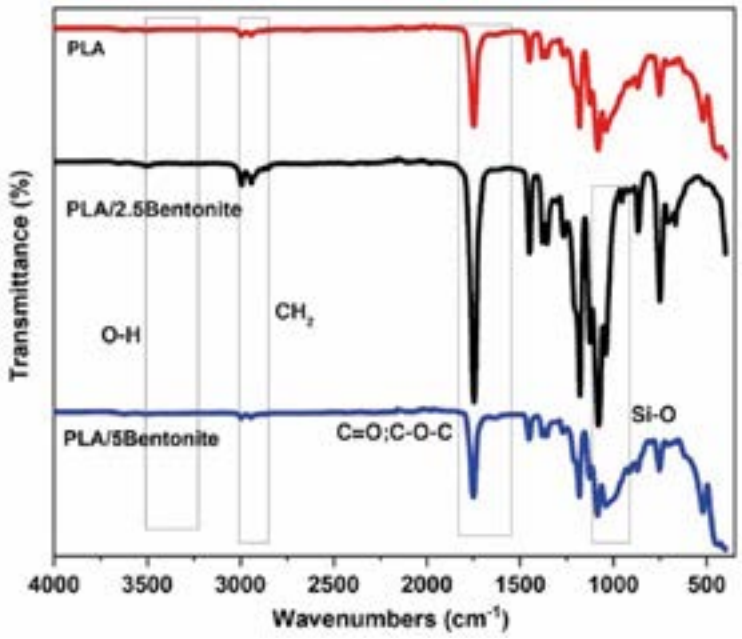

Figure 2: FTIR spectra of neat PLA, PLA/2.5 bentonite and PLA/5 Bentonite produced active films

3.2. Thermal characterization of produced active films

PLA/x-Bentonite active films' TGA curves are displayed in Figure 3. Table 1 provides a summary of the TGA results. PLA sheets degrading without bentonite can reach a maximum temperature of 380°C. Chain depolymerization is the primary cause of PLA's heat breakdown (13,18). The findings show that the degradation temperature fell from 380°C (PLA) to 372 °C for the film containing 2.5% bentonites as the loading amount of bentonites into PLA increased. The addition of bentonites did not improve the packing films' thermal stability. This is explained by the fact that bentonites have a poorer insulating efficacy than other silicate nanolayers, primarily because of their tubular form. Accordingly, they cannot stabilize the polymer matrix at low loading ratios (3,19). As anticipated, the percentage of char in the packaging films rose to 750°C as the amount of bentonite loaded increased. Char yields of 0.4%, 21.49%, and 33.08% were found for the packaging films with 0%, 2.5%, and 5% bentonites, respectively.

Table 1: TGA results of PLA, PLA/2.5 Bentonite, and PLA/5 Bentonite produced active films

Films	T5 (°C)	T10 (°C)	Tmax (°C)	Char (%)
PLA	104.71	133.61	380	0.4
PLA/2.5 Bentonite	114.78	183.45	384	21.49
PLA/5 Bentonite	123.53	199.73	372	33.08

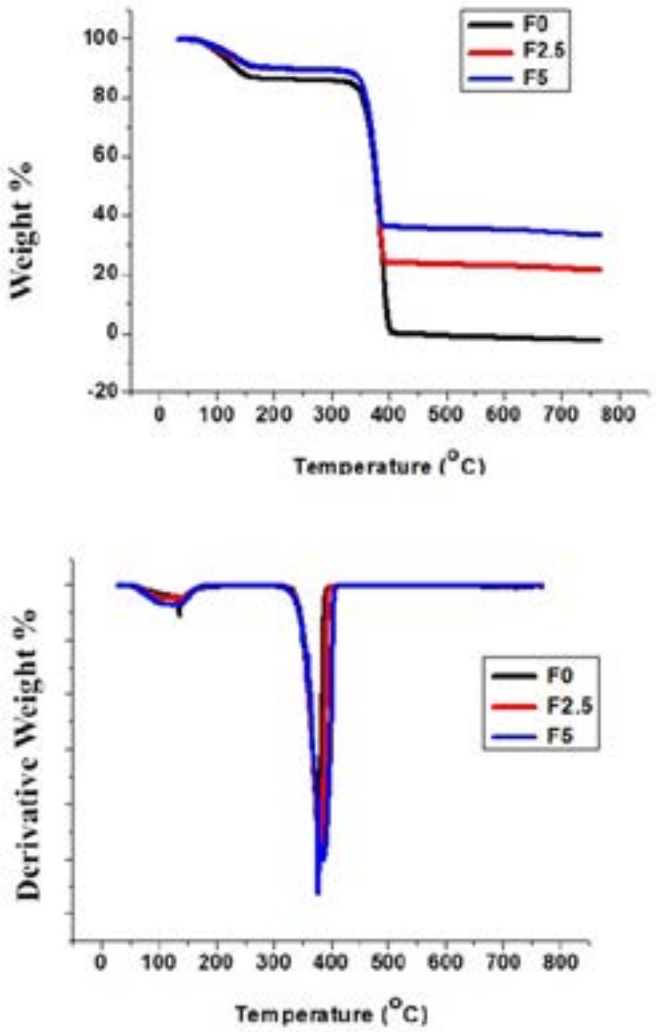

Figure 3: a) TGA curves of PLA, PLA/2.5 Bentonite, and PLA/5 Bentonite active films, b) DTG curves of PLA, PLA/2.5 Bentonite, and PLA/5 Bentonite active films

3.3. Storage studies of the packaging film

The cherry tomato is a climacteric fruit and continues to undergo the ripening process after harvesting due to the release of ethylene gas (20). Therefore, ethylene emission's effect on cherry tomatoes' decay was evaluated through photographic documentation after a 20-day storage period. Cherry tomatoes with uniform size and ripeness were obtained from a local market, sealed in airtight packaging, and observed daily through visual and tactile evaluations until signs of spoilage appeared. Figure 4 presents the appearance of cherry tomatoes packaged in packaging films over 20 days. Among the tested packaging films, PLA/5Bentonite packaging films displays the bigest ethylene scavenging capacity, behind PLA/2.5Bentonite. Figure 4 shows cherry tomatoes packaged in pure PLA began to decay after the 6th day. In contrast, cherry tomatoes wrapped in PLA/5Bentonite and PLA/2.5Bentonite films maintained a visual appearance close to their initial state even after 15 days. By the end of the 15th day, cherry tomatoes packaged in PLA/2.5Bentonite films started reveal signs of shrinkage. In contrast, cherry tometos are wraped with PLA/5Bentonite films kept their original aspects and carry on unspoiled at room temper-

ature for the entire 20-day period.

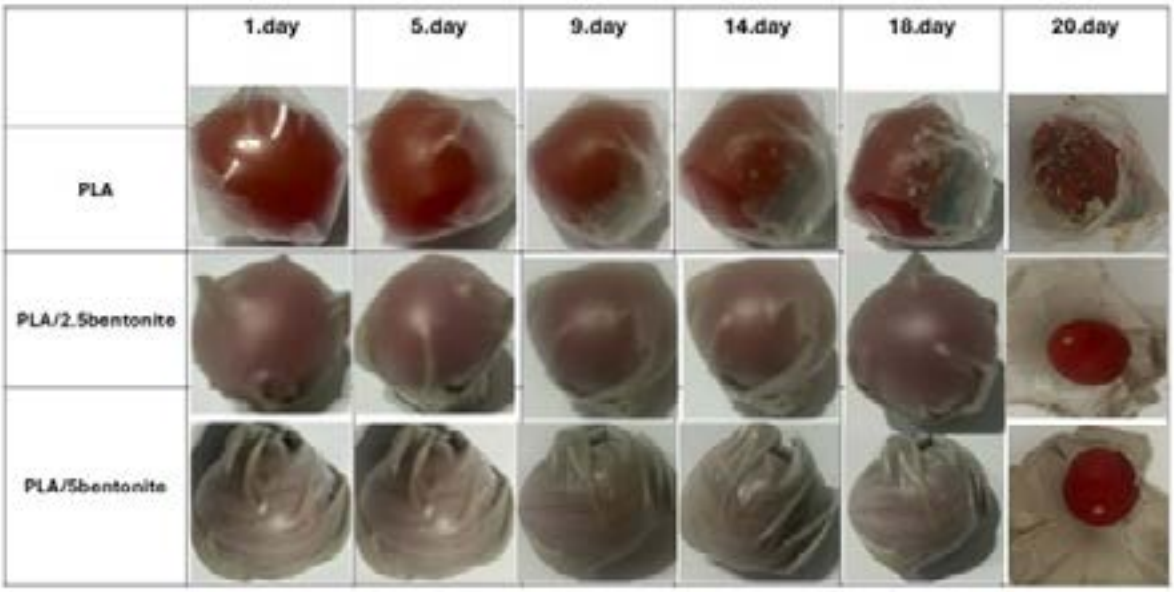

Figure 4: Evaluation of the preservation effect of packaging films on cherry tomatoes

3.4. Printability properties of produced active film

Fabricated packaging films' contact angles and surface energies were evaluated and presented in Figure 5. Upon examining Figure 5, neat PLA films' contact angle was measured 75°, which aligns closely with values reported in the literature (21). The contact angle was reduced by incorporating bentonite into the PLA matrix (PLA/2.5% Bentonite: 70.9°, PLA/5% Bentonite: 67.2°). This reduction is believed to be due to the increased surface energy resulting from the hydroxyl groups in bentonite, which enhances the produced films'polarity. Notably, decreasing in the contact angle comes more apparent with bentonite concentration of two formulations tested in study. These findings are consistent with previous studies in the literature (22).

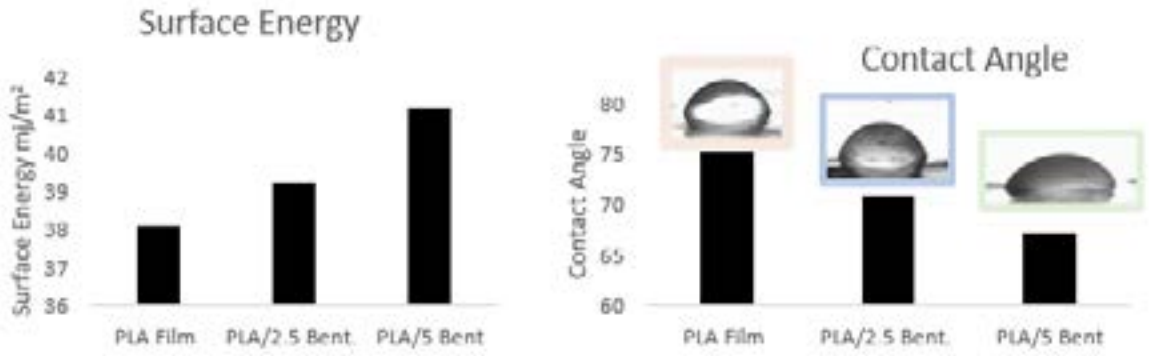

Figure 5: Contact angles and surface energies of PLA, PLA/2.5 Bentonite, and PLA/5 produced active films

Upon a simple visual inspection of the images, it is evident that the neat PLA films exhibited high transparency and a glossy finish. However, incorporating bentonite into the formulation, the resulting produced active films became semi-transparent. The color of

obtained films exhibited a brownish/yellow tint. Nevertheless, this alteration in appearance, the text on the movie remained legible. Table 2 presents the L*a*b* color coordinates, the color difference (ΔEa*b*), and the gloss values for the PLA, PLA/2.5 Bentonite, and PLA/5 Bentonite produced active films.

Table 2: Optical measurement results of PLA, PLA/2.5 Bentonite, and PLA/5 Bentonite produced active films

	L*	a*	b*	ΔE	Glos
PLA	90.30±0.09	-3.20±0.03	3.09±0.01	Reference	86.5±0.3
PLA/2.5 Bentonite	72.20±0.09	-2.80±0.04	15.01±0.03	15.13±0.1	66.7±0.6
PLA/5 Bentonite	57.35±0.1	1.67±0.03	24.50±0.03	28.62±0.09	52.3±0.4

Upon examining the color values in Table 2, it can be observed that a minimal change in the a axis of color of the produced active films with bentonite check against with neat PLA film, with the most significant difference occurring in the b axis. This shift manifests as a yellowish color. Change towards yellow is attributed to the natural ferrous and titanous content present in the bentonites. Furthermore, a significant decrease in the L value is observed when incorporating bentonite, corresponding to darker coloration and reduced transparency. As the bentonite content increases, the reduction in the L value becomes more pronounced, further corroborating the visual observations. When the color differences are analyzed, it is found that the color difference in films with added bentonite increases as the amount of bentonite is increased, with a Delta E greater than 6, indicating that "the two colors are not the same." As a result, the color gradually shifts towards yellow with increasing bentonite content. Upon evaluating the gloss values, it is determined that the neat PLA film exhibits a high gloss. At the same time, the addition of bentonite increases surface roughness, leading to light scattering and a decrease in gloss. These findings are consistent with the literature (23,24).
As shown in Figure 6, Neat PLA film has a transparent structure. The solvent casting method produced flexible packaging films that started to show translucent properties by adding bentonite into PLA. It can be seen that the transparency of PLA films containing bentonite decreased, and the color shifted toward brown/yellow. The results are line with the literature (13)

Figure 6: Images of packaging films

Flexographic printing was successfully performed with magenta ink on to the produced

active films. Ink viscosity was suitable for printing process. The adhesion test, conducted using tape after the prints had dried, demonstrated strong adhesion, as no visible printed color residue was left on the tape. The color results of the printed samples are presented in Table 3. Upon examining these results, it can be inferred that the incorporation of bentonite caused a shift in the color of the produced active films toward yellowish. Additionally, the printed samples displayed a slight yellowish shift, corresponding to the b-axis change. The color change is attributed to the natural components of bentonite. As the bentonite amount in the produced active films increased, the change to line with yellow in the prints and the ΔE value also increased. These findings are from previous studies in the literature (13).

Table 3: Optical measurement results of flexographic printed active produced films

	L	a	b	Delta E
PLA	57.50	80.20	-5.30	Reference
PLA/2.5 Bentonite	52.78	79.60	-3.45	4.51
PLA/5 Bentonite	50.93	79.31	1.50	6.82

4. CONCLUSION

This work created bentonite-reinforced PLA packaging films as a possible environmentally friendly, ethylene-scavenging active packaging material for cherry tomatoes. Solvent casting, a simple production technique, was used to create the packaging films. Bentonite content's effects on the packaging films' structural, thermal, printability, surface, and ethylene scavenging capabilities were examined. It was discovered that adding bentonite improved PLA's capacity to scavenge ethylene. The generated packaging films were found to be semi-transparent and transparent, and the addition of Bentonite caused a slight change in color to grey. It was found that all of the obtained packaging films had high printability qualities and could be printed without any issues using commercial ink. After analyzing the films' impacts on bananas, it was concluded that films with 5% Bentonite were appropriate for use as cherry tomato packaging materials. PLA/5 Bentonite packaging films have much promise as an efficient ethylene scavenger for fresh fruit packaging and a competitive substitute for synthetic packaging materials when considering their functional and physical characteristics.

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ORIGINAL SCIENTIFIC PAPER

DEVELOPMENT OF SMART LABELS USING HIBISCUS SABDARIFFA L. ANTHOCYANINS FOR REAL-TIME MONITORING OF CHICKEN FRESHNESS

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ABSTRACT

Due to the depletion of resources and the increasing demand for clean food, there is a growing need for next-generation packaging systems. Among these next-generation packaging systems, there are smart packaging, active packaging, and sustainable packaging. Smart packaging systems are products that allow monitoring of whether the food has spoiled without opening the package. Although smart packaging can operate on different principles, the most used type is smart labels that function based on colour changes related to pH variations. Hibiscus sabdariffa L. anthocyanins are naturally derived indicators capable of changing colour based on pH. In this study, Hibiscus sabdariffa L. anthocyanins (2.5%) were combined with sodium alginate and gelatine as binders to prepare smart labels using the solvent casting method. The colour change of the produced smart films in response to pH was analysed using UV spectroscopy, while properties such as contact angle (measured with a goniometer), colour parameters (measured with a colour spectrophotometer), solubility in water, swelling behaviour, and thickness were thoroughly examined. The chemical structure of the films, both with and without anthocyanins, was determined using FTIR. The stability of the colour parameters (L*, a*, and b*) of the films stored at 5 ± 2 °C was monitored over a 28-day period. The smart films produced were tested for spoilage detection with chicken. The experiments were conducted under temperature conditions of 25°C and 4 °C, with the colour change being monitored at different times. It was determined that the film containing Hibiscus extract changed colour visibly (from pink to green) when immersed in solutions of different pH values, depending on the pH level. The chicken application test results concluded that the colorimetric smart label was able to determine the real-time freshness of chicken by changing colour over a period of 72 hours.

Keywords: Hibiscus sabdariffa L., smart label, anthocyanin, colorimetric.

1. INTRODUCTION

In recent years, advancements in packaging technology have gained significant momentum, driven by growing demands for food safety, sustainability, and consumer needs. “Smart packaging,” which goes beyond traditional packaging to offer more functional and interactive solutions, has emerged as a promising innovation. Smart packaging refers to packaging systems that can respond to environmental factors, provide product information, or monitor the condition of the product. Through embedded sensors, interactive components, and innovative materials, these systems can perform critical functions such as monitoring food freshness, ensuring package integrity, and even providing real-time information to consumers (1-2).

Smart packaging is increasingly adopted across various industries, including food, pharmaceuticals, cosmetics, and electronics. The application of these technologies offers nu-

merous benefits, such as extending shelf life, reducing waste, increasing supply chain transparency, and minimizing negative environmental impacts (3). However, the widespread use of smart packaging also raises significant economic, legal, and ethical challenges (4).

One promising development in the field of smart packaging involves the use of natural extracts and biopolymers for the design of eco-friendly and functional packaging materials. Among these, hibiscus extract (Hibiscus sabdariffa L.) has recently gained attention as a natural colorant for food packaging, due to its vibrant colour, antioxidant properties, and biodegradability. Hibiscus extract contains anthocyanins, which are responsible for the red to purple coloration. These flavonoid compounds exhibit pH sensitivity, making them suitable for applications that require colour-changing features in response to environmental conditions (5). The colour change mechanism of hibiscus extract is based on the shift in the structure of anthocyanins, which occurs when the pH of the environment changes. In an acidic medium, anthocyanins appear red, whereas in alkaline conditions, they turn purple or blue. This property allows hibiscus extract to function as a pH indicator, providing valuable information about the freshness or spoilage of the product inside the packaging.

In addition to its role as a colorant, hibiscus extract also offers functional properties such as antimicrobial and antioxidant activities, which contribute to improving the shelf life and safety of the packaged products (5). The combination of these benefits makes hibiscus extract an attractive candidate for use in smart packaging systems.

Moreover, sodium alginate and gelatine have emerged as key biopolymers in the development of edible films and coatings. Sodium alginate, derived from brown algae, is known for its film-forming properties, biodegradability, and ability to create a moisture barrier. Gelatine, a protein-based polymer, complements these properties by providing flexibility and enhancing the mechanical strength of the films. The use of these materials as binding agents in the creation of edible packaging films not only enhances their functional properties but also promotes sustainability by offering biodegradable alternatives to synthetic polymers (6).

This paper aims to explore the design, functionality, and potential applications of smart packaging, with a particular focus on the innovative use of hibiscus extract, sodium alginate, and gelatine. It will delve into the mechanisms behind hibiscus extract's colour-changing properties, as well as the role of biopolymers in creating effective and eco-friendly packaging solutions. Additionally, the study will examine the challenges and future directions for these emerging technologies in the packaging industry.

2. MATERIAL AND METHOD

2.1. Material

In the study, sodium alginate was supplied by Carlo Erba Reagents, and gelatine was supplied by Sigma Aldrich. The hibiscus plant used in anthocyanin production is a product grown in Izmir/Turkey and was collected and dried in the dark. All solvents used were purchased from Sigma Aldrich.

2.2. Method

The dried hibiscus leaves were ground using a household blender and subsequently used in the extraction process. Following the methodologies outlined by Ramírez-Rodrigues et al. and Chumsri et al., water was selected as the solvent for extraction (7-8). A solid-to-liquid ratio of 1/40 was employed for the extraction of the dried hibiscus leaves. The process was carried out at approximately 90°C for 20 minutes, with stirring at 1000 rpm using

a heated magnetic stirrer. After the solution was filtered, the liquid extracts were concentrated under vacuum using a rotary evaporator. The remaining liquid extracts were freeze-dried with a lyophilizer. The efficiency of the obtained extract was determined using the following formula 1.

$$Extraction\ Efficiency(\%) = \frac{Produced\ hibiscus\ extract\ (g)}{Total\ amount\ of\ used\ hibiscus\ (g)} \times 100 \quad (1)$$

The colour change of the hibiscus extracts at different pH values was visually monitored, and their UV-VIS spectra were measured in the range of 400-800 nm using a UV-VIS spectrophotometer (Shimadzu 1800 UV-Vis). During the UV measurements, the pH of the solution was adjusted to the desired specified pH values by adding 1M HCl or 1M NaOH (9).
Sodium alginate and gelatine based smart films were prepared based on the method reported by Dou et al. A 4% (w/v) gelatine solution was prepared by dissolving gelatine powder in distilled water, followed by heating at 60°C under continuous stirring. Sodium alginate powder was then incorporated into the gelatine solution at a concentration of 3% (w/w, sodium alginate/gelatine), with gentle stirring at 45°C for 20 minutes in a water bath, resulting in a gelatine-sodium alginate film solution. Glycerol, used as a plasticizer at a concentration of 20% (w/w, based on the gelatine content), was subsequently added, and the solution was again heated and stirred at 45°C for 15 minutes. Finally, hibiscus anthocyanins were introduced into the solution at a concentration of 2.5%. To prevent the formation of air bubbles on the surface, the prepared film solutions were kept in an ultrasonic bath (35 kHz, 140/560 W, Wis brand WUC-D06H model) for approximately 1-2 minutes, until the air bubbles were removed, before being poured into Petri dishes. The prepared solutions were then poured into petri dishes and dried at 40°C for 24 hours. The films were removed from the Petri dishes as a whole and stored in a desiccator at room temperature in sealed petri dishes until analysis (10).
To determine the thickness and average weight of the smart films, three samples, each measuring 15mm x 15mm, were randomly selected. The weight measurements were taken using a balance, and the thickness measurements were carried out with a digital micrometre. When measuring the film thickness, readings were taken from five random points on the surface. The averages of the weight and thickness measurements were recorded (11).
The total soluble solid content of the prepared smart film in water was determined using the Peralta method. A 15mm x 15mm piece of the smart film was cut and weighed (W0). The cut film was then immersed in 30 mL of distilled water and left at room temperature for 2 hours. After removal from the water, the film was gently blotted with filter paper and any undissolved film was dried in an oven at 40°C for 24 hours. The dry weight (W2) of the film after oven drying was measured, and the solubility in water was calculated using the following formula (12). The test was repeated three times for each film formulation 2.

$$Water\ Solubility = \frac{W_0 - W_2}{W_0} \times 100 \quad (2)$$

Samples measuring 15mm x 15mm were cut from the smart film and their initial weights (W0) were measured. The cut films were then immersed in 30 mL of distilled water and left at ambient temperature for 2 hours. To remove excess surface water, filter papers were used. The final weights (W1) of the films were then recorded. The weight gain or swelling percentage (%SW) was calculated using the following formula (13). The test was repeated three times for each film formulation 3.

$$Swelling\ percentage = \frac{W_1 - W_0}{W_0} \times 100 \quad (3)$$

The chemical structure of the produced film and the anthocyanin-free control film was determined using a Perkin Elmer ATR-FTIR. The colour (L*, a*, and b*) stability of the films was evaluated using an X-rite Exact spectrophotometer. The films were stored in desiccators at 25 ± 2°C the colour parameters were assessed over a period of 28 days. To investigate the colour change of the films at different pH values, buffer solutions were used. The films, cut into 15mm x 15mm pieces, were immersed in each buffer solution (pH=4, 7, and 10) for approximately 15 minutes. After removal from the solutions, each film was placed on filter paper, gently blotted, and the colour change was recorded and compared to the initial colour. Smart film contact angle were measured with PGX pocket goniometer. The contact angles of produced films were found on Pocket Goniometer Model PG-X, version 3.4 (FIBRO Systems AB, Sweden). The images of droplets were then recorded by using a CCD video camera.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \quad (4)$$

An application test was conducted to determine the food spoilage properties of the anthocyanin-containing film. For the application test, chicken breast samples of approximately the same weight were placed in petri dishes. Anthocyanin-containing and control smart films were placed separately on top of these dishes. To ensure a sealed environment, the dishes were covered with stretch film. The experiment was conducted at 25°C and +4°C in a refrigerator. The initial colour of the films was recorded. Colour changes were monitored at specific intervals (24 hours, 48 hours, 72 hours), and the colour changes of the films were documented (14).

3. RESULTS AND DISCUSSION

The anthocyanin yield obtained from hibiscus leaves in the presence of water solvent at 90 °C for 20 minutes was calculated as 43.60%. The colour of the hibiscus extract solution containing anthocyanin visibly changed to pink, blue-purple, and green-yellow at pH values of 4, 7, and 11, respectively. The pH change causes the anthocyanin molecule's structure to shift, which causes the colour change. The colour change was like that reported literature (15). The solution initially had a pink colour under acidic conditions, suggesting the presence of colour-changing cations, but this colour soon changed to pink-purple as the colour-changing cations were converted to methanolic pseudo-bases and acidic hydroxyl groups. Anthocyanins, however, were converted into base structures that resembled green quinones at weak bases and eventually faded to yellow at strong bases. When the obtained pH values are in the acidic range, a broad anthocyanin peak around 530 nm is observed. However, as the pH shifts towards the base, this peak has been found to shift towards 630 nanometres. The relevant results are consistent with the literature (16).

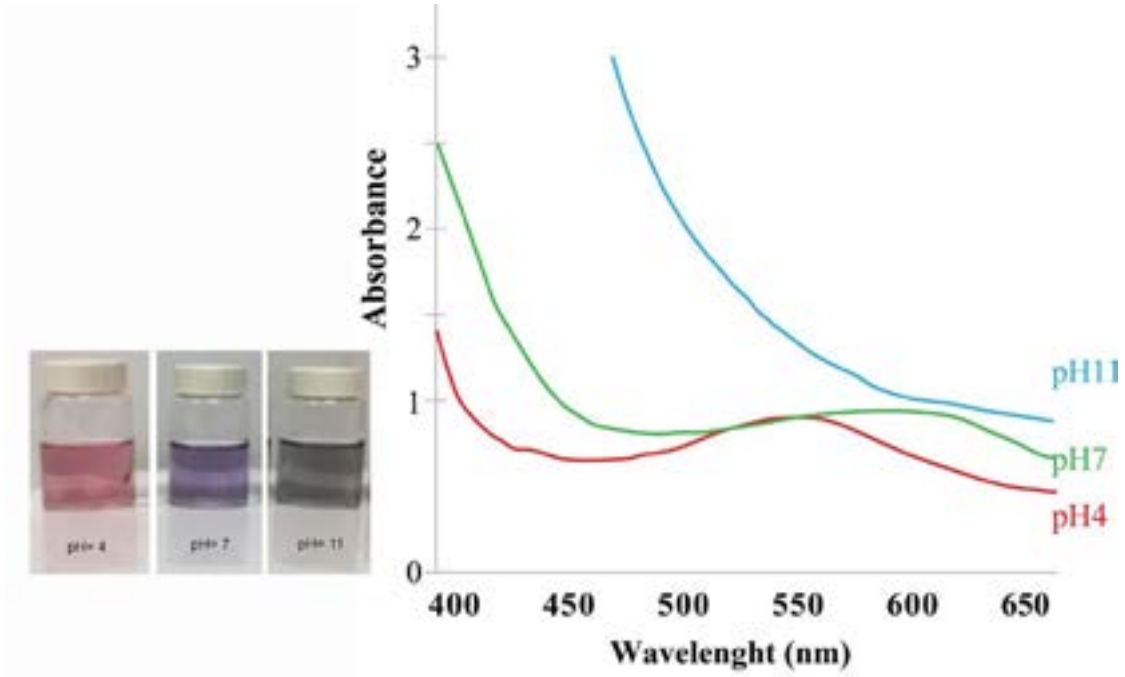

Figure 1: UV-Vis spectra of extracted anthocyanins and images at different pH values

Sodium alginate-gelatine smart films with or without anthocyanin were successfully prepared. The thickness and average weight values of the produced films were measured and are given in Table 1. When Table 1 is examined, the thickness and weight of the prepared films are very close to each other, which shows us that the film preparation was done homogeneously. There was no change in the thickness and average weight due to the very low amount of anthocyanin compared to the amount of biopolymer.

Table 1: Characterization of the Films Produced

	Sodium Alginate %	Gelatine %	Anthocyanin %	Thickness	Average weight	Swelling percentage %	Water Solubility %
Control film	50	50		0.07±0.01	0,030± 0,003	-	100
Smart film	50	50	2	0.08±0.01	0,030± 0,004	-	56.30± 2.45

In the water swelling capacity test of the films, the swelling behaviour could not be evaluated since the films disintegrated approximately 30 seconds after immersion in water. The results obtained are consistent with the literature (17).
It was determined that the film without anthocyanin was completely dissolved when immersed in water. However, the addition of anthocyanin produced from hibiscus to the film formulation significantly improved to the water resistance of the film. It was determined by Peralta et al. (12) that hydrophilic compounds such as organic acids and anthocyanins in hibiscus extract could reduce the water affinity of the biopolymeric matrix and thus reduce the film solubility. In this study, it was observed that the water solubility of hibiscus extract depended on the biopolymer from which the film was formed.

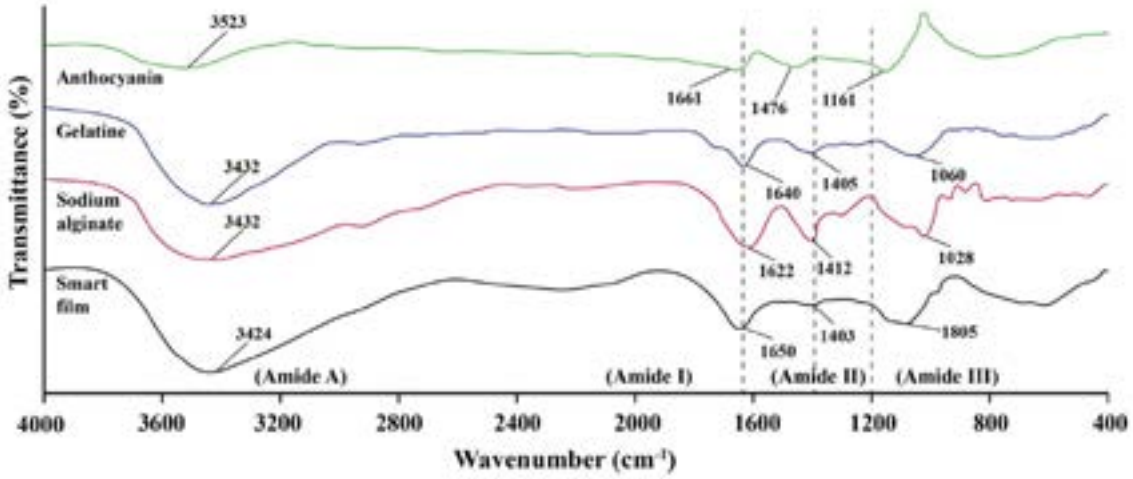

Figure 2: ATR-FTIR spectra of Anthocyanin, gelatine, sodium alginate and smart film

The ATR-FTIR analysis of the hibiscus extract revealed key peaks at 3432 cm^{-1} (O–H stretch), 1640 cm^{-1} (aromatic C=C stretch), and 1405 cm^{-1} (CH_3 stretch). For smart film, the amide A bands of sodium alginate (3432 cm^{-1}) and gelatine (3424 cm^{-1}) shifted to a higher frequency (3546 cm^{-1}), indicating hydrogen bonding due to intermolecular interactions. The smart film also showed red-shifts in the amide I, II, and III bands, suggesting electrostatic interactions between the components. Additionally, sodium alginate exhibited carbonyl stretching at 1622 cm^{-1} and 1412 cm^{-1}, associated with carboxylate ions. As anthocyanin content increased, the peaks shifted and broadened, indicating the formation of new hydrogen bonds between anthocyanin and the film matrix. The results suggest that only physical interactions, like hydrogen bonding and electrostatic forces, occurred between the sodium alginate, gelatine, and hibiscus extract. This finding is consistent with other studies on smart indicator films made from natural anthocyanins and polymers (18). The stability of the colour parameters (L*, a*, and b*) of the formed films was monitored for 28 days and measurements were taken with the help of a spectrophotometer. The graphics of the smart film were created and are given in Figure 3. It was observed that the values of the a* and b* colour parameters of the smart film increased between the 0th and 7^{th} days, and the lightness (L*) value decreased. This change may be related to the interaction of the compounds in the hibiscus extract with the two biopolymers. However, it was determined that the colour parameters of the films were stable until the end of the analysis after the seventh day and the total colour difference value (ΔE*) did not create a significant difference.

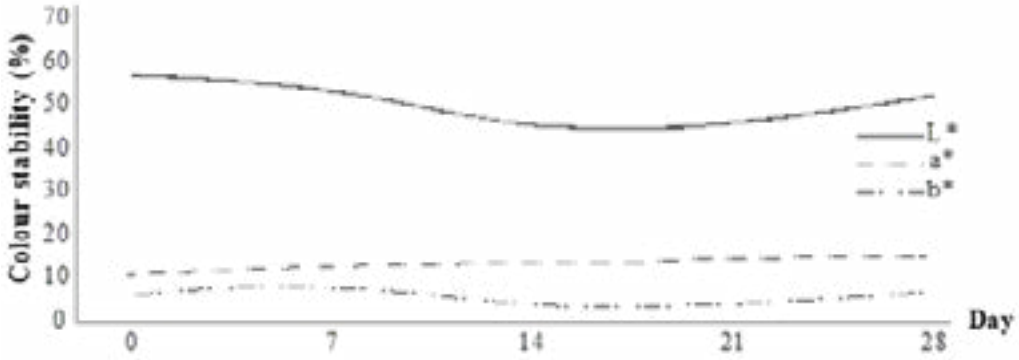

Figure 3: Colour parameters (L*, a* and b*) of smart film over 28 days

The surface water contact angle (WCA) of control film can be used to examine the hydrophilicity of the smart film, as indicated in Figure 4. Control film's' WCA was 38°, which suggests that they are hydrophilic. The water contact angle of the film decreased from 38° to 30° with an addition of anthocyanin. This may be because hibiscus anthocyanin contains a significant number of hydroxyl groups with extremely high-water absorption, which caused the WCA of the smart film to decrease with anthocyanin addition.

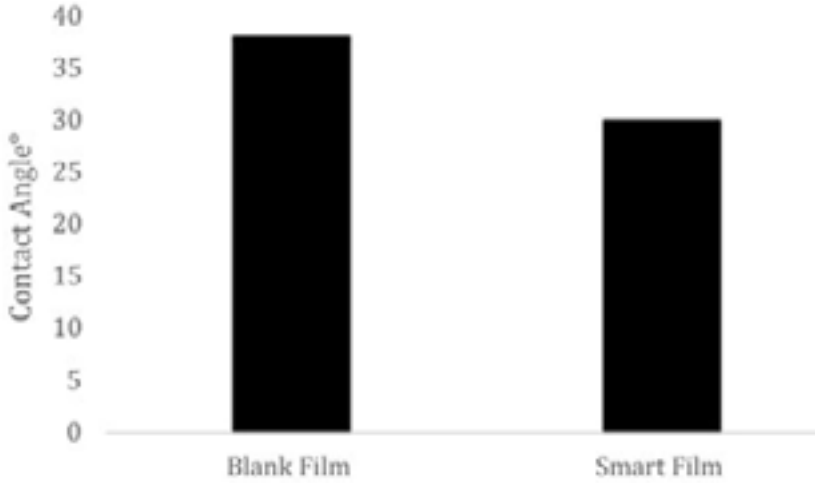

Figure 4: Water contact angle of produced films

During storage, the concentrations of volatile compounds trimethylamine (TMA), dimethylamine (DMA) and ammonia (NH_3) increase in the space between the package and the food in closed packaging due to microbial spoilage, and this increase causes the pH value to increase over time. Therefore, it is thought that there is a close relationship between pH value and food freshness. Application tests were conducted with chickens to evaluate the potential of the produced smart film to be used as a visual indicator of food spoilage and freshness. The colour change of the produced smart film is shown in Table 2. The smart film is initially pink. After 24 hours, it was observed that the colour changed from pink to yellow. After 48 and 72 hours, the film showed yellow colour at 25 °C. It has been determined that the smart film does not change colour for 72 hours at 4 °C. This shows that chicken meat can be stored in a refrigerator for 72 hours.

Table 2: Colour change of smart labels at 4 °C and 25 °C to determine chicken spoilage

Sample	0 Hour	24 Hours	48 Hours	72 Hours
+4 °C				
+25 °C				

4. CONCLUSIONS

In this study, smart label films were successfully developed using the solvent casting method. By incorporating anthocyanin extract into a biodegradable gelatine–sodium alginate polymer matrix, an effective and low-cost pH-responsive smart label film was produced. These films were applied to monitor the freshness of chicken breast samples. A distinct colour change from pink to yellow was observed after 24 hours, indicating spoilage, and this visual shift was confirmed through colorimetric analysis. Based on these findings, anthocyanin-loaded gelatine–sodium alginate films show strong potential as practical indicators for monitoring the shelf life and freshness of poultry products.

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PROTOTYPING OF BOOK BINDING - PICTURE BOOK FOR CHILDREN WITH VISUAL IMPAIRMENTS AND TACTILE ELEMENTS

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ABSTRACT

Designing a picture book for children with visual impairments, with a focus on tactile elements, was carried out with direct support from the experts. Realization binding of a book requires a specific technical-technological approach to creating the functional binding features, with the emphasis on the book block pages turning. Guidelines for the book block realization, including the Braille writing system, which aims to support good practices in the graphic materials selection as well as printing technologies choosing and post-printing technological processes determining. The best practices are also provided in the book format choice, and the paper's thickness of the book block determines whether it supports tactile elements and quality printing. Criteria for selecting the book binding type and its form are presented as standardized book binding quality goals of book products with a special purpose. The picture book prototype was tested by educational rehabilitation specialists. The prototype functionality was positively evaluated; the prototype is already used for inclusive education purposes.

Keywords: picture book prototype, tactile elements, the picture book technical-technological realization.

1. INTRODUCTION

Book prototyping for children with visual impairments requires careful selection of binding methods, materials, and design to ensure durability, accessibility, and functionality. This section presents guidelines for the prototyping process. The book must (1) withstand frequent handling and exploration by children, (2) ensure that tactile elements and Braille`s text are accessible and easy to explore, (3) use non-toxic graphic art materials with soft edges that are child-friendly, (4) integrate an accessible book design and binding style that allows easy page turning for children with motor difficulties, (5) prioritize the use of eco-friendly graphic art materials whenever possible, (6) ensure compliance with safety standards for children's products.

By incorporating a robust binding style, the book prototype must effectively meet the needs of children with visual impairments and encourage a love for reading and exploration. The prototyping workflow integrates layout sketches with tactile elements, such as Braille text, on book pages. The designer is responsible for determining the appropriate book size, selecting a suitable binding style and method, preparing tactile elements (e.g., embossed shapes and fabric textures), and designing proper alignment and spacing for a smooth reading experience. A key advantage of assembling book page prototypes is that pages can be added or replaced if the designer uses a mechanical binding method with a durable metal spiral. Currently, there is little discussion about the needs and obstacles faced by children with disabilities, yet these challenges are steadily increasing. One of the most significant issues arises in education, where children with disabilities are often not adequately integrated with their peers. Due to a lack of accessible picture books, blind children are deprived of early reading opportunities, which creates significant learning difficulties later in life. This work aims to raise awareness of the need for assistance for

children with visual impairments—assistance that can be provided in a simple yet effective way. The goal is to demonstrate a prototype of a book specifically designed for the early stages of education, particularly in kindergarten. This involves considering all essential aspects of the graphic arts process, from design and layout to printing and binding. Key design elements, such as font size, Braille text size, and image placement, must enhance the quality of the final graphic product. The expected outcome is a functional and comprehensible book prototype that incorporates adapted graphic elements into a picture book. The child should be able to use it independently, without requiring assistance to read or understand the images. Additionally, the book is lightweight, allowing the child to carry it easily and transport it from one place to another.

1.1. The role of prototyping in the book development process

Prototyping is a crucial step in turning an idea into reality. It (1) enables graphic designers and engineers to test book functionality, (2) identifies potential issues, (3) facilitates improvements before mass production, and (4) provides insights into how end users might interact with the final book product. These approaches (1–4) not only save resources and labour time but also reduce the risks associated with launching a new product on the market. Prototyping serves as the foundation for testing, gathering feedback, and continuously improving the book product. The process of transforming an idea into a prototype involves several steps: developing the core idea and product concept, creating a digital model or sketches of the product using graphic design software, producing a physical prototype of the book using binding techniques, testing and evaluating the book prototype, gathering user feedback, and refining the design before moving into the production phase [1].

The most important rule of prototyping is minimizing risks associated with mass production. Through prototype testing, problems can be identified and resolved before the final book enters large-scale production. Investing in book prototyping is a cost-effective solution that helps protect the budget. Book testing and user feedback are vital for refining the prototype. Identifying and addressing potential issues before mass production ensures a higher-quality final product. Prototyping methods, such as gathering, analyzing, and evaluating information, focus on (1) making improvements, (2) solving problems, and (3) creating enhanced prototypes. The future of prototyping lies in innovation and the use of advanced materials that enable sustainable book design. More functional, eco-friendly prototypes will not only provide a competitive advantage but also contribute to a better future for society [1].

1.2. Inclusive library programs for children with visual impairments

Children with developmental difficulties in the kindergarten and preschool education system include those with visual impairments, hearing impairments, speech and communication disorders, and personality changes caused by organic factors (such as psychosis, behavioral disorders, motor impairments, reduced intellectual abilities, autism, and multiple disabilities). Additionally, children with health issues and neurological impairments (including diabetes, asthma, heart conditions, allergies, and epilepsy) are also considered within this group [2].

Library inclusion is measured by the diversity of resource collections, which may include Braille books, large print materials, tactile resources, and dual-format books. Individuals with standardized reading difficulties have the same reading needs as other library users. Access to various popular educational resources should be available for different age groups [3]. Useful resources include audio-books, large print books, easy-to-read books, Braille books, video/DVD books with subtitles and/or sign language, e-books, and tactile picture books all of which support stakeholder inclusion within the library system [4].

These materials are specifically tailored for children who experience difficulties reading standard print. However, inclusive library programs provide limited support for organized activities related to creating tactile picture books. A shortage of library staff and reduced operational effectiveness hinder the development of inclusive library concepts. Accessible services for children with reading difficulties require the establishment of high-quality partnerships and collaboration with various external stakeholders [5,6], who play a crucial role in promoting the prototyping of tactile picture books.

1.3. Braille implementation in inclusive early childhood education settings

Implementing Braille is a vital step toward creating equitable learning environments. The combination of accessible graphic art materials in tactile book design and teacher training through supportive technologies empowers the inclusion of children in the early education system. This fosters an interest in learning and supports progress in later life stages. Integrating Braille into early childhood education is essential for ensuring equal learning opportunities. Introducing Braille at a young age supports literacy development and builds foundational knowledge and skills that enhance children's overall learning experience. Tactile illustrations and embossed graphics complement Braille text, enhancing the reading process. Teachers should be trained in Braille literacy and tactile teaching techniques to ensure an inclusive learning environment.

Assistive technologies, such as Braille typewriters, electronic Braille displays, and embossers, provide diverse tools for the learning environment. The use of dual-format resources (Braille and print) promotes interaction between visually impaired and sighted children. By utilizing these resources, children and parents can collaborate more effectively, extending Braille literacy training into the home. Technologies facilitate partnerships between families, educators, and specialists, supporting a child's continuous learning journey. Moreover, encouraging social inclusion fosters empathy, as children share their experiences in an equitable learning environment. Early Braille implementation strengthens reading and writing proficiency, which is critical for future academic success. Encouraging positive interactions and reducing stigma help promote a sense of belonging in society for visually impaired children [7].

Louis Braille lost his sight at a very young age, which inspired him to modify the "night writing" code and create an efficient written communication system for fellow blind individuals. Braille is a unique system (Fig. 1) of touch reading and writing for blind persons, in which raised dots represent alphabet letters. Braille is read by moving the hands from left to right along each line, with both hands engaged in the process and the index fingers primarily responsible for reading. Braille code is divided into three grades: Grade 1 consists of the 26 standard alphabet letters and punctuation, which are integrated into early childhood education settings; Grade 2 includes contractions that are commonly found in printed books; Grade 3 further shortens entire words to just a few letters for faster reading and writing [8].

Figure 1: Braille unique system [8]

2. THE ENGINEERING COMPREHENSION OF BINDERY STRATEGIES

Bindery efficiency is often challenged by technologically inappropriate book design concepts (Fig. 2). Designers frequently lack the technological knowledge and practical experience needed to anticipate binding limitations. The absence of expertise in following technical-technological procedures (ISO 16763:2016 and Framework for ISO/TC 130 Standards – Graphic Technology: 2019), as well as standard paper grades (EN 643:2001 Group 3), leads to inefficient resource utilization and increased technological waste, which directly reduces the efficiency of binding procedures. Consequently, departments such as prepress, printing, and bindery fail to meet technological expectations due to incorrect binding style solutions. For this reason, designers must rely on well-established technological practices to implement optimal book design concepts that align with bindery efficiency [9,10].

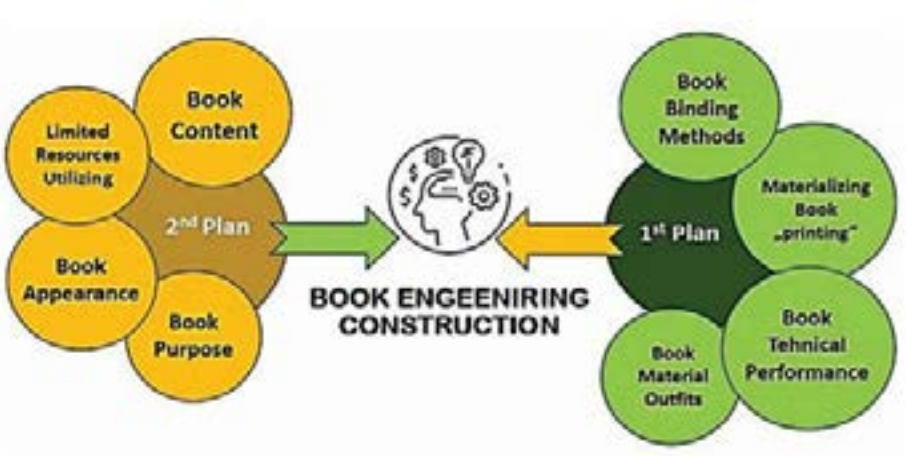

Figure 2: Book binding construction principles [10]

2.1. A comprehensive approach to book designing

Creative cognitive visualization helps everyone understand problems. Moreover, designers should create a book prototype and ask themselves, "Which standardized paper grade, including its grammage, provides the best binding style solutions?" By answering this question, awareness of book design concepts fosters new approaches and strategies

through bookbinder recommendations. Connecting current experiences with prior comprehensive binding knowledge leads to successful book design. Designers must try to clearly explain their design concepts to bookbinders. It is essential to understand various manufacturing procedures and technical and technological binding processes, both manual and mechanical. Designers should also be aware of the significant differences between short-run and large-scale binding production. Additionally, the intended purpose of the book must be determined long before it is sent for binding. Therefore, designers should develop advanced approaches to determine which binding forms and types are most suitable for the book's content. Enhancing book design strategies improves bindery efficiency. Bookbinders can produce high-quality books with superior visual and tactile performance and greater durability only if designers implement comprehensive bookbinding practices and concepts that meet end-user expectations [10,11]. Key strategies for planning, organizing, and ensuring the quality of book binding production begin with the analysis of the Request for a Quote—which includes details such as types and forms of binding, number of copies, quantity of bookbinding materials, delivery deadlines for semi-finished products and raw materials, and specific customer requirements [12].

3. PICTURE BOOK PROTOTYPING IN GRAPHIC ART DEPARTMENTS

The picture book prototype model consists of 16 pages in total, formatted on DIN A4 wide paper. The selected binding style includes a metal spiral and two trimmed hard cases. The book block design is enhanced with illustrations, important typography, and tactile elements. Font choices and spacing have a significant impact on the reading experience, particularly for individuals with visual impairments. Overall, the selected font and layout design work together harmoniously to ensure an optimal reading flow. Additionally, the inclusion of assistive Braille letters significantly promotes Braille literacy. The prototyping model procedures are precisely presented in Figure 3, along with the digital production system used (prepress, Braille digital printing technology, and craft bookbinding). Prototype procedures were carried out within a SEM enterprise for commercial publishing.

The page layout includes black text and multi-coloured illustrations designed to attract attention. In prepress, the assembled graphic elements (text and pictures) of complete pages are placed onto the printed sheets. The use of desktop publishing enhances efficiency in editing graphic elements. Knowledge and practical skills are crucial for understanding the printing and binding processes.

Digital (non-impact) printing technology significantly supports book model prototyping by reducing final production time, from assembling graphic elements on printed sheets to the book block. Moreover, advanced digital technologies enable the printing of Braille letters and tactile elements.

Unlike printing and prepress, the craft bookbinding process in the finishing section is not automated. Due to the complexity of the process, more manual intervention is required, especially for very short proof copies and medium print runs. Complete digitalization is only achieved when specific finishing processes, such as wire stitching, punching, and perfect binding, are incorporated into digital technologies. The functionality of the prototyping model depends on the preceding stages (prepress and printing). The organization of the binding procedure is essential for structuring individual processes (cutting, folding, gathering, binding style solutions, etc.), considering the transformation of semi-finished products and graphic art materials. The combination of the book block and cover (two hard cases) with a metal spiral results in a high-quality prototype picture book model.

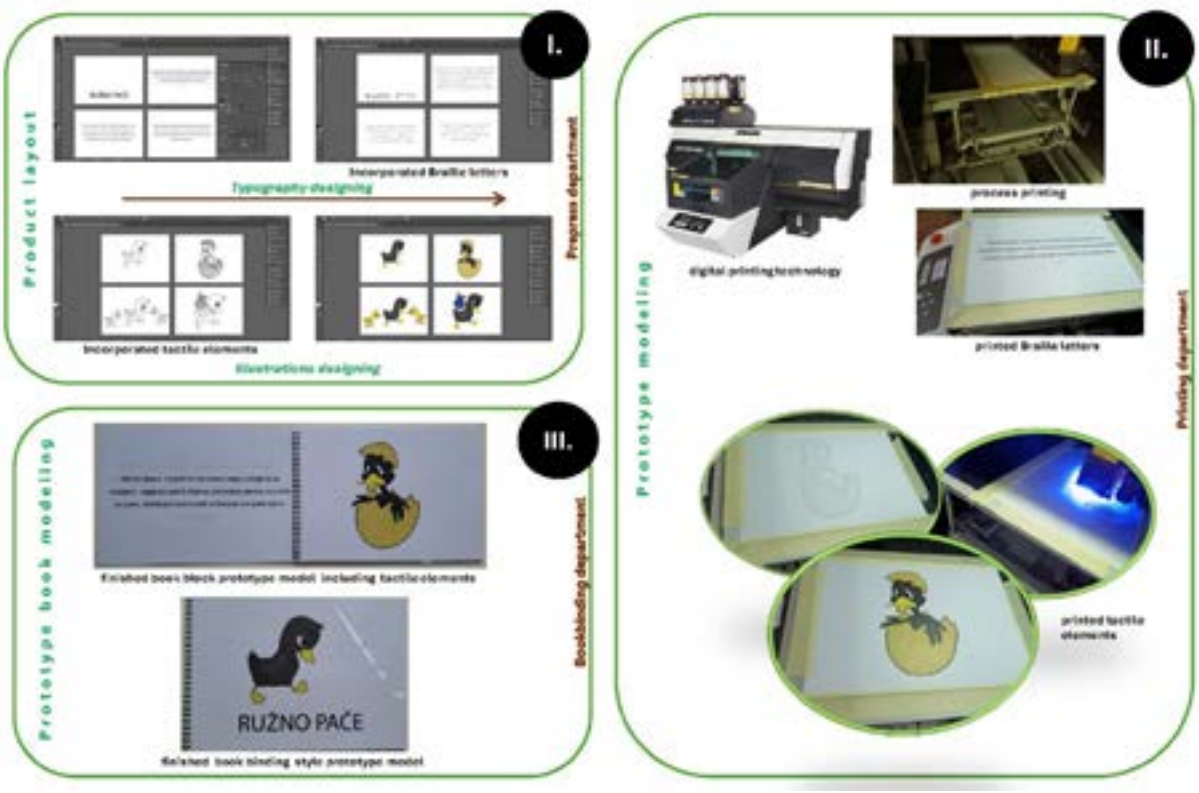

Figure 3: Book binding construction principles [13]

After production, children tested the picture book prototype to evaluate its functionality. All necessary conditions were met. An eight-year-old blind child interacted with the picture book, and the results were more than satisfactory. The child could easily navigate the text and illustrations within the book block. The prototype model not only met aesthetic requirements but also proved to be highly functional. Moreover, the prototype demonstrates how graphic design can positively impact the quality of life for people with disabilities.

4. CONCLUSION

Appropriately chosen graphic arts engineering concepts ensure both binding efficiency and book durability. The book prototype design maximizes the utilization of available technological capacities. A book designer's knowledge and practical skills play a crucial role in enhancing the efficiency of graphic art production. Individuals need to be familiar with technological practices across different graphic art departments.

Considering bookshelf life, prototyping procedures must satisfy both visual and tactile aspects of the book's appearance. Designers have to rely on verified graphic art practices based on both current experience and prior comprehensive knowledge. Moreover, designers must be aware that book design concepts should follow sustainable approaches and strategies. Future book prototyping should seamlessly integrate certified eco-friendly graphic art materials through standardized print production frameworks.

The tactile picture book The Ugly Duckling exceeded expectations in all aspects. The process lasted more than four months and required the application of knowledge acquired at the Faculty of Graphic Arts, particularly in the fields of craft bookbinding, photography reproduction, and print processing. Designed for preschool and early school-age children,

the picture book successfully provides clear visual and tactile information to aid comprehension. Prototype testing demonstrated excellent functionality of the book model.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

STRATEGIC INTEGRATION OF COVERT ADVERTISING IN CONTEMPORARY MEDIA: ETHICAL, COGNITIVE, AND REGULATORY DIMENSIONS

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ABSTRACT

This practice raises critical discussions on ethical boundaries and regulatory oversight in contemporary communication channels. The paper analyzes the theoretical foundations of covert advertising, its modalities, and its implications for consumer perception, distinguishing between visual, auditory, and narratively embedded advertising across film, television, print media, digital platforms, and news programming.
The empirical segment of the study is based on a survey of 107 respondents, assessing their recognition of covert advertising, its moral acceptability, and its influence on consumer decision-making. Findings indicate a high level of awareness, with audiovisual media emerging as the dominant channel for covert promotional content. Moreover, respondents' moral perceptions vary, predominantly oscillating between neutrality and disapproval, with most advocating for clearer and more explicit labeling of advertising within media narratives.
In conclusion, covert advertising remains an integral component of modern marketing strategies but simultaneously presents challenges in ethical regulation and consumer protection. Future research should refine regulatory frameworks to balance advertisers' strategic objectives with consumers' fundamental right to transparent and informed media consumption.

Keywords: covert advertising, strategic communication, audiovisual media, consumer perception, ethical regulation.

1. INTRODUCTION

In today's digital environment, characterized by a multiplicity of communication channels and increasingly sophisticated advertising techniques, consumers are more frequently exposed to promotional messages that are not explicitly identified as advertising. One such technique, known as covert advertising, involves the integration of promotional content into media formats in a way that maintains the narrative and visual coherence of the content while subtly influencing consumer perception and behavior.
Covert advertising is especially prevalent in audiovisual media, social networks, print publications, and other platforms that enable the inconspicuous positioning of products, services, or brands. This form of communication raises a number of concerns related to ethics, transparency, and the consumer's right to make informed choices. Amid market saturation and growing resistance to conventional advertising, covert advertising is emerging as a dominant strategy through which advertisers seek to reach their target audiences in emotionally and perceptually acceptable ways.
The aim of this paper is to provide a theoretical and empirical analysis of covert advertising as a form of strategic marketing communication in contemporary media. The focus lies on understanding how consumers perceive covert advertising across different media formats, particularly in relation to its modalities (visual, auditory, and narratively embed-

ded), its recognizability, ethical acceptability, and the perceived need for regulatory transparency.
The empirical segment of the study presents a quantitative analysis based on a sample of 107 respondents, examining how covert advertising is cognitively processed, morally evaluated, and positioned in terms of its influence on consumer decision-making.
This research contributes to a deeper understanding of the complexity of covert advertising and its implications for the media and information environment, offering a foundation for future studies and regulatory considerations.

2. RESEARCH BACKGROUND

Alongside product, price, and distribution, advertising represents a key component of the marketing mix, encompassing all activities aimed at attracting the attention and interest of the target audience. Its role is not merely informative, but also educational, persuasive, and differentiating, with the objective of increasing brand awareness and stimulating consumer behavior [1]. In the digital era, advertising has undergone rapid development, with over 4.8 billion internet users worldwide and more than 3.1 million in Croatia [2].
Advertising is the most recognizable form of sales promotion and refers to paid, non-personal communication directed at a broad audience, intended to inform consumers and influence their attitudes [3]. Despite the common belief that advertising directly drives sales, in modern business environments it is increasingly regarded as a necessary condition for market visibility, a condicio sine qua non for product or service awareness [4].
Within the broader advertising context, particularly in digital media, covert forms of advertising have emerged, those that do not openly disclose their commercial intent. Covert advertising, or product placement, refers to the integration of a product or service into media content without clearly identifying it as advertising [5]. This communication strategy utilizes narrative, visual, and auditory elements to seamlessly embed the message within the content, reducing its perceived promotional nature while increasing its persuasive potential [6]. These processes are closely linked to cognitive frameworks such as media literacy, which encompasses an individual's capacity to access, analyze, and critically evaluate media content [7]. Additionally, the concept of persuasion knowledge refers to the consumer's ability to recognize persuasive intent and respond accordingly [8]. Both constructs are essential for understanding how covert advertising is processed and morally assessed, particularly in environments saturated with subtle promotional cues.
As traditional advertising becomes increasingly saturated and consumers develop resistance to overt commercial messages, covert advertising is becoming a dominant strategy of influence, especially in audiovisual and digital media [5]. In this context, advertisers aim to trigger emotional identification by embedding products in scenarios, characters, or narratives that resonate with the audience [9].
There are three main modalities of covert advertising: visual (where the product is shown on screen), auditory (where the product or brand is mentioned in dialogue), and integrated (where the product is an essential part of the storyline) [6]. Moreover, covert advertising can be categorized by the medium in which it appears, film, television, print media, social media, music videos, and news programs, as well as by the method through which information is conveyed [9].
In films, for example, Top Gun (1986) featured Ray-Ban Aviator sunglasses and a pilot's jacket as elements of character development, which contributed to a 40% surge in the brand's sales [10,11]. Similarly, in television series, recurring product appearances build a connection between viewers and fictional characters. The iconic example of Sex and the City, where Manolo Blahnik shoes appeared in only 16 of 94 episodes, led to the global recognition of the brand [12,13].
Print media use covert advertising through editorial content, fashion layouts, or subtle

product mentions, as seen in the example of the iPhone in Attitude magazine [14,15]. In digital environments, especially on platforms like Instagram, influencers frequently embed products into their daily content without clear disclosures, further blurring the line between personal expression and commercial intent [16].
The music industry also embraces product placement, with brands appearing in music videos as props, visual motifs, or even lyrical references. Ariana Grande's video for Focus, which prominently features the Samsung Galaxy Note 5, demonstrates how a brand can align with the thematic content of the video [17].
A similar pattern is observed in reality and news programs, where products appear visibly on screen and presenters often wear or use items from partner brands, as seen with Cedevita GO in the Croatian version of show Pop Idol [18].
Covert advertising can also be classified by the strategy of information delivery: standard (product appearance without emphasis), narratively embedded (the brand becomes part of the plot, e.g., Coca-Cola in Stranger Things) [19,20], and verbal where the brand is mentioned but not shown (e.g., Ralph Lauren in Friends) [21].
Despite its effectiveness, covert advertising raises a range of ethical and regulatory concerns, as consumers are often unaware that they are being targeted by commercial messages, limiting their ability to make informed choices [5]. This has prompted increasing calls by regulators and industry bodies for transparent labeling of sponsored content across all forms of media.
In the European context, the Audiovisual Media Services Directive (AVMSD) sets standards for transparency in commercial content, including requirements for identifying sponsorship and product placement in broadcast and on-demand services [22,23]. Additionally, many countries have adopted self-regulatory advertising codes, such as the International Chamber of Commerce (ICC) Code, which outlines principles for honest and transparent communication, including covert advertising practices [24]. These frameworks provide a basis for interpreting the ethical and legal boundaries discussed in this paper.

3. METHODOLOGY

The empirical part of the paper is based on a quantitative study conducted using a structured questionnaire, with the aim of examining the level of awareness, moral evaluation, and influence of covert advertising on consumer perception and behavior. The research also investigates respondents' views on the ethical acceptability of such practices and the perceived need for clearer labeling of advertising content.
The research instrument was a closed-end survey questionnaire consisting of 15 questions. Most of the items included predefined responses, covering dichotomous questions, frequency scales, Likert-type rating scales, and multiple-choice formats. Certain questions offered an "Other" option for supplementary comments; however, these inputs were not analyzed as qualitative data and were reported only descriptively, without interpretative coding.
The questionnaire was structured into two main sections:

- a demographic section, collecting data on gender, age group, and education level;
- and a thematic section, focusing on awareness and recognition of covert advertising across various media formats, its perceived moral implications, and influence on consumer decision-making, including views on the need for regulatory intervention.

The survey was distributed online via social media and communication platforms (Facebook, Instagram, WhatsApp) between June 18 and June 27, 2024.
A total of 107 respondents completed the survey in full. Participation was voluntary and anonymous, and all respondents were informed in advance that their data would be used solely for the scientific purposes of the thesis.

The sample was convenient and non-probabilistic, but included a heterogeneous group in terms of age, gender, and education. Respondents ranged from 18 years of age and above, with educational backgrounds spanning from primary school to postgraduate qualifications. Although not representative of the general population, the sample provided relevant insights into consumer attitudes within contemporary digital and media environments.
To guide the empirical inquiry, the study was framed around the following central research question: "How do consumers perceive covert advertising across different media formats, in terms of its recognizability, ethical acceptability, and the perceived need for regulatory intervention?"
This question integrates the key analytical dimensions addressed in the questionnaire and reflects the theoretical emphasis of the paper. It enables the examination of both cognitive and evaluative aspects of consumer perception, how covert advertising is recognized, morally assessed, and positioned within broader expectations of transparency in media communication. The study adopts an exploratory-descriptive approach, aiming to capture patterns and tendencies in consumer responses that inform ongoing discussions on advertising ethics, media literacy, and regulatory frameworks.
Collected data were analyzed using descriptive statistical methods, including frequency distributions and percentage calculations, to identify dominant patterns in perception and consumer responses. Specific statements were further examined in relation to media types and the perceived intensity of influence on consumer behavior.

4. RESULTS AND DISCUSSION

The research sample consisted of 107 respondents of various ages, genders, and educational levels. The majority of participants were between 18 and 25 years old (54.2%), indicating a strong representation of the younger population, which is also the most exposed to digital media where covert advertising is prevalent. This group was followed by respondents aged 26 to 45 (25.23%), while 15.09% of participants were aged between 46 and 65. The smallest group consisted of those over 65 years old, making up only 5.6% of the sample. This age distribution further emphasizes that the findings largely reflect the perceptions of younger and digitally active consumers. In terms of gender, women constituted the majority of respondents. Regarding education, the dominant profile consisted of respondents with vocational or secondary school qualifications (72.89%). Only 18.69% held an undergraduate or graduate degree, and a smaller portion (2.8%) had completed postgraduate studies. Respondents with no or lower-level qualifications accounted for 5.6%. This structure indicates a sample primarily composed of individuals with mid-level education, which should be considered when interpreting the generalizability of the results. The sample composition suggests that the findings primarily reflect the attitudes of a younger, media-literate, and highly educated population, the group most frequently exposed to covert advertising, but also most capable of recognizing and critically assessing it. Therefore, the results should be interpreted within the context of digitally active and communication, aware users, further underscoring the importance of their awareness regarding the need for regulatory transparency.
While the sample composition offers valuable insights into the perceptions of younger, media-literate individuals, it is important to emphasize that the sample was not representative of the general population. Its structure reflects the distribution context, primarily relying on academic and peer networks, which naturally resulted in a predominance of younger respondents. This limitation should be considered when interpreting the results, especially regarding their generalizability to broader demographic groups. Future research should aim to include a more demographically diverse sample, employing varied distribution channels to capture attitudes across different age, education, and media exposure profiles. This would contribute to a more comprehensive understanding of how

covert advertising is perceived across society.
The survey provided valuable insights into consumer perceptions of covert advertising in contemporary media formats. Data analysis reveals a high level of awareness, with 91.59% of respondents reporting that they had heard of the term, while only 8.41% stated they were unfamiliar with it. This finding confirms that covert advertising is widely recognized among media users and suggests that the concept has become embedded in public discourse, especially among audiences exposed to modern communication channels. Most participants described themselves as being "well" or "very well" familiar with this type of advertising, while only a small portion rated their familiarity as "low" or "none" (Figure 1). Most participants described themselves as being "well" or "very well" familiar with this type of advertising, while only a small portion rated their familiarity as "low" or "none" (Figure 1). In more detail, the largest percentage of respondents (39.25%) reported being moderately familiar with the concept of covert advertising. A slightly smaller percentage (24.3%) stated they were well acquainted with it, while 18.69% claimed to be very well informed. On the other hand, 14.02% of participants declared they were only slightly familiar, and just 3.74% reported having no familiarity with the term at all. These results suggest that while a majority of respondents possess at least a moderate level of understanding, there is still room for improvement in media literacy related to covert marketing techniques.

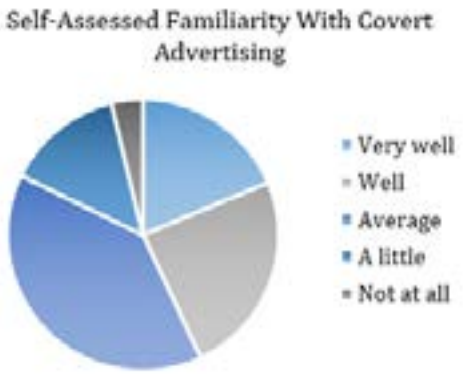

Figure 1: Respondents' self-assessed level of familiarity with covert advertising

Covert advertising is most frequently recognized in audiovisual and digital media. When asked whether they can identify such advertising in films, series, TV shows, music videos, and online formats (such as influencer content, vlogs, and livestreams), respondents most commonly answered "most of the time" or "occasionally," with both categories represented by 38.31% of participants. A smaller percentage reported that they can "always" recognize covert advertising (13.08%), while even fewer admitted they can do so "rarely" (7.48%) or "never" (2.8%) (Figure 2). This suggests that audiences are frequently aware of covert promotional techniques in dynamic, narrative-rich visual content, but this recognition is not absolute and tends to fluctuate depending on the media context.

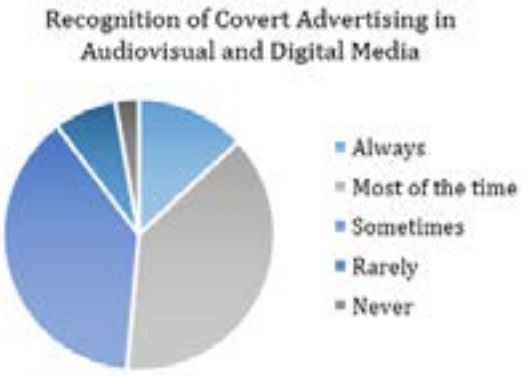

Figure 2: Respondents' recognition levels of covert advertising across audiovisual and digital content

In contrast, the recognizability of covert advertising in print media is considerably lower. The most frequent response was "occasionally" (41.12%), followed by "most of the time" (27.10%). Only 9.35% of respondents claimed they can always identify it in print, while a larger share stated they could do so only "rarely" (20.56%) or "never" (1.87%) (Figure 3). These findings suggest that the static and text-based nature of print makes covert advertising less noticeable, or at least less frequently detected, compared to its audiovisual counterparts.

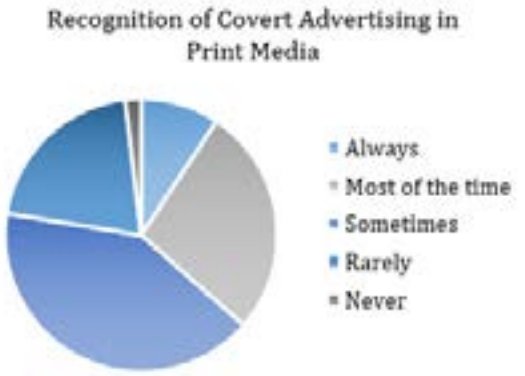

Figure 3: Respondents' recognition levels of covert advertising in newspapers, magazines, and books

This supports the argument that the audiovisual context is particularly conducive to the integration of covert advertising, due to the combination of narrative, visual, and auditory elements.

The ways in which respondents recognize covert advertising in audiovisual and digital content span a wide range of visual and narrative cues. The most commonly identified form involves situations where main characters use a specific product, reported by 52.34% of respondents. Close behind, 51.40% noticed products appearing in the background across multiple scenes, while 44.86% recognized covert advertising when a product was clearly visible on screen. The distribution of responses highlights that the most easily identifiable elements are those that are physically prominent in the frame and directly associated with the behavior or identity of the characters.

Conversely, some forms of covert advertising are far less recognizable. Only 20.56% of respondents noticed instances in which products were portrayed as solutions to characters' problems, and just 22.42% recognized products featured during dramatic or pivotal

moments in the storyline. Likewise, brand integration in song lyrics was seldom identified as advertising, with only 24.3% of respondents recognizing this form. These results indicate that more subtle, emotionally encoded strategies are considerably harder to detect and therefore potentially more effective, yet simultaneously more ethically problematic, precisely because they bypass the viewer's conscious awareness.

In print media, respondents most frequently recognize covert advertising through sponsored articles, which were identified as advertising by 57.64% of participants. This was followed by visual elements such as products featured in photographs, noted by 43.92% of respondents, and promotional stories and interviews, which were perceived as covert advertising by 41.12%. The findings imply that readers tend to identify covert commercial intent when editorial-style texts are paired with promotional purposes, especially when accompanied by product visuals.

Less recognizable forms include stylized infographics featuring prominent brands, which were identified by only 18.70% of respondents, and advertising that does not resemble traditional advertisements, noticed by just 16.82%. Similarly, discreet brand logos embedded within articles and product mentions in news stories or reports were detected by only 23–24% of respondents. These findings suggest that visually subtle and structurally integrated advertising elements often escape reader awareness, highlighting the complexity and effectiveness of covert advertising strategies in print media.

Upon being asked to evaluate the moral acceptability of covert advertising, the majority of respondents (43.92%) adopted a neutral stance. A total of 23.36% considered it "partially acceptable", while only 9.61% found it to be "completely acceptable". On the other side of the spectrum, 17.56% of participants viewed covert advertising as "partially unacceptable", and 5.61% deemed it "completely unacceptable". These results reveal an ethically ambivalent attitude among respondents, where neutrality dominates, but with notable portions expressing either approval or disapproval. This distribution confirms that covert advertising is perceived as ethically complex, lacking a unified moral consensus among consumers.

When it comes to influencing behavior, more than half of respondents admit that covert advertising "sometimes" or "often" affects their purchasing decisions, while a smaller portion claim that it has no impact. Specifically, 42.99% of participants stated that covert advertising occasionally influences their purchasing decisions, while 13.08% said it affects them most of the time. An additional 2.8% reported that it always influences their decisions. On the other hand, 28.03% of respondents indicated that covert advertising rarely influences them, and 13.08% believe it has no influence at all (Figure 4). These results underscore the persuasive power of covert advertising, even when consumers are consciously aware of its presence, and suggest that its impact often operates below the threshold of full awareness.

Figure 4: Respondents' perception of the influence of covert advertising on purchasing decisions

A significant majority of respondents (45.79%) believe that covert advertising should be more clearly labeled, indicating a strong demand for increased transparency and tighter regulation of communication practices. A smaller but still considerable portion of participants (32.71%) consider this issue irrelevant, while only 21.49% believe that clearer labeling is unnecessary. These findings underline a prevailing concern for ethical clarity in media content and emphasize the perceived need for consumer protection in an increasingly saturated and ambiguous advertising environment.

When asked about their acceptance of covertly advertised products, the majority of respondents (66.35%) stated that their willingness depends on the specific product or service. A smaller percentage indicated that they are generally willing to accept such products (18.69%), while 10.28% expressed unwillingness to do so. Only 4.67% said that their acceptance would depend on the price (Figure 5). The data further illustrates the ambivalent nature of consumer attitudes, ethical reservations regarding covert advertising do not necessarily preclude a willingness to consume, especially when the offer is perceived as attractive or personally relevant.

Figure 5: Respondents' acceptance of covert advertising based on product type or price

According to respondents' perceptions, covert advertising appears most frequently in influencer content, identified as the dominant channel by 76.63% of participants. This is followed by social media platforms, noted by 62.62%, and both television series and shows, each cited by 47.66% of respondents. These results confirm that digital and audiovisual formats are the primary platforms for the dissemination of covert advertising messages, likely due to their ubiquity in everyday life and their ability to establish emotional reso-

nance with the audience.
Conversely, the lowest levels of recognition were recorded in books, where only 3.73% of respondents identified the presence of covert advertising, followed by video games (10.28%) and live streams and tutorials (14.95%). These findings may reflect the less frequent or more subtle nature of advertising in these formats, or they may suggest a limited awareness among respondents regarding how covert advertising manifests in these specific channels.
In addition, respondents were asked to assess the effectiveness of covert advertising in enhancing brand recognition. The majority considered it effective (40.19%) or very effective (31.78%), confirming the strategic relevance of covert advertising despite ongoing ethical concerns. A smaller proportion of respondents rated covert advertising as neutral (17.76%), slightly effective (9.34%), or not effective at all (0.93%) (Figure 6). These findings reinforce the view that while covert advertising strategies may provoke ethical reservations, their functional impact on consumer brand perception remains significant.

Figure 6: Respondents' assessment of covert advertising effectiveness in brand visibility

The results obtained strongly support the key claims presented in the executive summary, confirming that covert advertising not only exists as a prevalent communication phenomenon, but also raises serious ethical concerns and calls for regulatory oversight.
The high level of awareness of covert advertising among respondents reinforces the notion that it is a widespread practice, one that is familiar to consumers, yet often not clearly identified as advertising. This further substantiates the study's conclusion that covert advertising is effective precisely because it avoids explicit labeling, thereby challenging the boundaries of acceptable communication.
The findings on recognizability across media channels are also consistently aligned with the summary's assertion that audiovisual formats represent the primary domain for covert advertising. Films, series, music videos, influencer content, and social media are perceived as the key spaces where advertising is "disguised" as content, blurring the line between information and promotion.
Ethical considerations emerge as a central theme in both the summary and the data: the moral evaluation of covert advertising among respondents predominantly ranges from neutral to negative, confirming that such practices are widely seen as controversial. Most participants expressed the belief that covert promotional content should be more clearly labeled, directly supporting the conclusion that transparency and informed media consumption are essential.
While ethical justifications remain contested, the majority of respondents acknowledge the effectiveness of covert advertising in boosting brand awareness and influencing purchasing decisions. This ambivalent perception, ethically questionable, yet functionally successful, illustrates the complexity of contemporary consumer attitudes toward adver-

tising communication.
Ultimately, the findings confirm the summary's concluding argument that covert advertising, although a fundamental component of modern marketing strategies, presents a systemic challenge in terms of consumer protection and the regulation of market communication. The need for updated regulatory frameworks, as emphasized in the executive summary, is empirically substantiated by the results of this study.

5. CONCLUSION

The research conducted in this study confirmed that covert advertising is a widespread and deeply embedded strategy in contemporary media, particularly within digital and audiovisual formats. Respondents' high awareness of such practices, along with their ability to recognize them, especially in content such as films, series, music videos, and influencer posts, suggests the development of media literacy and a critical stance toward covert promotional messaging.
However, the results also reveal a degree of ambivalence in respondents' attitudes. While the majority believe that covert advertising should be more explicitly labeled, highlighting the need for greater regulatory transparency, they simultaneously acknowledge its effectiveness in enhancing brand recognition and influencing their own purchasing behavior. This duality between ethical concern and pragmatic acceptance of commercial content underscores the complexity of the modern communication environment.
In conclusion, the paper demonstrates that although covert advertising is highly effective as a strategic communication tool, it raises important questions regarding ethics, consumers' right to informed choice, and the necessity of a clearer regulatory framework. Future research and policy efforts should focus on achieving a balance between the legitimate interests of advertisers and the public's right to transparent and accountable media communication.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

THE POTENTIAL FOR INCREASE OF THE ACCURACY OF DARK COLOUR MEASUREMENTS AFTER WATER-DISPERSIBLE WARNISHING

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ABSTRACT

The measurability and predictability of the printing process are significantly influenced by the method of water-based varnishing. While the primary function of this varnishing is to protect and enhance print quality, it can also induce changes in the colourimetric properties of solid colours, particularly in dark tones, across various wavelengths. Within this study, colour transfer models based on mathematical formulations were analyzed, with a specific focus on models developed to assess colourimetric changes in situations involving overlapping solid colours. The aim of the research was to investigate the impact of water-based varnishing on the colourimetric properties of dark tones and to evaluate the applicability of predictive models under such conditions. To quantify the colour changes induced by water-based varnishing, spectrophotometric and densitometric methods were employed in combination with mathematical analysis. The results clearly demonstrate that water-based varnishing significantly affects the colourimetric values of dark tones, causing variations that may pose challenges for maintaining colour consistency in the printing process. Although the study suggests certain limitations of existing models in accurately predicting colour changes under these conditions, it also indicates that the model can still be useful for improving the repeatability and stability of the process. Previous research has established the need to introduce a correction coefficient to enhance the accuracy of such measurements. In this work, correction coefficients for water-based varnishing were investigated. These coefficients aim to refine the predictive models and provide a more precise assessment of colourimetric changes, thereby contributing to better control and optimization of the printing process.

Keywords: Colourimetric changes; water-disperisble coating, coefficient V.

1. INTRODUCTION

Water-based varnishing is a coating technique in which the water from the varnish penetrates the printed substrate, while drying occurs through evaporation facilitated by infrared (IR) radiation or hot air. This coating method can be applied to cover the entire surface or used for partial spot varnishing [1]. One of the primary advantages of water-based varnishing is its ability to protect prints from mechanical damage, such as scratches and abrasion, thereby extending the durability of printed materials. Additionally, this coating reduces ink transfer, improving resistance to dirt and facilitating the handling of printed products. Furthermore, it shortens ink drying time, enabling faster subsequent processing and enhancing the efficiency of the production process.

Water-based varnishes enhance the visual appearance of prints by increasing gloss and providing a more professional finish. Depending on the application, they can also be used to create specific visual effects by combining glossy and matte surfaces. They are particularly beneficial for dark colours within the spectrum, as they help maintain colour intensity by minimizing undesirable changes caused by light or other external factors.

The composition of water-based varnishes includes modified acrylic resins, water-soluble

resins, waxes, and various additives, all suspended in water. The solid content of these varnishes typically ranges between 35% and 45%. Despite their numerous advantages, a challenge in the application of water-based varnishes is the unintended transfer of varnish and ink to rubber rollers, which can cause machine downtime. However, the use of specialized rollers helps mitigate these issues and improves coating quality. Water-based varnishing combines protective and aesthetic functions, making it an ideal choice for enhancing the durability and appearance of printed products. Its ability to improve print quality, reduce drying time, and provide both functional and visual benefits underscores its importance in modern printing processes [2] [3].
This study aims to determine whether the introduction of the coefficient V enables the prediction of colour change after varnishing with a water-dispersible varnish, specifically in the case of dark colours, which are most frequently varnished primarily to protect the print from mechanical impact, as well as to enhance gloss. The objective of the research is also to establish whether the coefficient V is consistent or varies among different dark colours. In their original 2010 study, Deshpande and Green introduced a simplified model for predicting the colour outcome of spot colour overprints. The model employs linear combinations of the reflectance values of two colours, taking into account the opacity of each ink, to predict the result of the overprint. It was evaluated on three different substrates, and the average ΔE*00 values between the measured and predicted colours were below 3 for both spot colours on all paper types. However, an analysis of the global literature reveals that there are no studies specifically addressing colour changes following the application of water-based dispersion varnishes.

2. MATERIALS AND METHODS

Due to the wide range of dark colours with varying halftone values, four visually distinct dark colours were selected for this study. Samples of the chosen colours, along with corresponding measurement and control strips, were printed using the offset technique on a Roland 200 printing press. The printing conditions were aligned with the international standard ISO 12647-2:2017 [4].
After printing, the ΔE^*_{00} values of the prints were measured, followed by the varnishing process. Upon completion of varnishing, the ΔE^*_{00} values were measured again, and predicted values were calculated using predefined formulas. A discrepancy was observed between the measured and predicted values, prompting the application of a correction coefficient (V) to achieve more accurate results.

2.1. Used materials

As the coating processes are most used on coated [5] [6] printing substrates, samples were printed on gloss coated paper Sappi Magno Gloss [7].

2.2. Used inks

For the purposes of this study, four colours with dark tones, commonly used in varnished products—primarily in packaging but also in commercial printing—were selected. Each chosen colour has precisely defined CIE L*a*b* values[8]. The tested colours differ in hue due to varying proportions of halftone values during printing. One of the colours contains a high proportion of black with smaller amounts of cyan, yellow, and magenta (Colour 1), while another has a red tone as the dominant component with a smaller proportion of black (Colour 2). The third colour features a blue tone achieved by the highest proportion of cyan (Colour 3), and the fourth colour leans toward a yellow tone, also with a smaller proportion of black (Colour 4). The colours were designed so that all have the same total proportion of halftone values. The colour proportions are presented in the table 1:

Table 1. Rasterized halftone values of tested colours

Halftone values	Cyan (%)	Magenta (%)	Yellow (%)	Black (%)
Colour 1	20	20	20	90
Colour 2	10	40	40	60
Colour 3	60	10	20	60
Colour 4	15	15	60	60

Figure 1: Colours used in testing according to values from table 1.

2.3. Printing and spectrophotometric measurement

The control strips for spectrophotometric measurements included measurement fields with solid tones. During the printing process on the Roland 200 printing press, the samples were subjected to water-based varnishing using a dedicated printing unit [13]. After printing, the samples underwent a 24-hour drying process, which included oxypolymerization and absorption under controlled climatic conditions (T 25°C, RH 55%), in accordance with the recommendations of the ink and substrate manufacturers [14]. Laboratory testing and measurements of the samples were conducted using an X-Rite eXact spectrophotometer [15], calibrated according to the international standard ISO 13655. Additionally, predictive analysis of the colourimetric changes in colours caused by coating processes utilized an existing model (Deshpande, Green, Hoffstadt), designed to predict changes in colourimetric values.

2.4. ΔE_{00} calculation

Predicted CIE L*a*b* values, obtained through the mathematical prediction method, were compared to actual measured CIE L*a*b* values, considering different printing substrates and coating types. ΔE^*_{00} differences were then calculated with ΔE^*_{00} (ΔE^*_{2000}) [16].

$$\Delta E'_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \quad (1)$$

The measurement was conducted according to the ISO 13655 international standard, using the M0 setting to obtain results closely aligned with visual perception, and a 45°/0° viewing geometry. An aperture size of 1.5 mm was used, and measurements were made on a white backing to ensure consistency across results.

3. EXISTING MATHEMATICAL MODEL

The existing model (Deshpande, Green, Hoffstadt), intended to predict the colourimetric values in situations of overprinting spot colour on colour (ink trapping) [17] was used for analysis of prediction model of colourimetric changes in PMS colours due to the coating

processes.

$$X = j_x \times (X_b \times X_f) + k_x, \quad (2)$$

$$Y = j_y \times (Y_b \times Y_f) + k_y, \quad (3)$$

$$Z = j_z \times (Z_b \times Z_f) + k_z. \quad (4)$$

where:

X, Y, Z: predicted tristumulus values of the overprint colour
X_b, Y_b, Z_b: measured tristimulus values of the background colour
X_f, Y_f, Z_f: measured tristimulus values of the foreground colour
j_x, j_y, j_z: scaling factors of the foreground colour depending on dot area
k_x, k_y, k_z: constants of the foreground colour depending on dot area.

$$k_x = \frac{(X_{pk} \times X_w - X_{pw} \times X_k)}{(X_w - X_k)}, \quad (5)$$

$$j_x = \frac{(X_{pw} - k_x)}{(X_w \times X_{pw})}, \quad (6)$$

X_{pw}, Y_{pw}, Z_{pw}: the tint percentage printed on white (substrate)
X_{pk}, Y_{pk}, Z_{pk}: the same tint percentage printed on black
X_w, Y_w, Z_w: the white (substrate) without overprint
X_k, Y_k, Z_k: the solid black without overprint.

4. RESULTS AND DISCUSSION

After measuring the ΔE*00 values following the varnishing process, the correction coefficients (V) were calculated, resulting in ΔE*00 values that closely matched the measured values.

4.1. CIE L*a*b* and ΔE^*_{00} values

The CIE L*a*b* values are presented in the context of the influence of different types of coatings and the degree of deviation from the reference colour caused by these coatings [18]. The axes on the graphs represent the Lab* values from the CIE L*a*b* colour space, where a* and b* denote chromatic differences, while the L* axis represents lightness [19]. According to Kiphan [13], colour differences are classified as follows: a colourimetric difference $\Delta E_{00} < 1$ indicates that the average human eye perceives no difference; ΔE_{00} values between 1 and 2 signify a slight difference; values between 2 and 3.5 represent a moderate difference; a range of 3.5 to 5 indicates a significant difference, while $\Delta E_{00} > 5$ suggests an unacceptable difference.

Different ink applications have a crucial impact on print quality, especially in multicolour printing techniques. Proper control of the amount of ink applied is essential for achieving optimal results, as excessive application can lead to technical issues, while insufficient application may result in poor saturation and loss of detail in dark areas of the print.

In the printing of dark colours, special attention must be paid to the total amount of ink applied, known as Total Ink Coverage (TIC) [20]. Dark shades in the CMYK model are created by combining cyan, magenta, yellow, and black inks. When all inks overlap at high percentages, the total ink coverage can exceed recommended values, causing various issues in the printing and drying processes. If the total ink coverage is too high, drying slows down, which can lead to smudging or offsetting onto the back of the next sheet during paper handling. Additionally, excessive ink application can cause a loss of detail in dark

areas, as oversaturation prevents precise reproduction of fine tonal transitions. Furthermore, excess ink can lead to issues with ink trapping due to paper stretching caused by moisture absorption, resulting in inaccurate printing.
To ensure proper reproduction of dark colours and avoid technical problems, it is important to adjust the total ink coverage according to the type of paper and printing technique. For example, in offset printing on glossy paper, the total ink coverage should not exceed 320%, while for newsprint, this limit is lower, around 240%. Therefore, this study investigated different combinations of black ink, where black and chromatic inks were mixed in varying proportions. This allowed us to determine the ratios of black to chromatic inks that resulted in greater or lesser colour differences (ΔE) after water-based varnishing [21].
The colourimetric values of predicted colours under the influence of different types of coatings were calculated using a predictive model within the CIE XYZ colour system and then converted to the CIE Lab* colour system. The first step in determining the predicted CIE L*a*b* values involved calculating the coefficients kx, ky, and kz, followed by the coefficients jx, jy, and jz, in accordance with equations (5) and (6). These calculations took into account changes caused by water-based varnishing. The calculated coefficient values were then inserted into equations (2), (3), and (4) to obtain the XYZ values of the predicted colours. Finally, the values of these predicted colours were obtained by converting them into the CIE L*a*b* colour system [22].

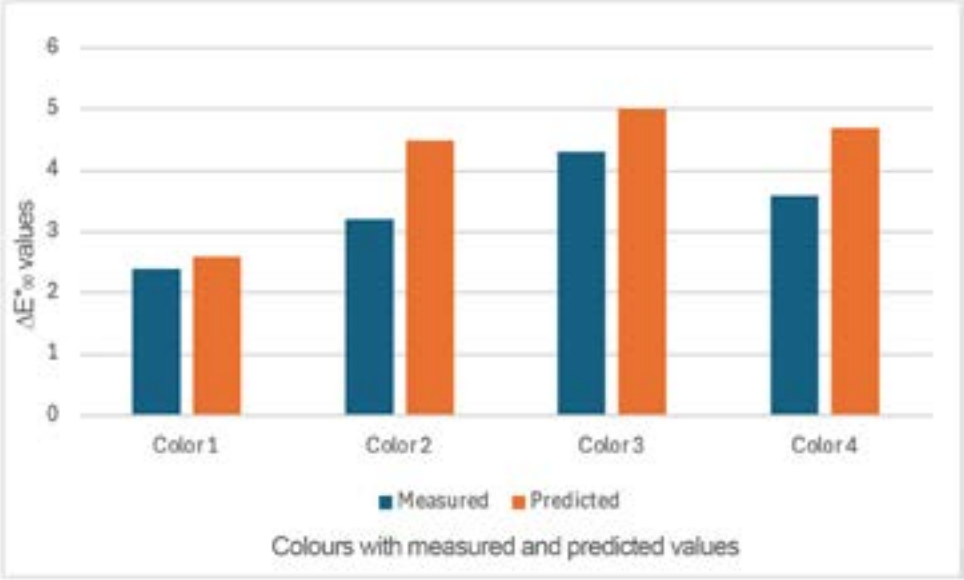

Figure 2: ΔE^*_{00} values with respect to measured and model predicted values

The results of ΔE^*_{00} values are presented in Figure 2. This figure illustrates the actual ΔE*00 differences and colourimetric changes caused by the water-based varnishing process. The analysis of the generated differences calculated using the predictive method shows that there was a change in the ΔE^*_{00} values between the measured and predicted CIE L*a*b* values. The graph compares the measured and predicted ΔE values for four different colours after varnishing. The blue bars represent the measured values, while the orange bars depict the predicted values obtained from the computational model.
Analysis of the data reveals certain discrepancies between the measured and predicted ΔE^*_{00} values. For Colour 1, the difference between the measured and predicted values is minimal, indicating high prediction accuracy for this colour. For Colour 2, it is noticeable that the predicted value exceeds the measured value, suggesting that the model over-

estimates the impact of varnishing on colour change. Colour 3 shows a slightly smaller difference between the predicted and measured values compared to Colour 2, but some deviation is still present. The greatest discrepancy between the measured and predicted values is observed for Colour 4, where the predicted value is significantly higher than the measured value. These discrepancies may indicate certain limitations of the predictive model used. Possible causes of the differences include variability in the varnishing process itself, the interaction of the varnish with pigments, and potential nonlinearities in colourimetric changes that the model does not account for. Furthermore, specific optical characteristics of the varnishes, such as increased reflection or light dispersion, may contribute to the mismatches between the measured and predicted ΔE^*_{00} values.
In conclusion, while the model provides relatively accurate estimates for certain colours, deviations are evident for others, highlighting the need for model optimization. In this study, correction coefficients were calculated to bring the predicted values closer to the actual measured values.

5. IMPROVEMENT OF PREDICTION COEFICIENTS

Prediction model does not show the same colour differences for tested types of varnishes and for the tested colours. To improve this model we can modify the scaling factors jx, jy, and jz by introducing a coefficient V. This coefficient will represent the degree to which the varnish influences the final appearance of each tristimulus component.

$$X = (j_x \times (X_b \times X_f) + k_x) + V_x \quad (10)$$

$$Y = (j_y \times (Y_b \times Y_f) + k_y) + V_y \quad (11)$$

$$Z = (j_z \times (Z_b \times Z_f) + k_z) + V_z \quad (12)$$

where Vx, Vx, and Vx, are the varnish coefficients for the X, Y and Z components, respectively. These components reduce or enhance each tristimulus component based on the varnish type and colour. Experimental changes to the coefficient V yield results where ΔE^*_{00} is closest to the actual measured CIE L*a*b* values.

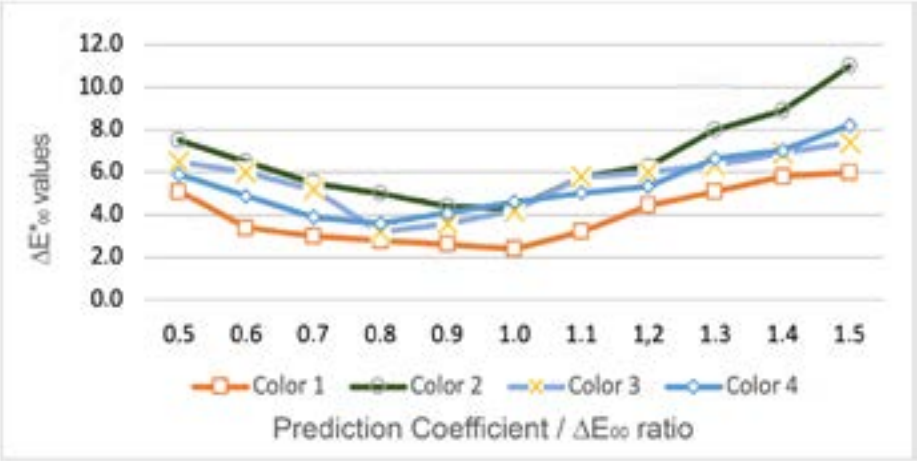

Figure 3: Correlation between coefficient V and ΔE*00 values

By introducing the coefficient V into equations (10-12), a shift in the values of the colour difference ΔE^*_{00} after water-based varnishing occurs. Figure 3. presents the results show-

ing how the ΔE^*_{00} values changed depending on the increase in the coefficient V. Analysis of the formula for predicting colour change reveals that a coefficient of 1 does not alter the value, so the research was conducted within intervals both below and above this value. The interval selection was based on theoretical values ranging from 0.8 to 1.2, but to observe the behavior of colour differences both below and above this range, the interval was expanded to 0.5–1.5 for the purposes of this study.
This approach allowed for a comprehensive examination of how variations in the coefficient V influence the ΔE^*_{00} values, providing insights into the sensitivity of the model and the potential for optimizing the predictive accuracy of colour changes induced by water-based varnishing.
The graph illustrates the relationship between the predictive coefficient V and the ΔE*00 values for four colours, analyzing changes in colourimetric differences based on varying coefficients V. The results of the study on the coefficient V revealed that colour changes differ depending on the proportion of chromatic colours in the tone as well as the proportion of the achromatic component. Although the colours appear quite similar, the tested colours have different halftone values, and Figure 2. shows that the colour changes after varnishing were smallest for Colour 1, where the proportion of black was the highest among all tested colours. This minimal change can be attributed to the pigmentation of the colour, which is primarily based on carbon black, while chromatic colours are made from different pigments, such as cyan from Copper Phthalocyanine Blue, magenta from Quinacridone Magenta, and yellow from Diarylide Yellow [23]. The coefficient V varies for the other three colours, where a similar trend in the shift of ΔE^*_{00} values is observed.

6. CONCLUSION

Analyzing the results of the dependence of colour difference ΔE^*_{00} on the coefficient V, as shown in Figure 3, it can be noted that all colours exhibit a certain pattern of variation in ΔE values. For Colour 1 (orange line), a trend of decreasing ΔE^*_{00} values is observed up to a predictive coefficient of 0.9, after which a gradual increase occurs. This colour shows the least deviation compared to the others, suggesting that the model predicts its changes relatively well. For Colour 2 (green line), the initial ΔE^*_{00} value is the highest among all analyzed colours. Although there is a slight decrease at lower predictive coefficients, after a coefficient of 1.0, a significant increase in ΔE^*_{00} values occurs. This result may indicate that the predictive model does not account for all relevant factors affecting this colour, leading to greater discrepancies between predicted and actual colourimetric changes. Colour 3 (blue line) shows a moderate decrease in ΔE^*_{00} values at lower coefficients, followed by stabilization and a slight subsequent increase. Given its relatively consistent values compared to the other colours, it can be concluded that the model is somewhat more accurate for this colour, but there is still a certain degree of variability. For Colour 4 (purple line), a similar trend to Colour 3 is observed, but the absolute ΔE^*_{00} values are slightly higher. The initial decrease in values suggests the possibility of model correction in the lower range of predictive coefficients, but the subsequent increase after a coefficient of 1.0 indicates the need for further optimization.
Mathematical models, including those developed by Deshpande, Green, and Hoffstadt, represent valuable tools for predicting colour changes. However, their application comes with certain limitations, stemming from the simplification of complex physicochemical processes, the specificity of environmental conditions, and the sensitivity to the precision of input data.
One of the main challenges in colour prediction is the difference between physical changes and human colour perception. Although models are based on spectral data, the human eye may interpret them differently, which can result in discrepancies in results. Additionally, models typically assume constant lighting conditions, using standard light sources such

as D65 or A. In real-world conditions, lighting varies, affecting colour perception and potentially limiting the practical application of models that do not account for these changes. To reduce the influence of various factors on colour perception, the varnishing coefficient V was introduced in this study. Its application allows for a reduction in the differences between predicted and measured ΔE^*_{00} values. Although not universal, it has been shown to improve prediction accuracy under certain conditions. For the tested prints, the value of the V coefficient ranged from 0.80 to 0.97, as shown in Table 2, and the results obtained after introducing the coefficient V are presented in Figure 4.
The research results, which yielded the coefficient V, indicate that it is possible to more accurately predict colour changes following the interaction of colour with a water-dispersible varnish. This reduces the likelihood of client dissatisfaction with colour alterations after varnishing in real-world graphic production and facilitates a more reliable prediction of the expected colour change after varnishing.

Table 2. Calculated coefficients V

Colour 1	Colour 2	Colour 3	Colour 4
0,97	0,93	0,85	0,80

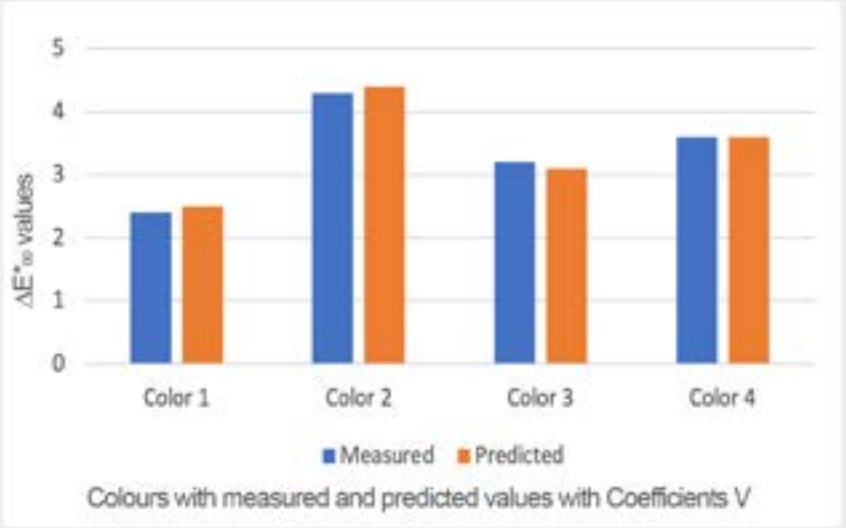

Figure 4: ΔE_{00} values with respect to measured and model predicted values with coefficient V

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

PROFESSIONAL PAPER

REDESIGN OF IVAN CANKAR'S BOOK MOJE ŽIVLJENJE

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ABSTRACT

The aim of the study was to redesign the collection of short stories Moje življenje by the Slovenian writer Ivan Cankar. This literary work holds an important place in Slovenian literature and is an obligatory part of the primary school curriculum for the ninth-grade students. The themes of the short stories are still topical and reflect the experiences that almost everyone had at some point in their lives. However, most of the previous editions of these short stories are outdated in terms of design. With the new edition of this collection, we wanted to make the book more appealing to primary school pupils and encourage them to pick it up and start reading. We also wanted to adapt the book for children with dyslexia, based on previous research, as older editions are very difficult and daunting for them to read. Firstly, we analysed the content of each short story. We identified and analysed the target group of readers. Based on this analysis, we began to redesign the collection. We realised that introductory illustrations could convey the essence of each story, thereby attracting readers and enhancing their understanding of the content. After testing different options, we found the best possible design solution. The final product is a modernised version of the collection of short stories Moje življenje with illustrations and typography that makes reading easier for people with dyslexia.
Keywords: book design, illustration, Ivan Cankar, layout.

1. INTRODUCTION

Books are an important part of our culture. Reading is one of the skills we use every day. We grow through books, and in childhood it is particularly important how books are presented to us, especially those that deal with more complex topics.

One such book is the collection of short stories Moje življenje (My Life) by Ivan Cankar. This literary work is an important part of our history and is still read and learnt in primary schools. However, all previous editions are somewhat outdated in terms of design and are not well suited for children with dyslexia.

Dyslexia is a specific neurological learning disorder. It is characterised by difficulties with accurate and fluent word recognition and poor spelling skills. As a result, there are also problems with reading comprehension, which hinders the expansion of vocabulary and the acquisition of basic skills. [1] Dyslexia has a significant impact on individuals and their daily lives. Reading quickly and clearly is a challenge, especially in the school environment. Various approaches can help to alleviate the negative effects of dyslexia. Studies have shown that certain typefaces make reading easier for people with dyslexia. Different text variables can affect reading, especially for those with dyslexia. These variables include typeface style, type size, letter spacing, word spacing, leading (i.e. line spacing), line length, and the colour of text and background. [2] The main finding of one study [3] was that different typefaces affect legibility in dyslexics. Based on the reading performance and subjective evaluation of the typefaces tested by the participants, it was found that sans-serif typefaces such as Helvetica, Arial, Verdana and Computer Modern are the most suitable for dyslexics. The italic style of a typeface, e.g. Arial Italic, on the other hand, significantly impairs reading performance. [3, 4] There are also several typefaces that have been specially developed for people with dyslexia (e.g. Open Dyslexic, Read Regular, Dys-

lexie). The advantages of dyslexia-friendly typefaces usually include bigger leading, and longer ascenders and descenders. [5] However, these typefaces are not always the best solution. One study [6] concluded that a typeface specifically designed for dyslexics alone does not necessarily improve the reading speed and accuracy. Instead, wider spacing between words has a significant impact on reading. This is primarily due to dyslexics having greater difficulty distinguishing between densely packed visual elements; hence, wider spacing between letters or words helps them read better. [6, 7] For normal readers, the optimal line length is between 60 and 65 characters, while shorter lines are beneficial for people with dyslexia. The recommended line length for dyslexic readers is 45 characters. [5] The recommended minimum type size for readers with dyslexia is between 12 and 14 pt. [4]

An illustration is a visualisation created by an artist. It can be a drawing, a painting, a collage etc. An illustration can often tell its own story without the need for a text. There is usually a meaning behind an illustration. [8, 9] Illustrations are thought to have existed as early as 15,000 BC. At that time, illustrations usually depicted the culture of people, their gods, battles and heroes. Illustrations became widespread in the 19th century when it became possible to reproduce images in books, newspapers and other works. [9, 10] There are different types of illustrations and their areas of application. Some of them are editorial, advertising, conceptual, fashion, technical illustrations, infographics and packaging illustrations. [8]

2. EXPERIMENTAL

We began the experimental part of the study with a detailed analysis of the short story collection Moje življenje. We thoroughly investigated the time, space and themes of the work in order to gain a deep understanding of its content, which later enabled us to design it appropriately.

Before designing the book, we identified the target group for the new edition of the short story collection. We decided that the target group should be upper primary school students (between 13 and 15 years old). This literary work is part of their curriculum; however, they are usually very reluctant to read it. They have many preconceptions about the author Ivan Cankar, especially that he is difficult to understand and outdated.

With a graphic redesign of the literary work, we want to bring the book, its content and the author closer to the primary school students, make the book more visually appealing and encourage them to pick it up with more enthusiasm.

2.1. Layout design

In the initial phase of the layout design, we defined the book format using Adobe InDesign. Our goal was to choose a format that would match the standard sizes of books of a similar genre while ensuring that it would not lead to excessive printing costs.

Based on the chosen book format, we determined the layout area for the book's content. We allowed for a larger bottom margin and 3 mm more for the inner margin as we wanted to prepare the book for softcover binding, where the book block would be trimmed and glued.

We decided in favour of a larger bottom margin to accommodate the page numbers as well. We placed the page numbers symmetrically on the outer edge of the layout area. We also opted for a running header at the top of the page, with the author's name on the even-numbered pages and the title of the book on the odd-numbered pages.

At the beginning of each chapter, we wanted to place an illustration above the title of each short story that thematically matches the content. To ensure consistent placement of the illustrations across all 24 chapter opening pages, we designed a grid divided into four horizontal sections and three vertical columns, aligned with the layout area and separat-

ed by 5 mm of white space. This grid allowed us to position the illustrations precisely. We placed each illustration in the centre rectangle of the top grid, extending it 5 mm into the white space on the left and right sides. Below the illustration, we inserted the text after leaving a further 5 mm of white space (Figure 1). As the illustrations were not all of exactly the same size, we had to visually adjust their height and width at the beginning of each chapter, despite the grid, to account for the different amounts of white space.
When selecting the typefaces, we paid particular attention to choosing a typeface that makes reading easier, even for children with dyslexia. However, as the book should also be suitable for other readers, we did not opt for a typeface specially developed for dyslexics. In accordance with the recommendations of various studies on the reading quality and speed in dyslexics, in which typefaces such as Arial, Verdana and Times New Roman were examined (1, 3–7), we opted for the humanist sans-serif typeface Verdana. The latter has a larger x-height, larger counter shape within the letterforms and larger letter spacing, which have been identified in research as important factors in facilitating reading for dyslexics.

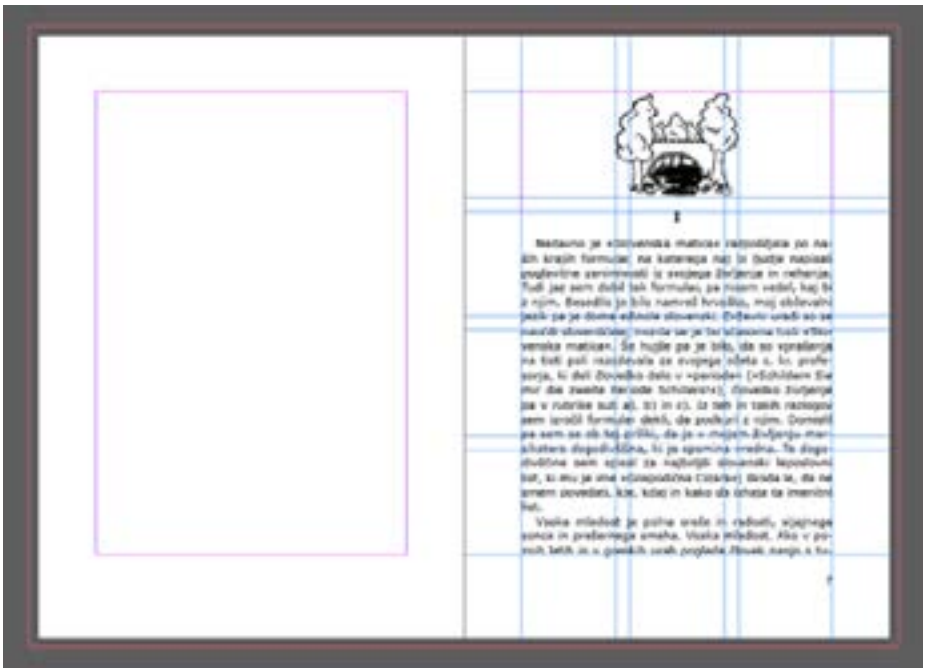

Figure 1: Grid layout for chapter opening pages

2.2. Illustration design

We started designing the illustrations after we thoroughly reviewed and read the literary work. We carefully analysed each story to identify the key messages and motifs it contained. Based on the analysis, we began sketching the illustrations on a tablet.
We considered different approaches, but eventually settled on smaller graphics to accompany each short story. These illustrations were placed at the beginning of each chapter, directly above the title of the story, to provide readers with a visual introduction to the content, and help them better understand and emotionally connect with the message of each story.
Once the sketches were finalised, we first exported them in the JPG format with a resolution of 300 dpi to get the highest possible quality. We then imported these sketches into Adobe Illustrator, where we converted them into vector graphics using the image trace tool. Due to the special pencil-like look achieved in the original drawing software,

the vectorised illustrations retained their distinctive appearance, which harmonised well with the book's content. We further customised the illustrations as required and exported them in the SVG format to ensure optimal quality for both print and digital media.

3. RESULTS WITH DISCUSSION

We chose the A5 portrait format for the book, measuring 210 × 148 mm, which we believe is best suited to our needs. The designed work consists of 112 pages, including the main title, the colophon, table of contents and 24 short stories, each accompanied by an illustration on the first page of the chapter.
The top, outer and inner margins of the layout were set at 20 mm. The bottom margin was adjusted from 28 mm to 29.275 mm in accordance with the baseline grid.
We decided to introduce running headings in the book. The author's name was placed at the top of the even-numbered pages, while the title of the book was placed at the top of the odd-numbered pages. The page numbers were placed symmetrically at the bottom.
For the body text, Verdana was used in the regular type style with a type size of 11 pt and leading of 13.2 pt. A type size of 10 pt was used for the page numbers and the colophon. The titles of the short stories were set in Verdana Bold with a type size of 13 pt to emphasise them.
We created 24 illustrations that were placed directly above the story titles on the first pages of each chapter. Each illustration is thematically related to the content of the respective short story (Figure 2).
In the illustration for short story I, we designed a bridge that represents the "Eleventh School under the Bridge", the central theme of the first story.
In the second short story II, we illustrated the equation "1 + 1 = ?", which refers to the teacher's question to Janez, which he did not want to answer as he thought it was insulting.
The third illustration for short story III shows a basket of dried pears, which is the main motif of the story. Janez, encouraged by his sister, steals dried pears that his mother locked in a cupboard. It is only when he is caught that Janez confesses his guilt and regrets his offence when he sees his mother crying.
In the fourth short story IV, the children dream of holidays such as Christmas and Easter, which is why we depicted a nativity scene in the illustration.
Short story V tells how Janez receives a groschen, which symbolises wealth for him, as a reward for good work. At first he wants to take it to his mother, but temptation overcomes him and he spends it on sweet dates.
In the sixth short story VI, the author reflects on his first Holy Communion, which is why we illustrated a chalice and holy bread.
For short story VII, we illustrated a skull and crossbones, as the story describes events in which the author encounters death as a child.
Short story VIII is about the author's deep longing for Ljubljana in his childhood; hence, we illustrated a street sign with "Ljubljana".
For short story IX, we illustrated a building that represents a school as the story is about the author's hatred of school in his childhood.
For short story X, we found it difficult to find an obvious motif; therefore, we decided to illustrate plums, as the author mentions them at the beginning of the story when he remembers how he liked to write rhymes about a particular type of plums as a child.
The short story XI contains various reflections of the writer in the days before his move to Ljubljana, which is why we illustrated a suitcase representing his move.
For short story XII, we illustrated a plate with cutlery, which represents dinner the evening before his move to Ljubljana. During this meal, the writer learns various things about his relationship with his mother.
In the short story XIII, Cankar describes his departure from home. We illustrated a cart

that the writer and his mother used on their journey to Ljubljana.
For short story XIV, we illustrated a handwritten sheet of paper and a fountain pen, as the author explains his reasons for writing these stories.
In the short story Njena podoba (Image of her), the author remembers his mother's last days. Cankar did not want to forget his mother; therefore, he drew her image to preserve it forever.
We illustrated a loaf of bread for the short story Sveto obhajilo (Holy Communion). The story describes how the children complain while waiting for their mother to bring them dinner.
In the short story Na peči (On the stove), the children dream of various treats they will receive at Easter and other holidays.
The short story Desetica (Ten kreuzer) tells how Cankar receives a letter with money and a note from his mother.
For the short story Mater je zatajil (He denied his mother), we chose an umbrella with muddy boots and a bundle underneath. The writer was ashamed of his mother's peasant appearance.
In the short story Večerna molitev (Evening prayer), we illustrated a rosary depicting Cankar's persistent prayer to God while his mother is dying.
For the short story Tuja učenost (Foreign knowledge), we illustrated a pile of books.
In the short story Skodelica kave (A cup of coffee), the motif of the story is very clear; thus, we illustrated a cup of coffee. In the story, the writer desperately wants a cup of coffee, but rudely refuses it, which he later deeply regrets.
For the short story Naš laz (Our assart), we chose a plant that grows out of the ground and symbolises a field or clearing.
For the last short story, Njen grob (Her grave), we illustrated a gravestone representing the grave of the author's mother.

Figure 2: All illustrations

The cover of the book shows a spilt coffee cup (Figure 3). The title of the book, Moje življenje, is moulded from the spilled liquid on the front cover. We used the Mistral typeface for the title, which resembles handwriting. At the bottom of the front cover we added the author's name, while on the back cover, we placed a short description of the book's content over the graphic of the spilt coffee. We estimated 10 mm for the width of the spine, where we added the author's name and the title of the book.

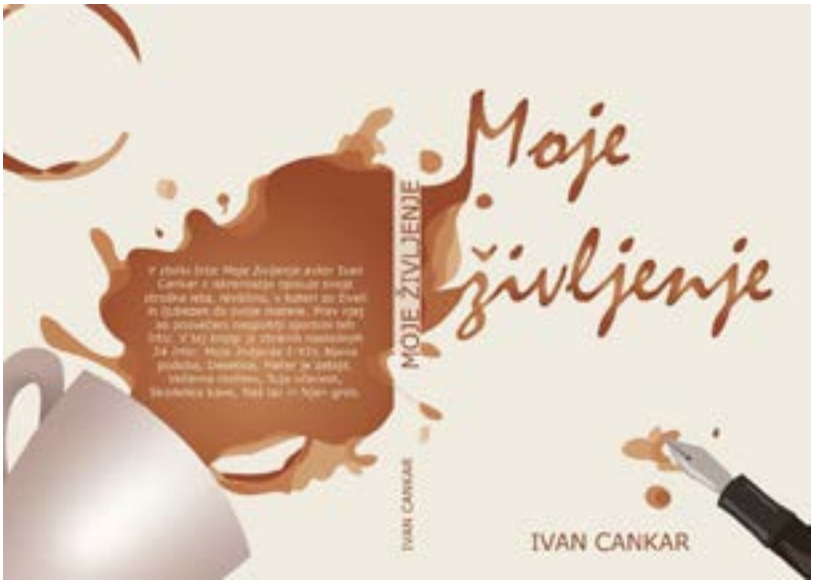

Figure 3: Book cover

4. CONCLUSION

The study focuses on the design of the layout, illustrations and cover of the book Moje življenje by Ivan Cankar. We emphasised the problem of the book's outdated design. The main goal was to make the book more attractive for primary school students who have to read it as part of their curriculum. To achieve this, we wanted to design an attractive and accessible edition that would facilitate reading and stimulate interest in the content.

The designed book contains 24 short stories and vector illustrations placed at the beginning of each chapter. We also designed a book cover that is more appealing and better suited to a younger audience.

When designing the book, we encountered the challenge of choosing typography that would make reading easier for children with dyslexia without hampering other readers. We also looked for the best way to incorporate illustrations that would match the content while appealing to young readers. A thorough analysis of the literary work was necessary to find the most suitable motif for each illustration.

We realised that the design process is demanding and time-consuming, as it requires careful adherence to design guidelines, as well as understanding of the book's target group and content. Moreover, precision and patience are crucial, as the process requires constant revisions and adjustments to optimise the final result.

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ORIGINAL SCIENTIFIC PAPER

DESIGN FOR DECENTRALISATION: PORTUGUESE VISUAL DISCOURSES THROUGH THE THEATRE POSTERS CASE STUDY (1960-2000)

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ABSTRACT

This paper focuses on mapping and analysing the evolution of Portuguese theatre cultural posters created between 1960 and 2000, specifically in the decentralised cases of theatre companies based in the cities of Almada, Braga, and Évora. For this study, samples were searched in various public archives, libraries, and museums. The period was set between 1960 — the year Portugal joined EFTA, which led to changes in the Portuguese dictatorship at the time — and 2000, marking the transition to a new century punctuated by the digitalisation of design processes. After a detailed inventory of the available archival material, the analysis of these samples was established as the starting point, followed by the identification of the authors — artists and/or designers — involved in the creative process of the cultural posters. The study also includes an analysis of formal features, taking into account the major political changes in Portugal throughout the period studied, especially after the revolution of April 25, 1974, which led the country to democracy. Throughout this study, we aim to deepen the understanding of the role of visual design developed and produced in Portugal during the analysed period, reflecting on the main technical and aesthetic changes recognised in these objects of Design Culture.

Keywords: Visual Communication and Design, Portuguese Theatre Posters, Design Discourses, Portuguese Graphic Design and Conservation, Digital Archive.

1. INTRODUCTION

Between 1960 and 2000, Europe was primarily defined by the Cold War and, from 1989 onwards, by the instability of the post-Cold War period, which brought significant political, economic, and social changes. Portugal, under the authoritarian Estado Novo regime until 1974, lagged behind much of Europe. However, following the fall of the dictatorship and the end of the colonial war, the country underwent a profound transformation. Portugal's economic modernization, particularly after joining the European Economic Community in 1986, played a significant role in its growth and integration into Europe.

Culturally, the end of the dictatorship opened new doors for creativity [1]. With the newfound freedom to create without restrictions, Portugal experienced a boom in design production, moving away from the limitations imposed by the Estado Novo [2]. The theatre, which had been heavily controlled under the Estado Novo, underwent a dramatic shift. While some plays had managed to skirt censorship—such as satirical Revista performances—it was only after 1974 that theatre fully embraced political and social freedom, addressing new themes in a liberated environment.

While Lisbon and Porto remained central theatre hubs, other cities emerged as important cultural centres. Braga, Almada, and Évora developed vibrant theatre scenes, challenging the dominance of Lisbon and Porto. Braga, known for its contemporary works, was home to companies like Companhia de Teatro de Braga. Almada gained international recognition for Companhia de Teatro de Almada's experimental productions and the Almada Theatre Festival. In Évora, Teatro Garcia de Resende and CENDREV — Centro Dramático de Évora

— formed strong ties with the region's cultural identity. Together, these cities contributed to a more diverse and democratic theatre landscape in Portugal.
Regarding the State of the Art, the fundamental bibliographic sources for this research focus on the history of design in Portugal, as well as its theatrical history. Equally important are the readings on the international context, since Portuguese designers were influenced by various movements from abroad, as well as by other arts, particularly painting and its evolution, as defended by the Swiss graphic designer Josef Müller-Brockmann [3]. Thus, the aim is to go beyond mere documentary collection and to embrace the challenge of a qualitative analysis of the posters under study. The work is driven by the intention to contribute to the organized body of knowledge surrounding the posters developed in Portugal for theatrical performances.
In an effort to preserve this rich history, a digital platform is being developed to archive theatre posters created between 1960 and 2000. Currently under development with no prototype available, this platform aims to serve as a resource for theatre enthusiasts and a conservation tool. It will enable designers and researchers to explore past works for inspiration and reference, offering valuable insights into the evolution of theatre design and safeguarding these contributions for future generations.

2. THE THEATRE POSTERS

Given the challenges in determining the total number of theatre posters created in Portugal between 1960 and 2000, and the difficulty in accessing them—some archives were destroyed along with theatre buildings—a representative sample was selected as the research corpus. Museums, theatres, exhibitions, and archives were contacted and visited whenever possible. Institutions such as Museu do Teatro, Theatro Circo, Teatro Garcia de Resende, the archive of Companhia de Teatro de Braga, the archive of Companhia de Teatro de Almada, and the archive of CENDREV were among those consulted. This effort resulted in the collection of 1303 posters across various theatre categories.
To better organize and map the graphic materials collected from the consulted cultural institutions, a matrix table model was created to manage and gather the necessary data for a preliminary study. Parameters such as year of production, theatrical genre, play, authorship, printing house, theatre or venue, theatre company, and observations were included — the latter serving as an initial filter to identify the main pictorial elements (Table 1).

Table 1: Matrix model for display and organising the theatre posters collected

Nº	Poster	Year	Theatre Genre	Play	Authorship	Printing House	Theatre	Theatre Company	Remark
1		1960	*Revista*	*A Vida é Bela*	TBC	TBC	Capitólio	Companhia de Teatro do Capitólio	Photography
2		1960	*Revista*	*Mulheres de Sonho*	Pinto Campos	TBC	Coliseu	TBC	Illustration
3		1960	Comedy	*Boa noite, Betina!*	TBC	TBC	Monumental	Vasco Morgado Production	Illustration
4		1960	Comedy	*Boa noite, Betina!*	TBC	TBC	Monumental	Vasco Morgado Production	Illustration

As previously mentioned, it is evident that the theatre scene in Portugal expanded beyond the primary urban centres of Lisbon and Porto [4], with Braga, Almada, and Évora demonstrating a significant output in poster production (see Table 2).

Table 2: Portuguese theatre posters produced between 1960 and 2000

City	Total amount of theatre posters between 1960 and 2000
Lisbon	593
Others	397
Évora	79
Braga	76
Almada	69
Porto	66
Funchal	16
Aveiro	7
Total	**1303**

For this study, the decision was made to focus on Portugal's decentralised theatre cases, specifically: Braga — with Theatro Circo and Companhia de Teatro de Braga; Almada — with Teatro Municipal Joaquim Benite (formerly Teatro Municipal de Almada) and Companhia de Teatro de Almada; and Évora — with Teatro Garcia de Resende and CENDREV. These regions, alongside Lisbon and Porto, exhibited the highest production levels in terms of poster count and, coincidentally, emerged as some of the main theatre centres in the country.
Special attention is given to Évora, which stands out as a pioneer in the cultural decentralisation movement that emerged in Portugal after the revolution of April 25. The establishment of CENDREV in 1975 marked a significant step in promoting cultural development in both the city and the surrounding region. CENDREV has since played a pivotal role in fostering regional cultural identity and has been recognised as a model for cultural decentralisation in Portugal.
For the next stage of this study, the primary goal was to organise the posters created for these three case studies, analyse them in terms of graphic approach, and, where applicable, assess their contribution to Portugal's cultural scene. To achieve this, it was determined that the most effective and accurate method would be to divide the analysis into three individual case studies.

3. THEATRO CIRCO AND COMPANHIA DE TEATRO DE BRAGA

The first case study, moving from north to south, was Braga. To better understand the dynamics behind theatre production in the city, it was necessary to consider the cultural context from which Companhia de Teatro de Braga and Theatro Circo emerged.
Between 1960 and 2000, Braga's theatre scene evolved significantly, transitioning from amateur performances to a dynamic cultural hub. The Carnation Revolution of 1974 marked a turning point, as newfound freedoms encouraged artistic expression and experimentation. A key player was the Companhia de Teatro de Braga, established in 1980, which became central to the city's theatrical development. The company embraced contemporary themes and innovative productions, contributing to Braga's reputation as a vibrant centre for the performing arts. Venues like Theatro Circo supported this growth, making Braga a prominent part of Portugal's decentralised theatre movement.
After reviewing the archives of Theatro Circo and the Companhia de Teatro de Braga, a total of seventy-four posters were identified. However, twenty-six remain unaccounted for, likely due to factors such as loss or difficulties in locating them within the archives.
Based on Aragão's [5] analysis, which examines the presence or absence of visual language elements in compositions—and can extend to other aspects of graphic artefacts, such as production or the arrangement of visual elements—the aim is to categorise the posters by graphic style and author.
From the collected sample, seven posters were identified as being composed solely of verbal elements (Figure 1), each employing varying sizes and layouts to emphasise different aspects of the play.

Figure 1: Posters from Companhia de Teatro de Braga between 1980 and 2000. A Cheia (1980), A Mesa - Palavra de Mulheres (1981), A História do Jardim Zoológico (1982), É Preciso que Uma Porta Esteja Aberta ou Fechada (1982), Preconceito Vencido (1987), O Teatro ou A Vida (1988), A Lição (1998).

In four of these seven posters, the text is enclosed within frames, with the play's title consistently receiving the most prominence — a defining characteristic across all the posters. A clear typographic hierarchy is evident in all the designs, achieved through variations in font size and text placement to establish layers of information.

The posters exhibit no standardised dimensions, layouts, or orientations, reflecting a flexible approach to format.

In terms of authorship, only A Lição (1998) has a designated author — Amadeu Santos — while the remaining posters, according to archival records from the Company, are not attributed to any specific designer. This lack of attribution suggests they were likely produced in-house by the Company's team or by the set designer, a common practice in the theatrical context of the time.

The posters from 1980 to 2000 reveal a strong emphasis on dominant pictorial elements, often in the form of illustrations or photographs that highlight key aspects or themes of the plays. These visuals are paired with textual elements presenting the play's title, author, and producing company. Of the forty-one remaining posters, thirty-four are illustrated (Figure 2), while seven incorporate photography (Figure 3), with some photographs manipulated to achieve a more cohesive and harmonious design.

Figure 2: Ei Lá! Você Exagera (1981), A Professora Margarida (1983), Sem Dinheiro (1983), A Ilusão Cómica (1984), Estampatórios e Arrezoados (1984), Lázaro, Também Ele Sonhava com o Eldorado (1984), A Incrível História de Thomaz Paramim e do Selvagem RHA (1985), A Menina Júlia (1985), Auto da Índia (1985), O Tesouro (1985), O Fim (1986), Sabina Freire (1986), Sá de Miranda - O Poeta em Cena (1987), Suppapos, Tacholetas, Pontapés e C.ª (1987), Com a Arma de Bogart (1988), Frei Luís de Sousa (1988), O Teatro ou A Vida (1988), Judeus (1989), Arquicoiso (1989), A Dança do Sargento Musgrave (1990), O Anúncio Feito a Maria (1990), O Rapaz de Bronze (1990), A Dama e o Mar (1991), Menina e Moça (1991), Os Mistérios de Chester - O Velho e o Novo Testamento (1992), O Cavalo Mágico (1994), O Fetichista (1995), Paralquimia (1995), Ísis Triste (1997), Olho na Rua (1997), A Pior das Profissões (1998), Fechei os Olhos e Vi (1998), O Tartufo (1998).

Figure 3: Leôncio e Lena (1982), Fantásio (1987), A Guia (1992), O Tempo e a Ira (1992), Dámabrigo (1993), O Morgado de Fafe em Lisboa (1994), Conversa com o Homem Roupeiro (1995).

Among the posters featuring pictorial elements, there is significant typographic diversity, ranging from calligraphic styles — as seen in Leôncio e Lena (1982) and O Tesouro (1985) — to the use of serif and sans-serif fonts. In terms of typographic arrangements, no consistent approach emerges, although it is evident that the textual information consistently plays a secondary role. In specific cases, such as Sabina Freire (1986) and Paralquimia (1995), the text is thoughtfully integrated into the composition, designed not to overshadow the imagery but to complement and harmonise with it.

As seen in the poster composed solely of verbal elements, the posters combining verbal and pictorial elements also display a variety of sizes. Of the forty-one samples, only three are horizontal. Most of the posters are MUPIs, though there are some examples where the dimensions differ, with a noticeably narrower width.

During the period under study, the Companhia de Teatro de Braga collaborated with a diverse array of authors, resulting in a wide range of contributors for posters combining images and text (Table 3). Based on the available research, it appears that the artists and designers involved in creating these materials changed frequently, with no single professional consistently responsible for their production. This approach reflects the Company's commitment to fostering regional talent by engaging local artists rather than relying on an in-house designer.

Table 3: Authors of Companhia de Teatro de Braga posters'

Author	Year of the Poster(s)	Pictorial Element
Moura Pinheiro	1981	Illustration
Acácio de Carvalho	1984; 1985 (2); 1990	Illustration
Rui Anahory	1985; 1986	Illustration
Manuela Campos	1985; 1986	Illustration
António Durães & Paulo Lobato Costa	1988	Illustration
Alberto Péssimo & Victor Silva	1989	Illustration
Paulo Lobato Costa	1989	Illustration

Inês Guedes de Oliveira	1990; 1991	Illustration
Alberto Péssimo & Inês Guedes de Oliveira & Victor Silva	1990	Illustration
Victor Silva	1991; 1992; 1993	Illustration
Henrique Botelho	1992; 1995	Photography
Victor Silva & Henrique Botelho	1992	Photography
Graça Castanheira & João Ribeiro Soares	1993	Photography
Ricardo Ramalhete	1995	Illustration
Amadeu Santos	1997; 1998; 1999	Illustration
Arlindo Fagundes	1997	TBC
Jaime Monsanto	1998	Illustration

3. TEATRO MUNICIPAL JOAQUIM BENITE AND COMPANHIA DE TEATRO DE ALMADA

During the period under study, Teatro Municipal de Almada and Companhia de Teatro de Almada emerged as foundational pillars in the evolution of Portuguese theatre. Founded in Lisbon in 1971 as Grupo de Campolide, the Company initially focused on a repertoire that seamlessly integrated classical and contemporary works, often distinguished by its innovative and socially engaged staging. Following the Carnation Revolution, the Company professionalised and, in 1978, relocated to Almada. This trajectory culminated in the opening of the Teatro Municipal de Almada in 1990, a landmark institution that not only provided a dedicated performance space but also became the cultural anchor of the annual Almada Theatre Festival, renowned for its international collaborations and experimental approaches. Together, these entities played a key role in cementing Almada's stature within the national theatrical landscape.

Joaquim Benite was integral to the development of both the Companhia de Teatro de Almada and Teatro Municipal de Almada, emerging as a central figure in Portuguese theatre. As the Company's founding artistic director, Benite was pivotal in shaping its artistic vision, curating a bold and diverse repertoire that balanced tradition with contemporary sensibilities. After his passing in 2012, the theatre was renamed Teatro Municipal Joaquim Benite in honour of his profound and lasting influence on Portugal's cultural and theatrical heritage.

From a graphic design perspective, the Company worked with an in-house professional who collaborated closely with Joaquim Benite and the Company to create the materials for communicating the plays. Although this designer/artist was not officially credited with the authorship of the posters, interviews with key collaborators confirm that they played a significant role in crafting the posters during the study period, despite their names not being included in the final graphic pieces. Therefore, the posters will be categorised solely based on whether they are composed of verbal and pictorial elements, or both, leaving the authorship question aside at this point.

While sixty-nine posters were identified as having been produced during the period under study, not all were found in the archives consulted. Nonetheless, forty-six posters were successfully retrieved and included in the present investigation.

Eleven posters (Figure 4) rely exclusively on verbal elements and feature a minimalist layout, occasionally incorporating unconventional text orientations to create visual inter-

est. Echoing the approach observed in the Companhia de Teatro de Braga, these posters prioritise the play's title, which is accentuated through larger font sizes and strategic positioning to draw the viewer's attention. The typography varies, ranging from a calligraphic style, as seen in A Queda dum Anjo (1979), to serif and sans-serif fonts, exemplified by Réus e Juízes (1985) and George Dandin (1986). In most instances, the posters utilise high-contrast backgrounds to enhance the visibility and impact of the textual elements.

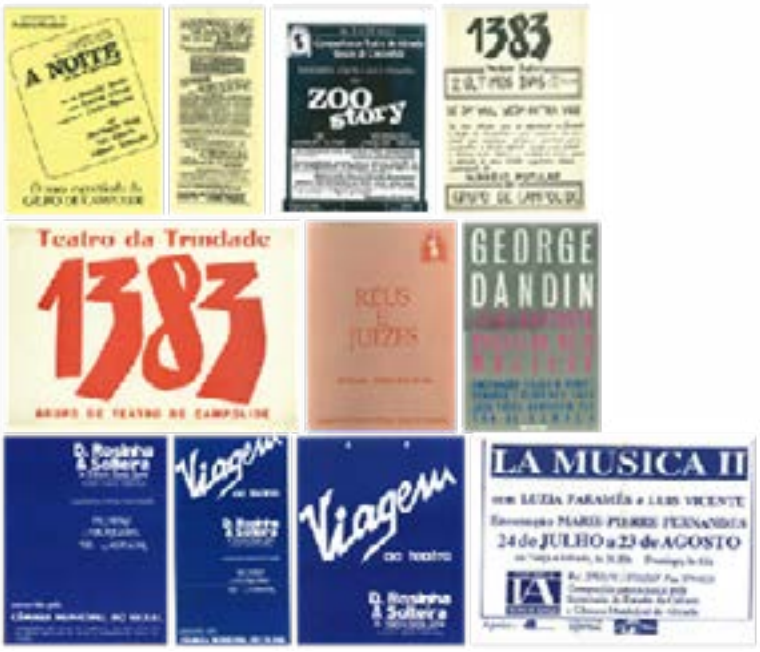

Figure 4: A Noite (1979), A Queda dum Anjo (1979), Zoo Story (1983), 1383 (1983), Réus e Juízes (1985), George Dandin (1986), D. Rosinha - A Solteira (1988), La Musica II (1992).

Between 1979 and 2000, most of the collected posters featured a mixed approach, combining both pictorial and verbal elements. Of these, thirty-six posters utilised illustrations (Figure 5), with the text carefully integrated to ensure the image remained the focal point. Ten posters incorporated photography (Figure 6), often showcasing scenes or elements directly from the play — the most prevalent strategy for photographic compositions.

Figure 5: A Queda dum Anjo (1979), O Pequeno Círculo de Giz (1979), Que Farei com Este Livro? (1980), Guerra? Não, Obrigado (1981), A Excepção à Regra (1981), O Espanta Pardais (1981), A Menina, o Rato e o Robot (1982), Tempos Difíceis (1982), 1383zinho de Natal (1983), 1383 (1983), Anastas (1983), Os Retratos (1984), Eugene O'Neill (1984), Como Matar o Tubarão (1984), O Capote (1985), Réus e Juízes (1985), O Cavaleiro e o Dragão (1986), A Menina Júlia (1986), O Fim da Enfermeira João (1987), Marco Milhão (1989), Amor, a Quanto Obrigas (1990), Felicidade e Erva Doce (1990), Othello (1993), Molière (1994), O Valente Soldado Schveik (1994), Calígula (1996), O Cerco de Leninegrado (1998), Amor de Dom Perlimplim com Belisa em Seu Jardim (1998), Medeia Estrangeira (1998), A Verdadeira História de Andreia Belchior (1999), O Corcunda por Amor e Noivado no Dafundo (1999), Viagens na Minha Terra (1999).

Figure 6: A Noite (1979), Dias Inteiros nas Árvores (197-), O Capote (1985), Como Está, Sr. Mozart? (1991), Marguerite Duras (1992), D. Quixote (1992), Filopópolus (1995), Razões e Corações (1996), Crónica Feminina (1999), Memorial do Convento (1999).

As previously noted, the posters did not adhere to standardised dimensions, featuring various orientations — predominantly portrait, but occasionally landscape — and a range of sizes.

An intriguing observation is that, in some cases, the same play was promoted with two or more distinct posters — sometimes using the same graphic solution in different arrangements, as seen with Que Farei com Este Livro? (1980), and at other times showcasing entirely different designs, as in the case of O Pequeno Círculo de Giz (1979).

From a graphic design perspective, no consistent style was established or uniformly applied by the Company in its poster production. The varying approaches observed in the posters reflect the evolving contributions of the in-house graphic team over time.

4. TEATRO GARCIA DE RESENDE AND CENDREV

Between 1960 and 2000, Teatro Garcia de Resende and the Centro Dramático de Évora (CENDREV) emerged as vital institutions in the preservation and reinvention of Portuguese theatrical traditions. Teatro Garcia de Resende, a historic landmark in Évora, became the base for CENDREV, which was founded in 1975 under the direction of Mário Barradas during the post-revolution cultural revitalisation. Barradas not only steered the company's focus toward regional identity and innovative theatrical practices but also contributed to its distinctive graphic production, which emphasised the diversity and richness of its repertoire.

CENDREV frequently drew upon Portuguese popular culture and traditional forms, such as puppet theatre (teatro de marionetas), while fostering artistic talent through collaborations with the Évora Theatre School (Escola de Teatro de Évora). This integration of production, education, and cultural heritage established Évora as a cornerstone of Portuguese theatre.

Throughout the study period, seventy-nine plays were identified and incorporated into the matrix models, though only seventy-seven posters were successfully retrieved from the archives. Regarding authorship, while several artists and graphic designers associated with the Company were identified, none of the posters could be conclusively attributed to a specific creator.

Drawing on Aragão's study [5] as a framework, seventeen posters composed exclusively

of verbal elements were identified. These posters demonstrated a clear emphasis on establishing a hierarchy of information, with the play's title consistently given prominence to enhance its visibility and impact (Figure 7).

Figure 7: Lux in Tenebris (1975), O Velho da Horta (1978), 15 Rolos de Moedas de Prata (1979), Jorge Dandin ou O Marido Enganado (1979), A Bilha Quebrada (1980), O Inspector (1981), Sagui e as Estrelas (1981), Auto da Índia (1982), A Grande Imprecação Diante das Muralhas da Cidade (1982), Os Estrangeiros (1983), Dissidente, Só (1983), Sem Alterações (1984), O Alquimista (1985), O Doido e a Morte (1985).

Regarding typography and the arrangement of verbal elements, the play's title invariably assumed the central role in the composition, while the name of the Company was often presented in a larger size, underscoring its significance in the theatrical landscape. The backgrounds were typically plain — often white or the natural colour of the paper — reflecting a rudimentary or handmade production process.

Graphically, the posters were straightforward and minimalist, prioritising clarity and function over aesthetic complexity. This simplicity suggests an intentional focus on drawing audiences to the performances, where the essence and meaning of the plays would be fully conveyed.

Most of the collected samples were graphic objects that combined both pictorial and verbal elements, showcasing a deliberate interplay between imagery and text (Figure 8). These compositions often used visual components, such as illustrations or photographs, to draw attention, while the accompanying text provided essential information about the play, including its title, author, and production details.

Figure 8: O Proprietário Puntila e Seu Criado Putti (1975), O Preconceito Vencido (1976), Histórias de Ruzante (1976), O Eucalipto Feiticeiro, Jerónimo e a Tartaruga (1976), O Conde de Notion (1977), Medida por Medida (1977), Os Palhaços (1977), A Noite dos Visitantes (1978), O Que Diz Sim, O Que Diz Não (1978), O Velho da Horta (1978), Ma Liang (1978), Auto d'El-Rei Seleuco (1980), Kikerikiste (1980), A Paz (1980), Falar Verdade a Mentir (1981), Frei Luís de Sousa (1981), O Amante Militar (1981), Como é que Ele se Chama? (1982), O Céu e o Inferno (1983), O Puto Bill, Uma Aventura de Louko Lukas (1983), Sobre Isto (1984), Uma Lua Entre Duas Casas (1983), O Alquimista (1985), O Doido e a Morte (1985), Amanhã, uma Janela para a Rua (1985), Horácio (1985), A Farsa de Inês Pereira (1985), O Vento e o Mendigo (1985), Cinco Pasos (1986), A Escola das Mulheres (1986), O Contra Palhaço (1986), Afonso III (1987), O Legado (1987), Auto da Ciosa (1987), O Cavaleiro da Mão de Fogo (1988), O Juiz da Beira (1988), Todos os Anos o Mesmo (1988), Tristão e Isolda (1989), A Ilusão Cómica (1990), Assembleia Geral do Teatro (1999), Zona Oeste (19-), Clérigos e Almocreves (19-), 3 Entremezes (19-), Woyzeck (19-), Lorca Lorca (19-), Helm (19-).

The collection of posters featured a mixed approach of pictorial and verbal representations; forty-six were designed with an illustrative style, while fourteen incorporated photographic representation (Figure 9) in capturing the plays for the public. In terms of graphic solutions and text presentation, no consistent style or methodology was maintained over time. This variation ultimately reflects the frequent changes within the Company's graphic team, resulting in the diverse visual identity found in these posters.

Figure 9: A Noite do 28 de Setembro (1975), O Soldado Raso (1975), O Pó da Inteligência (1977), A Grande Imprecação Diante das Muralhas da Cidade (1982), A Fé, a Esperança, a Caridade (1982), Corda Bamba (1982), A Menina Júlia (1983), Amorosos (1984), Interior (1986), Solness, o Construtor (1987), Auto dos Físicos (1997), Bye Bye, Lehrstuck (1999), Borda Fora (19-), Eu (19-).

As in all previous cases, no singular or cohesive graphic style emerged within the Company's overall visual identity. The collected samples reveal a range spanning from geometric illustration to scene photography, while also demonstrating the absence of a unified stylistic or conceptual framework among the various artists and designers who contributed to the Company's graphic materials.

Escola de Teatro de Évora produced a significant number of plays during the period covered by this study, though posters corresponding to some of these were not found in the archives. Given the School's experimental nature and based on available archival records, it became evident that several of the posters were created by the students themselves, reflecting their exploratory engagement with the graphic design process.

The typographic solutions include a variety of font styles, ranging from serif to sans-serif, and occasionally more calligraphic forms. Notable examples include O Contra Palhaço (1986) and O Cavaleiro da Mão de Fogo (1988), in which the calligraphic treatment lent a distinct aesthetic quality to the designs.

5. FINAL REMARKS

The analysis of the case studies reveals an absence of convergence in poster design or visual language among the three theatre companies. This heterogeneity reflects each company's ongoing commitment to innovative research, exploration of new styles, and collaboration with diverse authors. Alongside the post-dictatorship context, in which individuals could finally create without restrictions or ideological impositions, this culminated in a continuous search for a consistent visual identity. Such efforts have contributed to the dynamic evolution of the theatre scenes in Braga, Almada, and Évora, positioning these decentralised companies as influential forces within the broader Portuguese thea-

tre landscape.
The consistent use of varying text hierarchies indicates a deliberate intention to establish reading levels, with the play's title consistently serving as the primary verbal element. Strategically, titles are positioned in the upper centre, centre, or lower centre of the posters, effectively capturing the viewer's attention. Regarding pictorial components—whether illustrated or photographed—these elements typically depict characters or scenes from the plays, serving as visual representations of the central themes. Occasionally, poster designs incorporate images or illustrations of the playwright, further enriching the connection between visual and literary elements.
The study's findings suggest promising avenues for further analysis, including comparisons with cinema posters from the same period. Such comparisons could illuminate the interplay between different cultural expressions and their collective impact on the history of design in Portugal between 1960 and 2000.
Establishing a dedicated website to preserve these posters would provide an essential resource for future generations. This platform would not only serve as a repository for preservation but also as an inspirational tool for contemporary designers and enthusiasts, ensuring the enduring influence of these works within the design community.

Acknowledgement(s):

Present research is partially financed by UNIDCOM/IADE, Design and Communication Investigation Unit [Av. D. Carlos I, 4, 1200-649 Lisboa, Portugal] in the framework of FCT strategic programme: "UIDB/00711/2025".

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

BRIDGING LOCAL HERITAGE AND GLOBAL AUDIENCES: THE IMPACT OF DIGITAL PLATFORMS ON CULTURAL PRESERVATION

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ABSTRACT

Cultural heritage is often confined within national borders, limiting its global reach and impact. In Croatia, it is primarily promoted to locals and tourists, restricting its accessibility. National values and identity have the potential to transcend local contexts and become a recognizable part of the global cultural scene. Digital technologies offer new opportunities to transcend these limitations, making heritage available to a global audience, regardless of location or prior knowledge.

For heritage to become internationally relevant, it must be presented in an engaging and universally understandable way. Digital platforms, interactive content, and innovative approaches can modernize its communication and ensure broader appeal. One example is the Jewelry Hvala by Fabula Croatica project, which integrates the Glagolitic script into contemporary design. Fabula Croatica modernizes Croatian heritage through design and visual communication, making it accessible to a wider audience. From the 13th century onward, only Croats developed their own versions of this script, and they transferred it to printing during the Gutenberg era. While Glagolitic holds cultural significance in Croatia, it remains largely unknown internationally. To change this, a digital ecosystem is needed for its promotion and education.

This paper examines whether a target group would purchase such products and in which conditions without prior knowledge of their historical significance.

Keywords: Cultural heritage, design, Webflow, Fabula Croatica, Glagolitic script.

1. CULTURAL HERITAGE IN THE DIGITAL AGE: AN OPPORTUNITY FOR EUROPE

Cultural heritage is often confined within national borders, tied to local identity and the physical presence of visitors. In Croatia, for instance, cultural heritage is primarily promoted to locals and tourists who experience it during their stay. However, this approach limits its global reach and potential for valorization. The digital age offers a transformative opportunity to transcend these boundaries, making cultural heritage accessible to a global audience, regardless of geographical location or prior knowledge of a particular tradition. From interactive websites to video games [11], digital technologies are reshaping how heritage transcends borders. As Lowenthal (2005) asserts, all heritage is simultaneously 'natural' and 'cultural'—a dynamic construct shaped by present-day values as much as past traditions. This duality underscores why digital platforms are uniquely positioned to reinterpret cultural heritage like Croatia's Glagolitic script, making it resonate with contemporary global audiences while preserving its historical essence. This principle applies not only to Croatia but to all of Europe—a continent rich in cultural heritage yet facing challenges in its sustainability and global visibility.

For cultural heritage to achieve international relevance, it must be made understandable and appealing not only to those emotionally connected to its origin but also to a global audience. This requires redefining its usability and interpretation, ensuring accessibility to people from diverse cultural backgrounds. Through digital platforms, interactive content, and innovative approaches, cultural heritage can be adapted to contemporary communi-

cation channels, becoming a dynamic part of the global cultural dialogue [7].
An exemplary case is the jewerly Hvala by Fabula Croatica, which incorporates the ancient Glagolitic script as a key element of its identity (Figure 1).

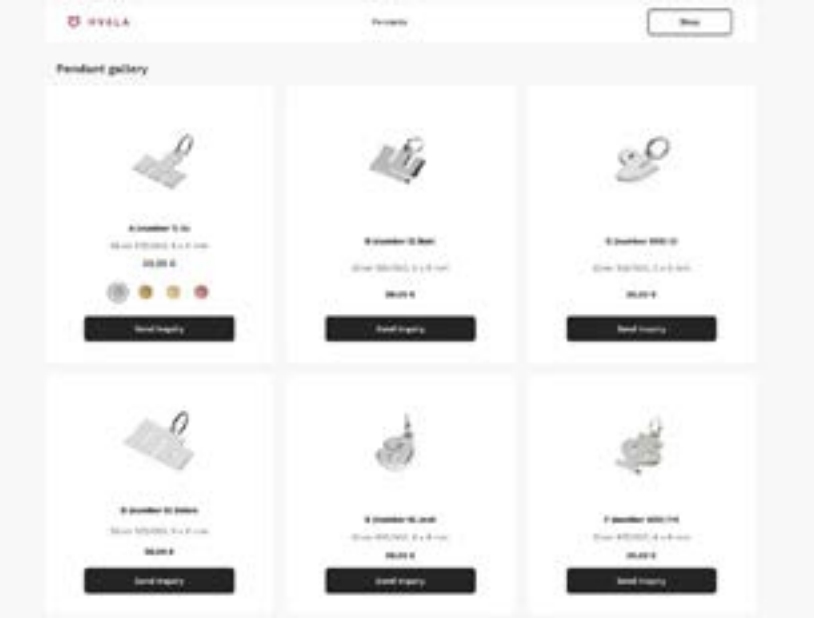

Figure 1: Pendant gallery through which a customer can order the product

While the Glagolitic script holds significant cultural value in Croatia, it remains largely unknown beyond its borders. To ensure broader understanding and integration into international cultural currents, it is essential to build an ecosystem of digital tools and platforms that facilitate its global promotion and education. As Pujol and Champion (2012) argue, digital heritage projects succeed when they create 'presence'—a sense of immediate access to cultural meaning—regardless of users' geographical or cultural distance [10]. Only through such a strategic and inclusive approach can cultural heritage become a bridge between the past and the future, the local and the global—not only in Croatia but across Europe.

1.1. Why is Glagolitic Script Unique and Can It Become a Brand?

Symbolism and Emotional Connection: The Glagolitic script is a coded system where each letter carries deep symbolism, reflecting the values and emotions of its time. Emotional relationships with brand's user base is a key characteristic of modern successful brands. This aligns with Ilicic et al.'s (2018) findings on brand authenticity in cause-related marketing, where perceived authenticity significantly enhances consumer engagement [9]. The Glagolitic script's historical depth and cultural symbolism inherently provide this authenticity, which can be leveraged to build emotional connections with global audiences unfamiliar with Croatian heritage.
Consistent Identity and Rich Narrative: The Glagolitic script has been used for over a millennium, permeating all aspects of Croatian society—everyday life, science, literature, art, and legal documents. Its consistent application and rich narrative provide a foundation for creating stories, projects, and products across various fields.
Innovation and Adaptability: The script has evolved over time, with four distinct forms—triangular, rounded, angular, and cursive. This adaptability makes it a powerful tool for branding and visual communication, combining historical value with modern innovation.

1.2. The Fabula Croatica project

The Fabula Croatica project aims to redefine the Glagolitic script as a brand by enriching it with new values through products and content that connect it to Croatian cultural heritage. The name, translating to "The Croatian Story" in Latin, reflects the project's international character. Its goal is to modernize parts of Croatian cultural heritage, present them effectively, and introduce them to a wider local and global audience using visual communication and design.

The project began by educating the public about the Glagolitic script, its nomenclature, and its graphic forms, with a focus on engaging young people and stimulating their interest in this heritage. This alignment between brand identity and cultural cause enhances authenticity and strengthens emotional resonance with consumers [9]. By integrating design and technology, Fabula Croatica demonstrates how forgotten or seemingly uninteresting aspects of cultural heritage can be revitalized and made relevant to contemporary life.

1.3. Adding value to cultural heritage

To make cultural heritage appealing, it is essential to add new value, encourage interaction, and form partnerships to create products that integrate heritage into everyday life [8]. This requires staying abreast of trends, implementing the latest technologies, and continuously analyzing user feedback to understand what resonates with the audience. This approach aligns with Carter and Grimwade's [12] principle of 'active preservation,' where cultural elements survive through contemporary adaptation rather than static conservation.

Design plays a crucial role in this process, as products must be shaped, packaged, and promoted effectively. Collaboration with industries such as printing, IT, and development is also necessary to bring these products to life. The best way to foster interest is through interaction and accessibility, ensuring that users can engage with the heritage in meaningful ways.

1.4. Jewelry Hvala

Jewelry Hvala is a jewelry line inspired by the Glagolitic script, created in partnership with Jewelry store Koci, a jewelry manufacturer in Zagreb. The name "Hvala," meaning "thank you" in Croatian, symbolizes gratitude and gift-giving, making the jewelry suitable for special occasions, anniversaries, or significant life events (Figure 2).

Figure 2: Details of the landing page of fabulahvala.com web page

The target audience for this product includes two segments: women aged 18–25 and

28–50. The promotional approach varies depending on the age group, with tailored visuals and messaging to appeal to each demographic. The concept leverages the mysterious nature of the Glagolitic script, akin to a tattoo in a foreign language, allowing wearers to carry a personal message through silver pendants.

1.5. Digital tools and user engagement

The website provides a pendant gallery detailing each piece's design, dimensions, and pricing. Customers can place orders online or visit the Koci jewelry store located at Frankopanska street 3, 10000 Zagreb, Croatia, to view and purchase the jewelry in person. By merging historical Glagolitic script with modern jewelry design, the HVALA collection offers a unique way for individuals to express personal messages while celebrating cultural heritage.

The project utilizes Webflow, a low-code platform, to create a visually appealing website that showcases the jewelry. Additionally, 3D models of the jewelry, created using web-based software Spline, allow users to explore each product from all angles, enhancing engagement. Providing interactive spatial representation fosters a sense of presence, which is crucial in cultural heritage projects to deepen emotional and cognitive connection [10]. To monitor user behavior, Google Analytics and Hotjar were integrated into the website. The website fabulahvala.com showcases HVALA jewelry line that integrates Glagolitic script into contemporary designs. Crafted from high-purity silver (925/1000), the collection features pendants shaped as Glagolitic letters, designed using the exclusive FC Epistula Croatica font, which imparts an organic and natural appearance to each character.

The page promotes customization where customers can personalize their jewelry by choosing and arranging pendants to form meaningful messages, names, or significant dates. The pendants can be aligned horizontally or vertically, connected by cylinders that maintain spacing, and worn as bracelets or necklaces, offering versatility in style.

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2. EXPERIMENT

A 14-day questionnaire study was conducted from 16 March to 30 March to evaluate market potential for cultural heritage-based products. The research aimed to analyze user interest, purchasing behavior, and the influence of cultural heritage on consumer decisions. The primary hypothesis stated that existing product category users would demonstrate interest in culturally-inspired products.

2.1. Methodology

The survey included the following key question categories:

1. Demographic Information
   - Gender
   - Age group
   - Geographic location
2. Online Behavior & Purchase History
   - Website visitation (Fabula Hvala)
   - Previous jewelry purchases
3. Purchasing Preferences

- Jewelry selection criteria (5-point Likert scale):
  - Price sensitivity
  - Material type
  - Brand significance
  - Symbolic value
  - Narrative elements
  - Design aesthetics
  - Other factors

4. Cultural Heritage Engagement
   - Interest in message-based jewelry
   - Purchase consideration post-website viewing
   - Appeal of Glagolitic script
   - Perceived relevance of heritage in daily life
5. Purchase Intent
   - Product inquiries submitted
   - Website return intention
6. Qualitative Feedback
   - Product improvement suggestions
   - Future collection expectations

The study included 23 participants of which 21 of them were female and 2 were male. Participants were distributed across age groups as follows: 7 respondents aged 22-28, 2 aged 29-36, 9 aged 37-44, 1 aged 45-52, and 5 aged 53-61. Notably, 20 of 23 respondents (87%) had visited the Fabula Hvala website prior to participation.
Ratings were as follows:

Table 1. Descriptive analysis

Importance of	Mean	Median	Standard Deviation	Range
Price	3.91	4	0.70	3-5
Material Type	4.09	4	0.70	3-5
Brand	2.43	2	1.28	1-5
Symbolism	3.39	3	1.33	1-5
Jewelry Story	3.17	3	1.34	1-5
Jewelry Design	4.65	5	0.49	4-5
Likelihood to Buy Jewelry with Custom Messages	3.91	4	0.95	2-5
Likelihood to Purchase from Fabula Hvala After Viewing Website	4.17	5	0.94	2-5
Interest in Glagolitic Script (Cultural Heritage)	4.13	4	1.02	2-5

Perception of Cultural Heritage in Daily Life	3.26	3	1.28	1-5

Based on data from Table 1. it is clear that Jewelry design is the most important factor to potential buyers and Brand is the Least Important. In order to improve the results more material options for jewelry products could be added because it could attract customers who prefer non-silver jewelry. Based on descriptive analysis alone, promotional images should be tailored to women aged 22-44, the most active respondents, highlighting design and customization. The interest in Glagolitic script could be leveraged by deepening story-telling around its cultural significance.

From this conducted research several statistically significant variables have been found that are relevant for this hypothesis.

Customization Interest correlates with Revisit Intent

Objective here was to determine whether willingness to buy personalized jewelry predicts likelihood of revisiting the Fabula Hvala website. Respondents were split into High (4-5) vs. Low (1-3) interest in personalized jewelry and they were compared with web site fabulahvala.com revisit intent using ANOVA and t-test.

Independent Variable (Continuous): "Would you buy jewelry that allows you to engrave a personally meaningful message?" (1-5 scale, 5 = very likely)

Dependent Variable (Continuous): "Would you like to visit https://www.fabulahvala.com again?" (1-5 scale, 5 = very likely)

Correlation Analysis Results
Pearson's r = 0.48 (moderate positive correlation)
p-value = 0.02 (statistically significant at $\alpha = 0.05$)

Based on these results higher interest in personalized jewelry is associated with higher web revisit intent.

Table 2. High vs. Low Interest group Comparison

Group	N	Mean Revisit Intent	SD
High Interest (4-5)	15	4.67	0.49
Low Interest (1-3)	8	3.63	1.30

Independent Samples t-test:
t = 2.93, p = 0.008 (significant difference)
Effect Size (Cohen's d) = 1.07 (large effect)

Customers interested in personalized jewelry are significantly more likely to revisit the website. The correlation (r = 0.48) suggests that ~23% of revisit intent variability is explained by this factor. It can be concluded that personalization is a key driver of customer retention for Fabula Hvala and enhances long-term engagement. Promoting personalization options on web should be further researched.
Interest in Glagolitic Script vs. Website Revisit Intent

Analysis Results
Moderate Positive Correlation: r = 0.47 (p = 0.023)
Statistical Significance: Significant at α = 0.05 level
Mean Values:
Glagolitic interest: 4.13 (SD = 1.02)
Revisit intent: 4.35 (SD = 0.94)

The moderate correlation (r = 0.47) suggests a meaningful relationship between cultural interest and revisit likelihood. Respondents who found Glagolitic script "very interesting" (5/5) had higher revisit intent (mean = 4.71) than those with neutral interest (mean = 3.80). Cultural heritage element in this example serves as a differentiator for customer retention (22% of revisit intent variability (R^2 = 0.22)). The significant correlation demonstrates that interest in Glagolitic script as cultural heritage positively influences customers' likelihood to revisit the website. This cultural connection foster stronger brand engagement beyond typical jewelry purchase considerations.

Purchase Intent correlates with Revisit Intent

Analysis Results
Strong Positive Correlation: r = 0.72 (p < 0.001)
Highly Statistically Significant: p-value = 0.0001
Mean Values:
Purchase Intent: 4.17 (SD = 0.94)
Revisit Intent: 4.35 (SD = 0.94)

The very strong correlation (r = 0.72) indicates a robust relationship between initial purchase interest and likelihood to return to the website. Nearly all respondents (91%) who expressed high purchase intent (4-5/5) also planned to revisit the site (4-5/5). The analysis reveals a strong relationship between initial purchase intent and future revisit likelihood (52% of the variability in revisit intentions (R^2 = 0.52)). Better product presentation as well as clear value proposition should be further explored because first website experience serves as a critical gateway for building lasting customer relationships.

Purchase History correlates with Purchase Intent
Analysis Results
Moderate Positive Correlation: r = 0.42 (p = 0.047)
Statistically Significant: p-value < 0.05
Mean Purchase Intent by Purchase Frequency:
Regular buyers: 4.67 (n=3)
Periodic buyers: 4.36 (n=11)
Rare buyers: 3.63 (n=8)

Regular buyers demonstrated 29% higher purchase intent than rare buyers. Periodic buyers showed consistently high intent (mean=4.36). Regular or periodic jewelry buyers are more likely to convert which means that prior purchase experience positively influences conversion likelihood. Based on the results further research on how premium, luxury or limited collections and loyalty programs influence purchase intent, should be conducted. Additional research needs to be conducted in order to see which variables (like product education reviews, quality guarantees or other) influence may less experienced buyers to convert

Revisit Intent Across Cultural Heritage Perception Levels (1-5)

The objective is to determine whether revisit intent differs significantly based on how strongly respondents perceive cultural heritage ("Do you perceive cultural heritage as part of your daily life?", rated 1–5). ANOVA test was used to test this.

Independent Variable (Grouping Factor): Cultural heritage perception (5-point Likert scale, 1 = Not at all, 5 = Very much).

Dependent Variable: Revisit intent ("Would you like to visit the website again?", 1–5 scale).
Test: One-way ANOVA (compares means across 5 groups).
Post-hoc Test: Tukey's HSD (if ANOVA is significant).

Table 3. Descriptive statistics for Revisit intent correlation with cultural heritage relevance

Cultural Heritage Rating	N	Mean Revisit Intent	SD
1 (Lowest)	5	3.00	1.41
2	4	3.50	1.29
3	6	4.33	0.82
4	5	4.80	0.45
5 (Highest)	3	5.00	0.00

ANOVA Output
F-statistic: 6.72
p-value: 0.002 (Statistically significant at $\alpha = 0.05$)
Effect Size (η^2): 0.53 (Large effect)

Table 4. Post-hoc Tukey Test

Comparison	Mean Difference	p-value	Significance
1 vs. 5	-2.00	0.002	Sig.
2 vs. 5	-1.50	0.022	Sig.
3 vs. 5	-0.67	0.320	Not sig.
1 vs. 4	-1.80	0.005	Sig.
2 vs. 4	-1.30	0.048	Sig.

Respondents who strongly identify with cultural heritage (ratings 4–5) have significantly higher revisit intent than those who disregard it (ratings 1–2). Customers who see cultural heritage as personally relevant (4–5/5) are most loyal. Cultural heritage perception significantly impacts revisit intent, with a large effect size ($\eta^2 = 0.53$).

Regression Analysis: Does Cultural Heritage Perception Predict Purchase Likelihood?

The objective is to determine whether cultural heritage perception ("Do you perceive cultural heritage as part of your daily life?", 1–5 scale) predicts purchase likelihood ("After viewing the Fabula Hvala website, would you buy the jewelry?", 1–5 scale). Simple Linear Regression was used.

Dependent Variable (Target): Purchase likelihood (1–5).
Independent Variable (Predictor): Cultural heritage perception (1–5).

Table 5: Regression Analysis Summary

Metric	Value	Interpretation
R^2	0.28	28% of purchase intent variance explained by cultural heritage perception.
Adjusted R^2	0.25	Moderate explanatory power.
F-statistic (p-value)	8.21 (p=0.009)	Statistically significant ($p < 0.05$).

Table 6: Regression Coefficient Analysis

Variable	Coefficient (β)	Std. Error	t-value	p-value
Intercept	2.36	0.59	4.01	0.001
Cultural Heritage	0.47	0.16	2.86	0.009

Cohen's $f^2 = 0.39$ (moderate-to-large effect).
Predicted Purchase Intent by Heritage Rating:
Rating = 1: 2.83
Rating = 3: 3.77
Rating = 5: 4.71

Cultural Heritage Matters for Conversions. Stronger cultural affiliation leads to higher purchase intent. For every 1-point increase in cultural heritage perception, purchase likelihood increases by 0.47 points (on a 5-point scale). Top heritage raters (5/5) are 66% more likely to buy than bottom raters (1/5). Cultural heritage perception significantly predicts purchase intent, with a moderate-to-large effect. When promoting cultural heritage as a product one should prioritize heritage storytelling for high-affinity segments.

3. FUTURE RESEARCH

Future studies should examine several key areas to enhance understanding of cultural heritage products:
Promotional Content Analysis
Investigate whether emphasizing the Glagolitic script's cultural significance in marketing materials correlates with increased purchase intent [11,12].

Educational Content Development
Assess whether developing educational materials about the script's historical context and meaning enhances product relevance among target audiences [13].

Product Line Expansion
Research the potential impact of additional product collections on consumer purchase decisions.

Attribute Emphasis Testing
Evaluate whether jewelry products highlighting design and quality attributes over cultural heritage elements appeal to less heritage-interested consumers.

4. LIMITATIONS

The current study's limitations include:

- Restricted sample size (N=23)
- Predominantly Croatian respondents (with potentially higher baseline Glagolitic script awareness)
- Limited geographic and demographic diversity

These factors may affect the generalizability of findings and should be addressed in future research through expanded sampling methodologies [12,13].

5. CONCLUSION: CULTURAL HERITAGE AS A GLOBAL BRAND

By measuring engagement using Hotjar over the course of fourteen days from 16 March to 30 March, the results showed that users spent an average of 36 seconds on the site. 17.9% of users were returning ones. These results revealed that even individuals unfamiliar with the Glagolitic script or Croatian cultural heritage expressed interest in the jewelry, demonstrating the potential of well-presented cultural products to attract a broad audience. Purchase intent and cultural connection (Glagolitic interest) show the strongest predictive power. Personalization features has also been highlighted as one of the factors that drive retention. Emotional drivers like cultural connection and customization outperform practical factors like price and type of materials and show the strongest relationships with customer engagement metrics. This suggests Croatia's cultural heritage competitive advantage lies in its ability to connect jewelry purchases with deeper personal and cultural narratives (Heritage-focused), rather than competing on traditional factors like price or materials. Age and location in Croatia showed weaker relationships with outcomes which means that a universal appeal across segment should be implemented. Jewelry Hvala by project Fabula Croatica demonstrates how cultural heritage can be modernized and integrated into contemporary life. Cultural heritage must be made accessible and appealing to a global audience through digital innovation. In order to do that collaboration between designers, technologists and cultural experts is essential. Besides that continuous analysis and adaptation are crucial to ensuring the relevance and sustainability of cultural products. By embracing these principles, Croatia and other nations can turn their cultural heritage into a tool for global recognition and economic growth. The findings demonstrate that cultural heritage can have the potential to become a foundation for economic sustainability when adapted for global markets, supporting Pressey and Selassie's [7] argument that cultural differences often emphasized in global markets, their actual impact on buyer-seller relationships may be overstated. This suggests that Croatia's Glagolitic script—despite its niche cultural origins—can achieve global appeal without requiring deep prior knowledge of its heritage, aligning with Fabula Croatica's strategy of universal design and digital storytelling [10]. National values and identity can gain global recognition through innovation, adaptation, and contemporary presentation methods, provided that such use is balanced with preservation to maintain authenticity and long-term value [12]. Projects like Jewelry Hvala by Fabula Croatica exemplify how national identity markers gain international recognition for new generations when presented through contemporary design by blending tradition with modern design, integrated with modern consumption patterns, and leveraged via digital platforms. For Croatia and other nations, cultural heritage is not just a relic of the past but a living organism that must be adapted to the modern world. By nurturing cultural identity and leveraging digital platforms, countries can create a sustainable future where heritage is not only preserved but also lived and celebrated. This aligns with Zhao et al.'s [8] model of culturally driven sustainable consumption, where heritage authenticity and sustainability narratives resonate strongly with consumers.

Fabula Croatica's integration of Glagolitic heritage into modern design not only preserves culture but also fosters a sense of shared global responsibility, appealing to consumers who value sustainability and cultural authenticity. Successful cultural commercialization requires specialized expertise, digital transformation, cross-sector collaboration, and continuous market analysis. This requires investment, expertise, and strategic planning which transform cultural assets into drivers of economic growth, global recognition, and cultural sustainability [7,8,12].

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

THE INFLUENCE OF ICC PROFILES ON THE QUALITY OF VARIOUS PRINTING TECHNIQUES

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ABSTRACT

This study analyzes the impact of different ICC profiles on color reproduction in digital printing, comparing five distinct ICC profiles with the reference ICC profile Fogra 39. The examination was conducted using two digital printing technologies: electrophotography and inkjet technology. The primary objective was to quantify colorimetric deviations and determine how the choice of ICC profile affects color accuracy in relation to a standardized reference sample.
The experimental part of the study involved printing standardized test samples using selected ICC profiles and performing a colorimetric analysis of the resulting prints. Measurements were conducted using a spectrophotometer, and color differences were expressed in ΔE values within the CIE L*a*b* color space. The analysis considered key aspects of colorimetric deviations, including hue, lightness, and saturation, aiming to identify significant variations between different ICC profiles and the reference standard.
This research highlights the importance of selecting the appropriate ICC profile in the digital printing process and its impact on the final quality of color reproduction. The obtained results can serve as guidelines for optimizing color management in the graphic industry, enabling printers and designers to better understand the colorimetric characteristics of different printing technologies and adjust them to specific printing requirements.

Keywords: ICC profile, electrophotography, inkjet, ΔE, colorimetric analysis

1. INTRODUCTION

In the modern printing industry, the quality of color reproduction is a key determinant of the final product's success. Accurate color management is becoming increasingly important in both digital and traditional printing, aiming to achieve consistent and high-quality results. In this context, ICC (International Color Consortium) profiles play a crucial role in ensuring accurate color reproduction across different devices and printing techniques. Proper selection and adjustment of ICC profiles can optimize the printing process, minimize color discrepancies, and enhance the overall visual quality of prints.
The advancement of printing technology has enabled more sophisticated color management methods while simultaneously introducing challenges in selecting optimal printing parameters. One of the key factors influencing print quality is the amount of ink or toner application. [1] Precisely balancing ink deposition can significantly impact the final outcome, preserving details, maintaining appropriate saturation levels, and ensuring correct tonal rendering. Adjusting ink deposition to specific printing requirements can improve output quality; however, such modifications may also lead to variations in color stability and reproduction accuracy.
This study examines the comparison of six different ICC profiles in the printing preparation process and analyzes their application on inkjet and laser printers. The experiment involves printing identical visuals using different profiles and analyzing the differences in color reproduction, tonality, and saturation between the two printing methods. A particular focus is placed on ink deposition analysis, emphasizing controlled variations in ink

application to maintain print quality. The conducted tests encompass the selection and adaptation of ICC profiles for different printing techniques, evaluating variations in the final print appearance and its stability.
To ensure an objective color analysis, measurements were conducted using a spectrophotometer and colorimetric methods. The differences between prints were quantified using ΔE values, which precisely determine deviations between target and reproduced colors. Based on the obtained results, the study explores the potential for optimizing ink deposition without compromising print quality, contributing to the economic and environmental efficiency of the printing process.
The structure of this paper is organized as follows: the first section presents the theoretical aspects of ICC profiles and their role in printing. This is followed by a description of the methodology and experimental procedure. Subsequently, the results are analyzed, and their implications are discussed. Finally, the paper provides conclusions and recommendations for practical applications in the printing industry.

2. THEORETICAL

2.1. Color Management System

The Color Management System (CMS) is not merely a technical necessity but also a fundamental element in maintaining color consistency, particularly in industries such as printing, graphic design, photography, and digital production.[1] Since different devices can interpret colors in distinct ways, a CMS ensures that all devices within the production workflow (from scanners to printers) share a common language, enabling consistent and accurate color reproduction despite technical differences.[2]
One of the challenges in color management systems is reducing "color variation," a phenomenon caused by differences in color production across devices. For example, colors that appear perfect on a computer screen may look entirely different when printed on a press due to variations in color display technologies (RGB vs. CMYK) or limitations in reproducing certain colors on specific devices. A CMS minimizes this issue by implementing strategies for precise color mapping from one device to another, reducing visual discrepancies that arise during the printing process.
Recent trends in CMS include the use of advanced algorithms for automating color management and the application of artificial intelligence (AI) to predict and correct undesirable color variations. For instance, AI can analyze color patterns in specific printed materials and automatically adjust settings to achieve the most accurate color simulation on the final product.
Additionally, there is a growing initiative to integrate color management systems into cloud-based platforms and online applications, allowing for real-time process optimization. These systems enable centralized color settings that can be adjusted from a single location, facilitating seamless collaboration between multiple teams working on different devices. This ensures standardized color management regardless of location.
Finally, the maintenance and calibration of color management systems have become vital for industries that rely on precision and color quality, such as the packaging printing industry, the fashion industry (textile coloration), and the automotive and construction industries, where color plays a crucial role in manufacturing processes.

2.2. ICC Profiles

During the early 1990s, as analog graphic reproduction processes transitioned into digital workflows, the need for color management systems that were not mutually compatible became apparent. In response, leading manufacturers such as Adobe, Agfa, Apple, Kod-

ak, Microsoft, Silicon Graphics, Sun Microsystems, Fogra, and Taligent established the International Color Consortium (ICC) in 1993. The primary goal of this consortium was to develop standardized files that would enable precise characterization of a device's color reproduction properties. The ICC specification precisely defines the format of these profiles but does not prescribe exact methods for data processing within them, allowing for variations in software solutions and color management systems that utilize ICC profiles. [2]
In 2003, the ICC initiated collaboration with the ISO technical committee for graphic technologies, further advancing the evolution of color management systems.
An ICC profile is a file that links device-specific color values with device-independent color values that represent the actual color perceived by human vision. A device uses control signals, typically RGB or CMYK, to reproduce colors, whereas the device-independent color values reside in a reference color space such as CIEXYZ or CIELAB. The ICC standard strictly defines the profile format but does not dictate the method for processing or generating data within the profiles, allowing for differences among software applications and systems that implement them. Essentially, an ICC profile serves as a bridge between a device and a reference colorimetric space, aligning machine-generated color output with human visual perception. If a device or document lacks an appropriate ICC profile, it cannot be integrated into a color management system (CMS). The ICC profile provides essential information for color conversion between a device's color space and the reference color space.[3][4]

2.2.1. Structure and Characteristics of ICC Profiles

A device profile contains three primary variables that define its characteristics:

- Gamut – the range of colors a device can reproduce.
- Dynamic range – the scope of colors and brightness levels between the white and black points.
- Tone – the characteristics of color reproduction on the device.

The structure of an ICC profile consists of a header, lookup tables, and data structures. The profile header includes key information necessary for software interpretation, such as the profile type, device color space, device-independent color space, preferred module, and metadata related to the media type and light source. The lookup tables store identifiers, positions, and sizes of each structure, while the data structures contain both mandatory and optional data elements.

2.2.2. Types of ICC Profiles

Device profiles are categorized into three primary types: input profiles, which are designed for scanners and digital cameras and define the conversion from the input device's color space to a reference color space; display profiles, which are used for monitors and flat-screen devices and must be bidirectional since screens can function as both input and output devices, requiring the CMS to accurately reproduce the colors seen on the display; and output profiles, which are intended for printers, photocopiers, film recorders, and printing presses, facilitating conversion between the Profile Connection Space (PCS) and the output color space, enabling CMYK image reproduction across various printing devices.

2.3. Printing Methods and Relationship with ICC Profiles

2.3.1. Electrophotography

Electrophotography is currently the most widely used process within Non-Impact Printing (NIP) technology, which enables printing without physical contact. This technology is applied in the production of proof prints as well as in monochrome and multicolor digital printing machines. Its fundamental principle is based on the photoelectric effect, which occurs when semiconductor plates are exposed to light. During this process, a controlled electric potential is generated on the conductive surface, accompanied by the emission of ions from metallic grids.[5]
Electrophotography is a well-established and widely used printing technology. The most common application of electrophotographic printers involves a scanning laser beam or an array of light-emitting diodes (LED strip) as a light source, developing a latent image using dry toner. Despite its extensive use, this technology has certain limitations in terms of image quality. For instance, the color consistency of electrophotographic printers has yet to reach the standards set by offset or gravure printing. One of the key reasons for color inconsistency in electrophotographic printing lies in the low or insufficient quality of individual pixels. Current research indicates that in dry-toner electrophotography, it is not possible to print individual white and black pixels within the same image. Since an individual pixel represents the smallest dot a printer can generate, its size is primarily determined by the diameter of the laser light spot or the individual LED within the LED strip.
The fundamental principle of electrophotography is based on a physical phenomenon known as the photoconductive effect. This effect is characteristic of materials that are normally non-conductive or weakly conductive under standard conditions, most commonly occurring in single crystals or crystalline masses such as crystallized selenium, tellurium, cuprous oxide, thallium sulfide, and thallium oxide. When exposed to intense light, the structure of these crystals undergoes changes, resulting in increased electrical conductivity.[6]

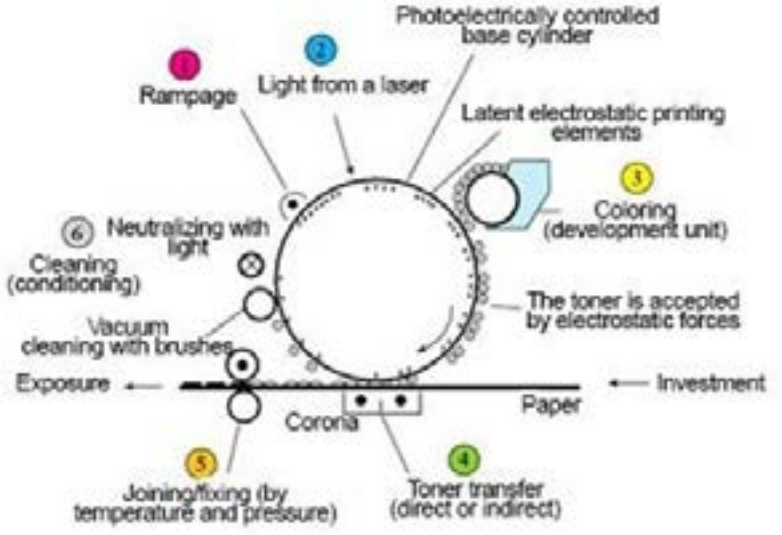

Figure 1: Principle of Electrophotographic Printing [9]

2.3.2. Inkjet

Inkjet is a non-contact printing technology based on the dot-matrix principle. In this process, tiny ink droplets are ejected through a small nozzle directly onto the selected area of the medium, thereby creating an image.[7]

Depending on the methodology of droplet deflection, a continuous inkjet system can be designed as either a binary or a multi-deflection system. In a binary system, ink droplets can be either charged or uncharged. Charged droplets freely travel toward the medium, while uncharged droplets are redirected into the recirculation channel (Figure 2).

In a multi-deflection system, droplets are further charged and directed to different levels of the medium. Uncharged droplets, as in the binary system, end up in the recirculation channel. This method allows a single nozzle to print a small segment illb image. Both methods have found widespread use in the marking, coding, and labeling industries. Companies such as VideoJet, Domino, Imaje, Toxot, and Willet actively develop and market products based on this technology.[7]

Recently, the company Nur Advanced Technologies introduced an inkjet printer utilizing continuous inkjet technology, capable of printing big billboard sup. Besides these methods, the Hertz continuous inkjet process has been developed as a specialized technique that uses a unique method of creating grayscale tones through a series of small droplets. The Hertz concept is applied in products such as the Iris Realistic printer for graphic arts and the Scitex Digital Press for high-speed on-demand printing.

Today, the greatest advancements in inkjet printing are occurring in drop-on-demand (DOD) printing methods. Depending on the droplet formation mechanism, this technology is divided into four main methods: thermal, piezoelectric, electrostatic, and acoustic inkjet printing. Most commercially available printers use the thermal or piezoelectric principle. On the other hand, electrostatic and acoustic inkjet printing are still in the development phase, with many registered patents but few products available on the market.

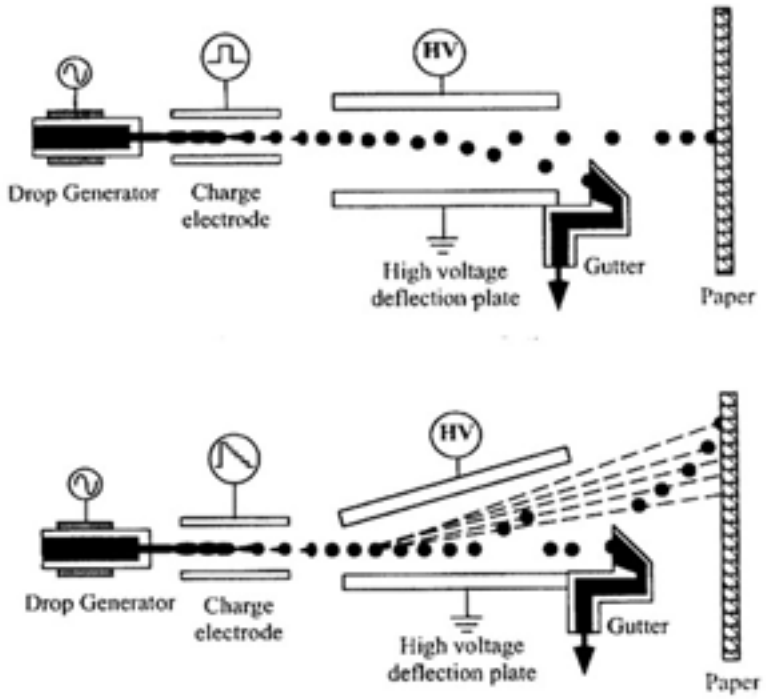

Figure 2: Inkjet Operation Principle

2.3.3. ICC Profiles and Printing Techniques

ICC profiles play a crucial role in ensuring consistent and accurate color reproduction across different printing technologies, including electrophotography and inkjet printing. These profiles enable color standardization between various devices, ensuring that colors are displayed consistently regardless of the printing technology used.
ICC Profiles in Electrophotography: Electrophotographic devices, such as laser printers, use toners to reproduce colors. ICC profiles for these devices allow for compensation of specific color characteristics. Each printer has unique color characteristics, and by using the appropriate ICC profiles, it is possible to adjust output colors to achieve the most faithful reproduction of the original content.[3]
Standardization Between Devices: ICC profiles facilitate color matching between different electrophotographic printers, ensuring consistent results regardless of model or manufacturer.
ICC Profiles in Inkjet Printing: Inkjet printers use liquid inks that are applied directly to the medium. In this context, ICC profiles are used for adjusting colors to specific combinations of printers, inks, and papers. Each combination of these elements has a unique color gamut. By using the appropriate ICC profiles, it is possible to optimize color reproduction for a specific combination of printer, ink, and paper.[8] They are also used for ensuring color consistency across different devices and media: With ICC profiles, it is possible to achieve consistent printing results across different media and printers, which is essential for professional photographers and designers.[9]

3. EXPERIMENTAL PART

3.1. Methodology

3.1.1. Selection of ICC Profiles

For the purposes of this study, multiple standard ICC profiles will be analyzed. The profiles used in this research include Fogra 39, Fogra 29, SWOP US, Japan Coated, Web Coated Eu Fogra 28, and Euroscale Coated, applied across different printing technologies: electrophotography and inkjet. These profiles define color characteristics and tonal ranges, ensuring consistent color reproduction across various printing techniques. For the purposes of this study, measurement fields were printed as defined in Figure 3. Since the aim of the test was to compare color deviations relative to the Fogra39 profile, the test file was converted to the remaining profiles for evaluation and test form was printed.
To precisely determine the differences in color representation when applying different profiles, a quantitative analysis will include measurements of CIE L*a*b* values [2]. In order to compare colors and identify discrepancies, the ΔE^*_{00} metric is employed. ΔE^*_{00} quantifies the difference between the reference and reproduced colors. The resulting measurements provide an assessment of print accuracy.[10]

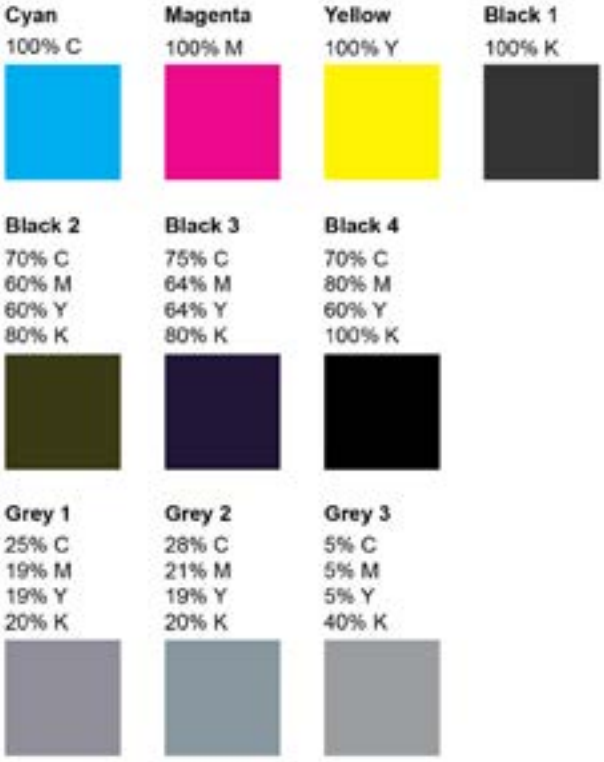

Figure 3: Measured fields with defined halftone values

3.1.2. Used Machines and Devices

A spectrophotometer was used for conducting the research, a precise optical instrument designed to measure spectral reflection and transmission of light. This device enables detailed color analysis through the CIEL*a*b* system and calculates the ΔE deviation between the reference and reproduced colors.[11]
Electrophotographic printing was performed using a professional digital printing press, which allows for high color precision and print stability. Inkjet printing was carried out using an advanced inkjet printer, capable of precise control over ink deposition and the colorimetric properties of the print.[12]

3.1.3. Used Materials

The research was conducted on standard uncoated A4 paper, selected due to its widespread use in the printing industry and its impact on color reproduction across different printing techniques.

3.2. Research Results

All measurements were recorded in a table, and the formula for calculating ΔE*00 was applied[9]. The ΔE formula is an improved version of the calculation for colorimetric differences between two colors in the CIE L*a*b* color space. Compared to the older ΔE76 formula, ΔE_{00} better models human color perception, particularly in cases of small deviations and in areas of low saturation.
ΔE differences were then calculated using ΔE^*_{00} (ΔE^*_{2000}).

$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \quad (1)$$

In the digital and electrophotographic printing industry, acceptable ΔE values are often higher than those in traditional printing. The typical thresholds are as follows:
According to Kipphan, color differences are classified as follows:

$\Delta E_{00} < 1 \rightarrow$ indicates that the average human eye perceives no difference
$\Delta E_{00} = 1\text{-}2 \rightarrow$ signifies a slight difference
$\Delta E_{00} = 2\text{-}3.5 \rightarrow$ represents a moderate difference
$\Delta E_{00} = 3.5$ to $5 \rightarrow$ indicates a significant difference
$\Delta E_{00} > 5 \rightarrow$ suggests an unacceptable difference.

The obtained ΔE^*_{00} measurements were used to calculate the mean value using the following formula:

$$\bar{x} = \frac{\sum xi}{n} \quad (2)$$

The minimum and maximum deviations were determined.

Additionally, the standard deviation of the sample was calculated using the following formula:

$$s = \sqrt{\frac{\sum (xi - \bar{x})^2}{n-1}} \quad (3)$$

In electrophotographic printing, the standards for the mean value and standard deviation of color difference (ΔE) are not universally defined but depend on the specific requirements of the project, client expectations, and the technical capabilities of the equipment. Generally, acceptable ΔE tolerances in the printing industry are as follows:
Mean ΔE: It is recommended that the average color difference be as small as possible, ideally below 3, in order to ensure high color reproduction quality.
Standard Deviation ΔE: A lower standard deviation indicates consistency in color reproduction. Although specific values may vary, the goal is to maintain a low standard deviation to ensure print consistency.[10]

3.2.1. Electrophotography

Table 1: Display of CIE L*a*b* and ΔE*00 measurement data for the ICC profiles Fogra 39 and Euroscale Coated

FOGRA 39 -STANDARD				EUROSCALE				ΔE*00
	L*	a*	b*		L1	a1	b1	
cyan	48.2	-25.91	-40.12	cyan	48.06	-25.21	-40.55	0.83
magenta	43.24	69.17	1.84	magenta	43.28	68.58	2.32	0.76
yellow	83.54	-4.37	90.02	yellow	82.97	-3.32	88.64	1.83
black 1	7.7	-1.28	1.66	black 1	7.18	-1	1.46	0.62

black 2	7.56	-1.07	1.48	black 2	6.41	-0.64	1.32	1.24
black 3	6.76	-0.82	2.11	black 3	13.37	0.12	0.67	6.83
black 4	8.57	-0.39	3.42	black 4	15.13	0.38	1.21	6.96
grey 1	61.1	-0.08	0.62	grey 1	64.39	-0.47	-3.63	5.39
grey 2	46.02	-1.74	-9.5	grey 2	49.65	-0.16	-11.67	4.51
grey 3	76.49	2.45	-7.22	grey 3	76.69	2.13	-7.58	0.52

The first table presents measurements of the reference colors from the ICC profile Fogra 39 and the tested colors from the ICC profile Euroscale Coated. Analysis of the results revealed that the mean ΔE value is 2.95. The minimum deviation is 0.52, while the maximum deviation is 6.96. The standard deviation is 2.673.
In this case, when comparing the standard ICC profile Fogra 39 and the Euroscale Coated profile, the maximum deviation is 6.96 (for black color). This deviation exceeds the acceptable threshold and may pose a problem for more demanding prints. The standard deviation of 2.673 indicates significant variability, which may also suggest inconsistent color control.

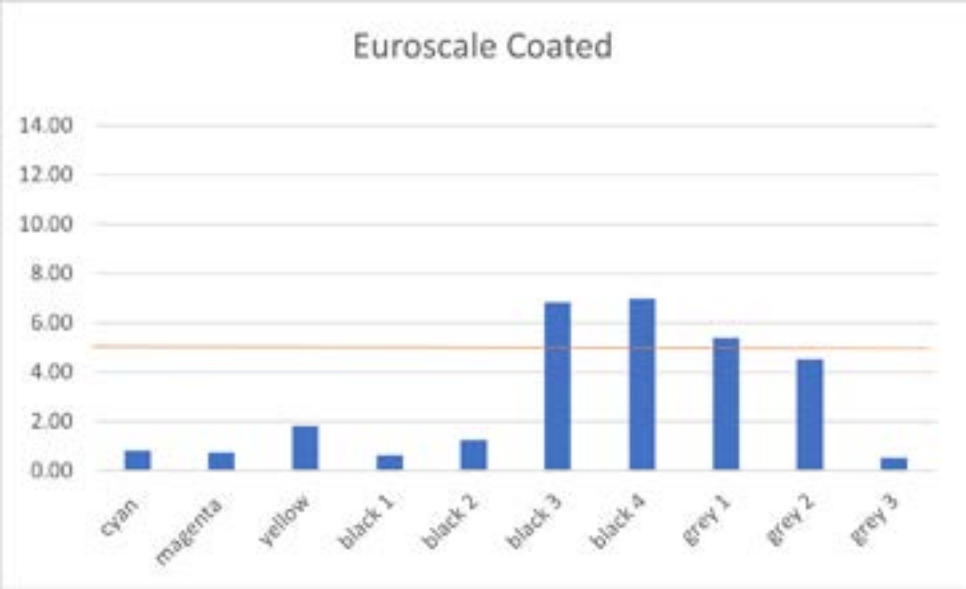

Figure 4: Graphical representation of ΔE^*_{00} deviations for the Euroscale Coated profile

Table 2: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and Fogra 29

FOGRA 39 -STANDARD				FOGRA 29				ΔE*00
	L*	a*	b*		L1	a1	b1	
cyan	48.2	-25.91	-40.12	cyan	48.44	-26.08	-41	0.93
magenta	43.24	69.17	1.84	magenta	43.6	69.59	2.31	0.73
yellow	83.54	-4.37	90.02	yellow	83.36	-4.33	88.62	1.41
black 1	7.7	-1.28	1.66	black 1	8.51	-0.85	1.66	0.92
black 2	7.56	-1.07	1.48	black 2	7.6	-0.72	1.75	0.44
black 3	6.76	-0.82	2.11	black 3	7.13	-0.78	1.66	0.58
black 4	8.57	-0.39	3.42	black 4	9.18	0.48	3.6	1.08

grey 1	61.1	-0.08	0.62	grey 1	61.57	-0.34	-1.7	2.38
grey 2	46.02	-1.74	-9.5	grey 2	47.39	0.04	-10.31	2.39
grey 3	76.49	2.45	-7.22	grey 3	74.26	2.75	-4.99	3.17

The table presents measurements of the reference colors from the ICC profile Fogra 39 and the tested colors from the ICC profile Fogra 29. Analysis of the results revealed that the mean ΔE value is 1.40. The minimum deviation is 0.44, while the maximum deviation is 3.17. The standard deviation is 0.92.
When comparing the standard ICC profiles Fogra 39 and Fogra 29, the maximum deviation is 3.17 (for gray color 3). This deviation is acceptable and should not cause significant issues with color perception.
The standard deviation is 0.922, indicating relatively stable color reproduction. The colors are fairly stable and within tolerance limits.

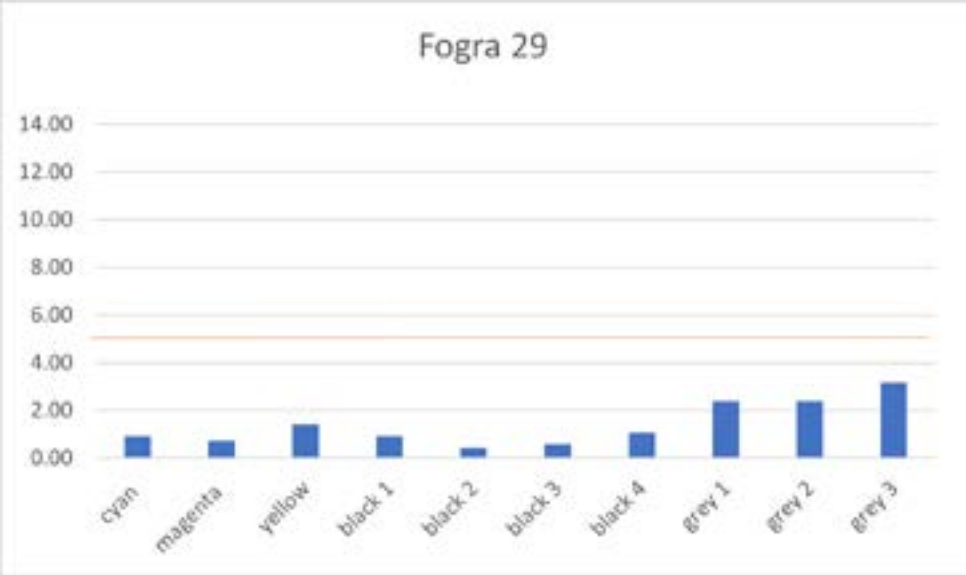

Figure 5: Graphical representation of ΔE^*_{00} deviations for the Fogra 29 profile

Table 3: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and Web Coated Eu Fogra 28

FOGRA 39 -STANDARD				WEB FOGRA				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.2	-25.91	-40.12	cyan	47.99	-25.02	-40.97	1.25
magenta	43.24	69.17	1.84	magenta	43.46	67.9	2.3	1.37
yellow	83.54	-4.37	90.02	yellow	82.75	-4.33	87.77	2.38
black 1	7.7	-1.28	1.66	black 1	6.16	-0.67	0.88	1.83
black 2	7.56	-1.07	1.48	black 2	6.21	-0.75	-0.9	2.75
black 3	6.76	-0.82	2.11	black 3	5.88	-0.5	1.49	1.12
black 4	8.57	-0.39	3.42	black 4	8.05	0.79	3.12	1.32
grey 1	61.1	-0.08	0.62	grey 1	59.95	0.3	-2.18	3.05
grey 2	46.02	-1.74	-9.5	grey 2	45.39	1.04	-9.87	2.87
grey 3	76.49	2.45	-7.22	grey 3	73.92	2.35	-4.56	3.70

The table presents measurements of the reference colors from the ICC profile Fogra 39 and the tested colors from the ICC profile Web Coated Eu Fogra 28. Analysis of the results revealed that the mean ΔE value is 2.17. The minimum deviation is 1.12, while the maximum deviation is 3.70. The standard deviation is 0.907.
When comparing the standard ICC profiles Fogra 39 and Web Coated Eu Fogra 28, the maximum deviation is 3.70 (for gray color 3). This deviation is acceptable and should not cause significant issues with color perception.
The standard deviation of 0.907 indicates relatively stable color reproduction. The colors are fairly stable and within tolerance limits.

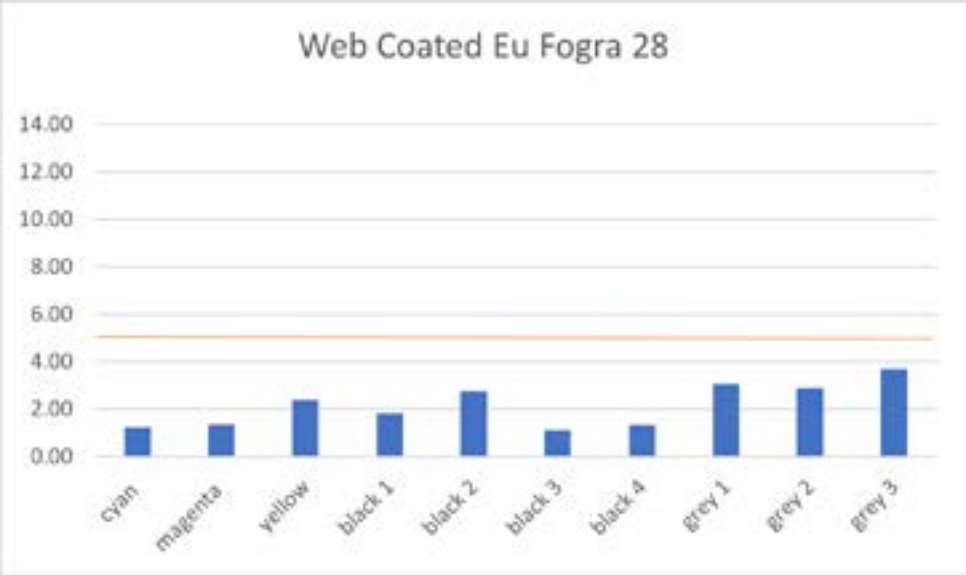

Figure 6: Graphical representation of ΔE^*_{00} deviations for the Web Coated Eu Fogra 28 profile

Table 4: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and Japan Coated

FOGRA 39 -STANDARD				JAPAN				ΔE*00
	L*	a*	b*		L1	a1	b1	
cyan	48.2	-25.91	-40.12	cyan	48.21	-25.59	-39.61	0.60
magenta	43.24	69.17	1.84	magenta	43.5	68.96	1.98	0.36
yellow	83.54	-4.37	90.02	yellow	84.02	-4.41	91.59	1.64
black 1	7.7	-1.28	1.66	black 1	6.71	-0.8	1.47	1.12
black 2	7.56	-1.07	1.48	black 2	6.91	-0.59	1.71	0.84
black 3	6.76	-0.82	2.11	black 3	6.49	-0.73	2.13	0.29
black 4	8.57	-0.39	3.42	black 4	7.5	-0.07	2.58	1.40
grey 1	61.1	-0.08	0.62	grey 1	60.7	0.21	-1.31	1.99
grey 2	46.02	-1.74	-9.5	grey 2	44.87	1.62	-10.99	3.85
grey 3	76.49	2.45	-7.22	grey 3	73.66	2.63	-4.62	3.85

The table presents measurements of the reference colors from the ICC profile Fogra 39 and the tested colors from the ICC profile Japan Coated. Analysis of the results revealed that the mean ΔE value is 1.59. The minimum deviation is 0.29, while the maximum devi-

ation is 3.85. The standard deviation is 1.307.
When comparing the standard ICC profiles Fogra 39 and Japan Coated, the maximum deviation is 3.85 (for gray 2 and gray 3 colors). This deviation is acceptable and should not cause significant issues with color perception.
The standard deviation of 1.307 indicates greater variability than desired, suggesting inconsistent color control.

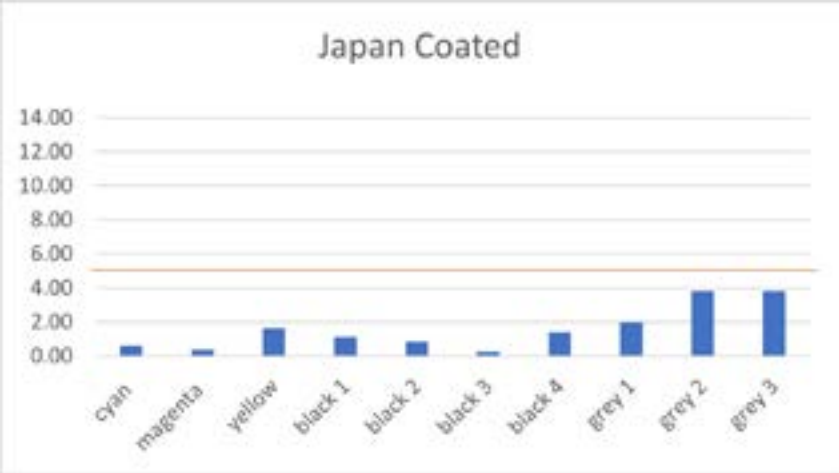

Figure 7: Graphical representation of ΔE^*_{00} deviations for the Japan Coated profile

Table 5: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and SWOP

FOGRA 39 STANDARD				SWOP				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.2	-25.91	-40.12	cyan	50.81	-24.6	-43.65	4.58
magenta	43.24	69.17	1.84	magenta	47.38	62.78	-2.55	8.79
yellow	83.54	-4.37	90.02	yellow	82.45	-2.27	83.48	6.95
black 1	7.7	-1.28	1.66	black 1	19.83	-0.24	-1.36	12.54
black 2	7.56	-1.07	1.48	black 2	15.62	0.39	-1.11	8.59
black 3	6.76	-0.82	2.11	black 3	18.05	-0.36	-0.81	11.67
black 4	8.57	-0.39	3.42	black 4	19.51	0.77	-0.61	11.72
grey 1	61.1	-0.08	0.62	grey 1	63.32	0.02	-1.67	3.19
grey 2	46.02	-1.74	-9.5	grey 2	50.9	0.57	-8.6	5.47
grey 3	76.49	2.45	-7.22	grey 3	75.21	2.71	-4.92	2.64

The table presents measurements of the reference colors from the ICC profile Fogra 39 and the tested colors from the ICC profile SWOP. Analysis of the results revealed that the mean ΔE value is 7.62. The minimum deviation is 2.64, while the maximum deviation is 12.54. The standard deviation is 3.627.
When comparing the standard ICC profiles Fogra 39 and SWOP, the maximum deviation is 12.54 (for black color 1). This deviation is noticeable and will be problematic for detailed printing.
The standard deviation of 3.627 indicates greater variability than desired, suggesting in-

consistent color control.

Figure 8: Graphical representation of ΔE^*_{00} deviations for the SWOP profile

3.2.2. Inkjet

Table 6: Presentation of CIE L*a*b* and ΔE^*_{00} measurement data for ICC profiles Fogra 39 and Euroscale Coated.

FOGRA 39 -STANDARD				EUROSCALE				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.82	-14.81	-42.31	cyan	46.64	-13.84	-41.36	2.57
magenta	49.14	56.43	19.6	magenta	47.22	57.28	19.79	2.11
yellow	79.71	12.59	96.29	yellow	80.23	11.36	89.55	6.87
black 1	8.96	0.35	0.01	black 1	26.79	0.94	-4.86	18.49
black 2	9.05	0.22	0.04	black 2	24.87	0.75	-0.21	15.83
black 3	11.31	1.1	1.04	black 3	24.33	1.06	0.58	13.03
black 4	17.82	2.05	0.53	black 4	26.17	3.25	-0.33	8.48
grey 1	73.89	1.85	-8.07	grey 1	71.69	2.75	-8.89	2.51
grey 2	62.75	0.8	-13.1	grey 2	60.61	1.85	-13.49	2.42
grey 3	80.76	3.06	-7.54	grey 3	79.76	3.56	-7.8	1.15

The table shows the measurements of the reference colors for the ICC profile Fogra 39 and the tested colors of the ICC profile Euroscale Coated in Inkjet printing. The analysis of the results revealed that the average ΔE value is 7.35. The minimum deviation is 1.15, while the maximum deviation is 18.49. The standard deviation is 6.380.
When comparing the standard ICC profile Fogra 39 and Euroscale Coated, the maximum deviation is 18.49 (black color). This deviation is noticeable and may present a problem for finer printing.
The standard deviation of 6.380 indicates inconsistency in color reproduction and a reduction in the consistency of the print itself.

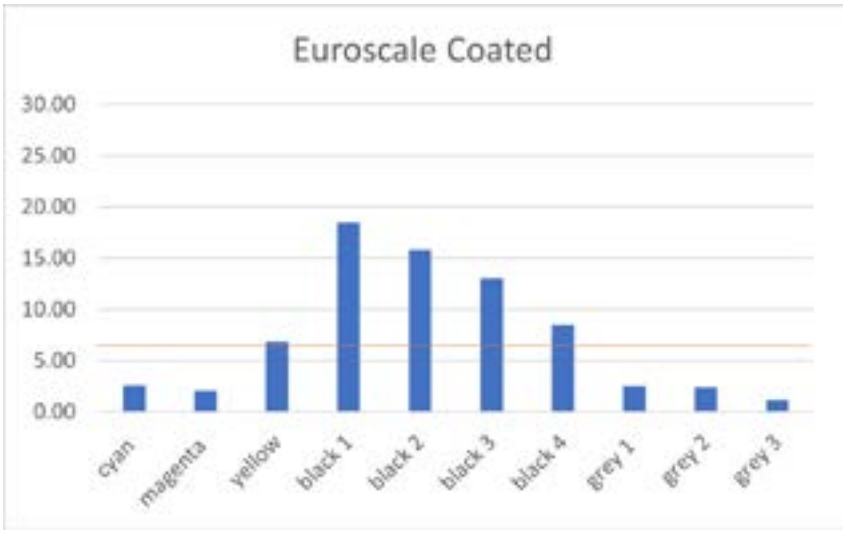

Figure 9: Graphical representation of the ΔE^*_{00} deviation for the Euroscale Coated profile.

Table 7: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and Fogra 29.

FOGRA 39 -STANDARD				FOGRA 29				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.82	-14.81	-42.31	cyan	46.03	-15	-41.16	3.02
magenta	49.14	56.43	19.6	magenta	53.82	44.72	9.63	16.08
yellow	79.71	12.59	96.29	yellow	80.7	10.07	77.5	18.98
black 1	8.96	0.35	0.01	black 1	20.58	0.99	-3.5	12.16
black 2	9.05	0.22	0.04	black 2	11.78	0.21	-0.37	2.76
black 3	11.31	1.1	1.04	black 3	12.01	0.26	-1.02	2.33
black 4	17.82	2.05	0.53	black 4	19.06	0.95	-2.29	3.27
grey 1	73.89	1.85	-8.07	grey 1	72.23	2.45	-9.34	2.17
grey 2	62.75	0.8	-13.1	grey 2	61.88	1.21	-13.37	1.00
grey 3	80.76	3.06	-7.54	grey 3	79.93	3.4	-7.21	0.96

The table shows the measurements of the reference colors of the ICC profile Fogra 39 and the tested colors of the ICC profile Fogra 29 for Inkjet printing. The analysis of the results indicates that the mean value of ΔE is 6.27. The minimum deviation is 0.96, while the maximum deviation is 18.98. The standard deviation is 6.770.
When comparing the standard ICC profiles Fogra 39 and Fogra 29, the maximum deviation is 18.98 (yellow). This deviation is noticeable and will be problematic for detailed printing. The standard deviation of 6.770 indicates inconsistency in color reproduction

and a reduction in the consistency of the print itself.

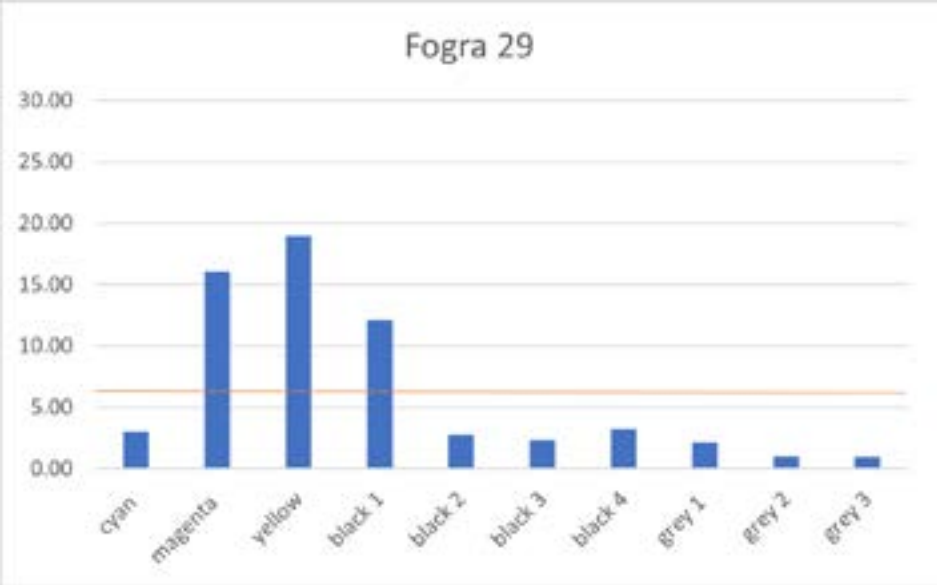

Figure 10: Graphical representation of ΔE^*_{00} deviation for the Fogra 29 profile

Table 8: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and Web Coated Eu Fogra 28.

FOGRA 39 -STANDARD				WEB FOGRA				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.82	-14.81	-42.31	cyan	48.13	-14.87	-41.16	1.34
magenta	49.14	56.43	19.6	magenta	47.47	57.95	20.38	2.39
yellow	79.71	12.59	96.29	yellow	80.79	9.94	80.29	16.25
black 1	8.96	0.35	0.01	black 1	17.19	1.02	-2.21	8.55
black 2	9.05	0.22	0.04	black 2	7.52	0.55	0.1	1.57
black 3	11.31	1.1	1.04	black 3	10.66	0.85	-0.1	1.34
black 4	17.82	2.05	0.53	black 4	15.78	2.19	-0.65	2.36
grey 1	73.89	1.85	-8.07	grey 1	73.21	2.19	-9.4	1.53
grey 2	62.75	0.8	-13.1	grey 2	61.91	0.79	-13.73	1.05
grey 3	80.76	3.06	-7.54	grey 3	80.4	2.86	-7.25	0.50

The table presents the measurements of reference colors for the ICC profile Fogra 39 and the tested colors for the ICC profile Web Coated Eu Fogra 28 in Inkjet printing. The analysis of the results revealed that the average ΔE value is 3.69. The minimum deviation is 0.50, while the maximum deviation is 16.25. The standard deviation is 4.969.
When comparing the standard ICC profiles Fogra 39 and Web Coated Eu Fogra 28, the maximum deviation is 16.25 (yellow). This deviation is visible and will be problematic for more detailed printing. The standard deviation of 4.969 indicates inconsistency in color reproduction and a decrease in the consistency of the print itself.

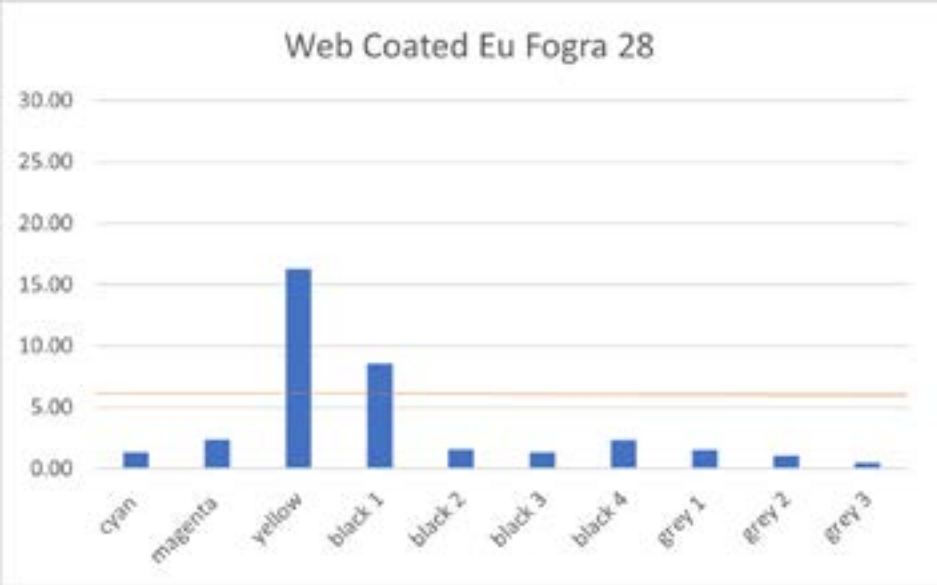

Figure 11: Graphical representation of ΔE^*_{00} deviations for the Web Coated Eu Fogra 28 profile

Table 9: Display of CIE L*a*b* and ΔE^*_{00} measurement data for the ICC profiles Fogra 39 and Japan Coated.

FOGRA 39 -STANDARD				JAPAN				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.82	-14.81	-42.31	cyan	48.4	-14.97	-41.82	0.66
magenta	49.14	56.43	19.6	magenta	48.49	56.12	18.89	1.01
yellow	79.71	12.59	96.29	yellow	79.34	13.85	96.28	1.31
black 1	8.96	0.35	0.01	black 1	18.24	0.88	-2.16	9.55
black 2	9.05	0.22	0.04	black 2	11.57	0.6	1.09	2.76
black 3	11.31	1.1	1.04	black 3	12.04	1.06	1.39	0.81
black 4	17.82	2.05	0.53	black 4	16.51	2.06	0.71	1.32
grey 1	73.89	1.85	-8.07	grey 1	73.26	2.26	-9.04	1.23
grey 2	62.75	0.8	-13.1	grey 2	62.44	1.02	13.48	26.58
grey 3	80.76	3.06	-7.54	grey 3	80.51	3.02	-7.45	0.27

The table presents the measurements of reference colors from the Fogra 39 ICC profile and the examined colors from the Japan Coated ICC profile for Inkjet printing. Analysis of the results revealed that the average ΔE value is 4.55. The minimum deviation is 0.27, while the maximum deviation is 26.58. The standard deviation is 8.202.
When comparing the standard ICC profile Fogra 39 with Japan Coated, the maximum deviation is 26.58 (grey 2 color). This deviation is too large and visually noticeable, which will also present problems for high-quality printing.
The standard deviation of 8.202 indicates inconsistency in color reproduction and a decrease in the consistency of the print itself.

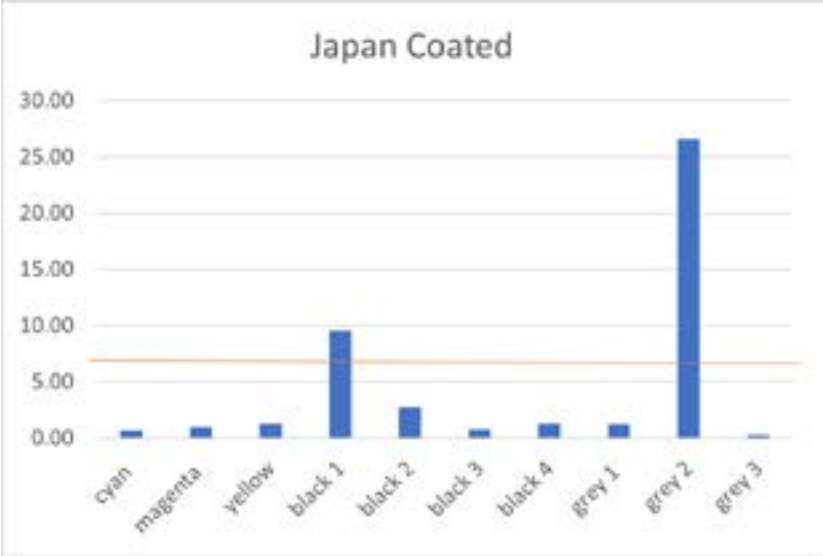

Figure 12: Graphical representation of ΔE^*_{00} deviations

Table 10: Presentation of CIE L*a*b* and ΔE^*_{00} measurement data for ICC profiles Fogra 39 and SWOP.

FOGRA 39 -STANDARD				SWOP				ΔE^*_{00}
	L*	a*	b*		L1	a1	b1	
cyan	48.82	-14.81	-42.31	cyan	47.75	-15.67	-41.71	1.50
magenta	49.14	56.43	19.6	magenta	48.87	55.34	18.15	1.83
yellow	79.71	12.59	96.29	yellow	82.25	6.98	73.41	23.69
black 1	8.96	0.35	0.01	black 1	17.7	1.04	-2.33	9.07
black 2	9.05	0.22	0.04	black 2	11.13	0.8	0.43	2.19
black 3	11.31	1.1	1.04	black 3	13.55	1.06	0.83	2.25
black 4	17.82	2.05	0.53	black 4	15.86	2.24	0.53	1.97
grey 1	73.89	1.85	-8.07	grey 1	72.91	2.17	-9.21	1.54
grey 2	62.75	0.8	-13.1	grey 2	62.02	0.9	-13.54	0.86
grey 3	80.76	3.06	-7.54	grey 3	80.16	3.09	-7.84	0.67

The table presents the measurements of reference colors for the ICC profile Fogra 39 and the tested colors for the ICC profile SWOP in Inkjet printing. Analysis of the results shows that the average ΔE value is 4.56. The minimum deviation is 0.67, while the maximum deviation is 23.69. The standard deviation is 7.140.
When comparing the standard ICC profile Fogra 39 and the SWOP profile, the maximum deviation is 23.69 (yellow). This deviation is too large and is visible to the eye, which will also pose a problem for high-quality printing.
The standard deviation of 7.140 indicates inconsistency in color reproduction and a reduction in the consistency of the print itself.

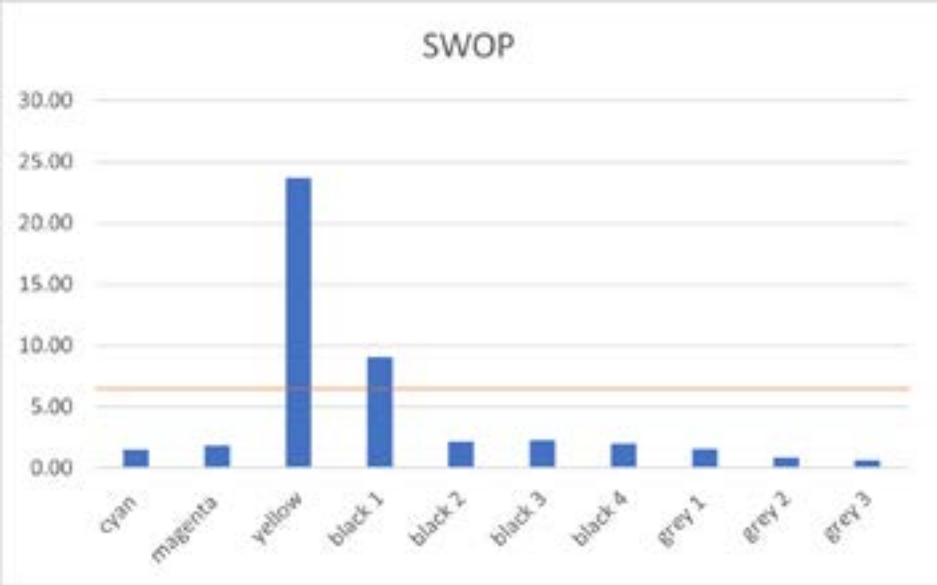

Figure 13: Graphical representation of ΔE^*_{00} deviations for the SWOP profile

3.3. Comparison of printing technologies

Table 11: Comparison of measurement values between electrophotography and inkjet printing technologies.

	Electrophotography	Inkjet
Mean Value	3.15	5.28
Min ΔE	0.28	0.26
Max ΔE	12.54	26.58
Standard Deviation	3.12	6.63

The electrophotographic printer ensures more accurate color reproduction compared to the inkjet printer. The inkjet printer shows higher deviations, indicating it is not always reliable for printing tasks that require high colorimetric precision. In both cases, there are certain colors that exhibit very small deviations, while some colors show significant deviations from the standard.

4. CONCLUSIONS

The results of this study indicate significant differences in color reproduction between electrophotographic and inkjet printing when using different ICC profiles, with the reference ICC profile Fogra 39 as the standard. The electrophotographic printer demonstrated greater stability and precision in color reproduction, with smaller deviations in colorimetric values. This consistency makes it more suitable for applications where achieving a high level of color accuracy in relation to the reference sample is crucial.
On the other hand, the inkjet printer exhibited larger deviations in color reproduction, making it less reliable for applications where color precision is critical. These deviations may be attributed to the color application technology, the characteristics of the inks used,

or limitations in achieving precise colorimetric matching with the reference profile. Despite this, inkjet technology may still be suitable for applications where high color precision is not a priority, and greater attention is given to other factors such as print texture, material adaptability, or cost-efficiency of production.

This research also confirms that the choice of ICC profile is crucial for quality color reproduction. Different printing technologies can lead to significant deviations from standardized colorimetric values, highlighting the need for proper calibration and profile optimization in line with the device's technical capabilities. Precise color management has become an indispensable step in achieving consistent and predictable results, especially in industries where brand visual identity is of paramount importance.

For industrial applications with high color requirements, the use of ICC profiles optimized for specific printing techniques is recommended. Standardizing and customizing profiles according to the printing device, paper type, and printing conditions can significantly reduce colorimetric deviations and ensure a high level of color accuracy. Further research in this field may contribute to the development of advanced color management strategies, enabling even better alignment of digital printing with reference standards.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

PROFESSIONAL PAPER

COMPARATIVE ANALYSIS OF PRINTING TECHNIQUES DURING THE DEVELOPMENTAL PERIOD OF INDUSTRIALIZATION IN EGYPT AND CROATIA

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ABSTRACT

The main goal of this document is to provide a direct, parallel comparison of the development of printing in Croatia and Egypt, from the introduction of the printing press to the late 20th century. While each country followed a unique path, both share a rich printing heritage shaped by cultural and historical influences.
Over the last 150 years especially, printing houses in both nations have played key roles in shaping public discourse, education, and culture. This study combines historical research with hands-on analysis, including laboratory testing conducted by the author using a Dino-Lite digital microscope on selected printed materials from Croatia and Egypt. The findings reveal details about printing techniques and ink properties used across time.
Beyond the technical side, the study explores how political, economic, and social factors—such as foreign influence, government policies, and technological shifts—impacted the growth of the printing industry. Together, these insights offer a comprehensive overview of the historical development of printing in both countries within a broader global context.

Keywords: Lithography, Printing Press, Printing Technique, History, Printing Machine, Century.

1. INTRODUCTION:

The journey of printing, from its early beginnings to its profound global impact, is a rich tale of technological innovation, cultural exchange, and political influence. This thesis delves into the multifaceted origins and history of printing, with a particular focus on the late 19th and early 20th centuries, an era marked by significant advancements in printing technology and a dramatic expansion of its use across the globe. The study examines the crucial developments in offset printing, largely attributed to German innovations, the contributions of the French to lithography, and the widespread influence of printing in various regions, including Croatia, the United Kingdom, the Arab world, the Ottoman Empire, and Asia. By highlighting these areas, this thesis offers a comprehensive view of the global printing landscape during a time of transformative change.
Central to this exploration are the origins and evolution of printing in Croatia and Egypt, two nations with rich and intertwined printing histories. In Croatia, the roots of printing can be traced back to the Glagolitic language and early printing work in Senj, which was closely linked to Venetian influences and the contributions of Blaž Baromić. The development of Croatian printing from the late 18th century through the post-World War II era, and into the late 20th and early 21st centuries, reveals significant technological advancements and the crucial role played by key Croatian figures in shaping the nation's printing industry [1].
Similarly, the history of printing in Egypt begins with the French expedition, which led to the establishment of some of the country's most important printing houses. The development of printing presses under Muhammad Ali's rule and the introduction of Ara-

bic type played a major role in the evolution of the printing industry. This narrative also tracks the expansion of printing technology throughout the 20th century, from the early printed materials to the advent of advanced printing machines. The study extends into the post-monarchy era, examining the political connections between Egypt and Croatia during the mid-20th century, particularly in terms of their shared printing interests. It also explores the state of printing in Egypt during the 1970s, 1980s, and 1990s.
Additionally, this thesis makes use of modern tools such as Dino-Lite to analyze Croatian and Egyptian documents, offering a contemporary approach to the historical study of printing. By uncovering the common ground between Croatia and Egypt, especially through the lens of the French expedition and the subsequent evolution of printing in both nations, the thesis aims to shed light on the shared heritage and mutual influences that have shaped the printing industries in these countries. Through this comparative analysis, the research contributes to a broader understanding of how printing technologies were disseminated and adapted in different cultural and political contexts, ultimately reshaping the way information was shared across continents.

2. THE EVOLUTION OF PRINTING: GLOBAL INFLUENCES AND TECHNOLOGICAL ADVANCEMENTS

2.1. Worldwide Printing in the Late 19th and Early 20th Centuries

The origins of printing date back over a thousand years, emerging around 700 CE in China during the Tang dynasty (618–907 CE). Once widely adopted in China, printing technology spread across East Asia, Southeast Asia, and eventually worldwide, revolutionizing the dissemination of information.
Printing originated around 700 CE in China during the Tang dynasty and gradually spread across East and Southeast Asia before revolutionizing global communication. Offset printing began taking shape in the late 19th century, with a major turning point in 1904 when Ira Washington Rubel accidentally discovered the offset process. His innovation greatly improved image quality and lowered costs for mass production. It remained dominant thanks to enhancements like photoengraving, computer-to-plate (CTP) systems, and direct imaging technologies. Cašpar Hermann also contributed significantly to its development. Even with the rise of digital printing, offset remains favored for high-volume, high-quality outputs such as newspapers and books. Germany played a crucial role in printing history through lithography, invented by Alois Senefelder in 1796. He developed the technique by using greasy crayons on limestone to reproduce texts, a discovery that laid the foundation for modern offset printing [2]. Lithography thrived due to its ability to produce precise images using oil and water chemistry, and it became the basis for 20th-century mass media. Germany's printing innovation supported the rapid expansion of illustrated magazines and advertising campaigns, such as Coca-Cola's substantial investment in print media by 1901. France contributed to printing's evolution through artistic innovation. Jules Chéret, known as the father of the modern poster, pioneered four-color lithography and helped elevate poster design into a respected art form. Chéret's techniques significantly influenced visual advertising and remained influential in poster design history. Meanwhile, Japanese press manufacturers were gaining traction, indicating growing global competition in the printing technology market [3].
The first edition of Narodne novine debuted in Zagreb as Novine Horvatzke on January 6, 1835, with Ljudevit Gaj as publisher and editor. Its second issue (January 10) introduced a literary supplement, Danicza Horvatzka, Slavonzka y Dalmatinzka. The printing house later gave rise to Narodne novine Press (1874) and the Croatian Graphic Institute. At the same time, the United Kingdom experienced rapid growth in newspaper production, no-

tably with The Times printing its first steam-press edition in 1814. By the 1830s and 40s, publications such as the Illustrated London News used wood engraving to incorporate visuals, while the 1880s brought halftone photography and evolving design standards that reshaped British journalism. In the United States, lithography became essential to advertising's growth. Early agencies focused on brokering ad space, but the landscape changed when firms like McCann Erickson emerged in the early 1900s. Founded in 1902, McCann Erickson expanded globally by mid-century and helped establish advertising as a professionalized, creative industry. Arabic-script printing developed later than its European counterparts. The first Arabic press was founded in Syria in 1706 but had limited longevity. More successful was Lebanon's Shuwayr Press in 1733. Napoleon's 1798 invasion of Egypt introduced presses with Arabic and Greek fonts, setting the stage for the cultural renaissance under Muhammad Ali, during which Egypt's Bulaq Press became a regional powerhouse of publishing [4].

In the Ottoman Empire, early printing was introduced by Jewish and Armenian communities in the late 15th and 16th centuries. The first official Turkish-Muslim printing press was founded by Ibrahim Müteferrika in 1727, but high costs and low demand hindered its success. Nonetheless, by the late 19th century, printing had become widespread under Sultan Abdulhamid II, marking a print culture boom. Printing in Asia also began in China with woodblock techniques, later expanding to Vietnam and parts of Southeast Asia through missionary efforts. Missionaries were instrumental in early regional publications, such as the 1839 Old Testament in Thai and the 1829 New Testament in Javanese. British colonies like India and Malaysia saw printing take hold by the 19th century, making printed materials more accessible throughout the region [5].

Offset printing gradually replaced letterpress in the mid-20th century. Originally developed using stone and later metal plates, it became more efficient with automatic plate loading and CTP systems. Waterless offset and computerized calibration techniques enabled high-precision color management. These innovations brought consistency and quality to modern printing, allowing it to evolve into a streamlined, digitally supported industry [6].

2.2. The Origin of Printing and Printing Houses in Croatia

Printing arrived in Croatia not long after Gutenberg's invention spread across Europe. In the late 15th century, Croatian craftsmen began working in Venice, one of the continent's busiest printing hubs. Cultural and trade ties between Venice and regions like Dubrovnik made it natural for Croatians to participate in the printing revolution. Venice alone produced nearly a third of Europe's books between 1470 and 1500. Prominent early Croatian printers included Dobrić Dobričević from Lastovo, Andrija Paltašić from Kotor, and Juraj and Grgur Dalmatin, all of whom helped lay the groundwork for Croatian print culture. Early Croatian publications were printed in Latin or Glagolitic—the latter being a script specifically designed for Slavic liturgical texts [7].

The Glagolitic script played a vital role in Croatian identity. Introduced in the 9th century by Saints Cyril and Methodius, it was used in religious settings for centuries. The first Croatian printed book in Glagolitic was the Missale Romanum Glagolitice, published on February 12, 1483, likely in Venice or possibly Kosinj, Lika. This missal, printed in high-quality type and richly ornamented, was intended for worship in Dalmatia, Istria, and the Kvarner islands. Only six known copies of this edition survive today, preserved in Zagreb, Rome, Vienna, and Washington, D.C. Its design likely drew on older manuscripts like the 1368 Novak Missal, bridging handwritten and printed traditions. The foundation of Slavic printing in Croatia can be traced back to the missionary work of Saints Cyril and Methodius, whose translation of Christian texts into Slavonic laid the linguistic foundation for Glagolitic print [8]. The town of Senj became especially important in this context. In 1494, Canon Blaž Ba-

romić established one of Southeast Europe's earliest printing houses there, dedicated to Glagolitic publications. The Senj press produced at least seven significant works, including Spovid općena and a two-column, red-and-black printed Missale. Baromić had trained in Venice, bringing back the skills and equipment needed for high-quality printing. He even introduced a new typographic technique called composite ligatures, reflecting Glagolitic manuscript aesthetics [9].

Senj, built on Roman ruins, experienced a revival in the 12th century under the Templars and later the Dukes of Krk. In 1248, Pope Innocent IV granted Senj's bishop the right to use the Glagolitic script in liturgy, boosting its prominence through the 14th and 15th centuries. This tradition set the stage for one of Southeast Europe's first printing presses, established in Senj in 1494 by Canon Blaž Baromić. The press focused on Glagolitic works, producing at least seven books, both religious and secular, including Missale po zakonu rimskoga dvora and Spovid općena. The religious texts were printed in red and black ink, while the secular ones used only black. Baromić, originally from Vrbnik, began as a scribe and became a canon in Senj by 1484. His journey to Venice in 1493 was pivotal—there he learned typesetting and acquired the tools needed to establish the Senj press. Upon his return, he and his team printed the first bichrome, two-column Glagolitic missal in August 1494. Baromić also introduced the innovative composite ligature technique, which replicated the look of handwritten Glagolitic texts, marking a unique contribution to typography. The roots of Croatian journalism emerged in the late 18th century. Ephemerides Zagrabienses, printed in Latin in 1771, was the first newspaper. In 1806, Kraljski Dalmatin became the first Croatian-language newspaper, published in Zadar in both Croatian and Italian. Although it served as a French propaganda tool during Napoleon's rule, it also played a vital role in regional communication. Its production by Antonio Luigi Battara's press marked a key milestone in Croatian media history [10].

Between 1789 and 1849, Croatia produced 19 newspapers in Croatian, German, and Italian. The revolutionary spirit of 1848 spurred rapid growth in the press, though many outlets were soon shut down by the authorities. After the Austro-Hungarian Compromise of 1867, press freedom returned, and socialist and political publications flourished. By 1894, Croatia had 110 newspapers, including seven daily political papers. World War I brought strict censorship, and the subsequent formation of Yugoslavia further limited press freedom, stalling industry growth. Despite these setbacks, Croatian printing saw renewed progress in the late 20th century. During the 1990s, amid war and independence struggles, the industry remained resilient. New technologies and international collaborations modernized production. The decade became a golden age for newspapers, with Večernji list reaching a peak daily circulation of 450,000 copies. After the war, the printing sector bounced back, embracing digital solutions that enabled shorter runs and flexible publishing, while continuing to play a vital role in education, cultural preservation, and public discourse.

2.3. The Origin of Printing in Egypt

Printing in Egypt began in 1798 with Napoleon Bonaparte's expedition, which introduced the first presses alongside scholars and scientists. These presses, equipped with Arabic and Greek typefaces, served as tools of French propaganda but also planted early seeds of public discourse and nationalism. Much like in Dalmatia during Napoleon's rule, where new publications emerged, Egypt's brief French occupation catalyzed a lasting cultural impact. After the French left in 1801, the presses stopped, but their influence endured, especially through publications like Le Courrier de l'Égypte, Egypt's first newspaper, which chronicled French ambitions and local news during the occupation. Under Muhammad Ali's rule (1805–1849), the legacy of French printing was revived and expanded. In 1819, he transformed the earlier press into al-Matbaʻah al-Ahliyah, soon relocated to Bulaq and

known as the Bulaq Press or Amiriya Press. It played a key role in Egypt's modernization, translating European texts and producing Arabic works in science, literature, and education. French scholars were invited, and Egyptian students were sent abroad, mirroring the way Croatia embraced outside expertise to build its own printing tradition [11].
A notable example is Niqaim al-Masabiki, a Syrian immigrant sent by Muhammad Ali to study printing in Italy in 1815. He returned with printing equipment, and by 1820, the Bulaq Press was operational. This path resembles Croatia's adoption of printing through Italian-trained artisans. The first book printed by the press was an Italian-Arabic dictionary by Father Raphael Rahib in 1822. Though often mistaken as the press's founder, Rahib simply oversaw the printing of his own work—Masabiki was the true director, running the press and managing its production. Arabic printing posed unique challenges due to the cursive script and artistic value of calligraphy. Each Arabic letter has multiple forms depending on its position in a word. Early European presses had already experimented with Arabic typefaces, and in Egypt, further improvements came in 1826 when students were sent to Paris to study engraving. Persian calligrapher Sin klâh Afandî later developed refined Arabic typefaces, particularly Nashk and Nastaliq styles. By 1934, a standardized set of 132 shapes and 46 signs was recommended to improve efficiency [12]
The Bulaq Press continued to shape Egypt's print culture through the 19th and early 20th centuries. Though eventually closed, its machinery and type were preserved and later displayed in the Bulaq Press Museum, opened in 2005. Restoration efforts were launched in cooperation with international partners, preserving the legacy of one of the Arab world's most influential presses. By the mid-20th century, printing in Egypt intersected with political developments. In the 1960s, the relationship between Egyptian President Nasser and Yugoslav leader Tito led to deeper cultural ties through the Non-Aligned Movement. Both leaders promoted state-run press systems that advanced nationalist and socialist ideologies. In Egypt, Nasser established centralized printing houses to support his vision of Arab unity and modernization, using the press as a tool for mass education and political messaging. Yugoslavia followed a similar model, with Tito's regime using the media to foster unity and share NAM ideals. While there's no record of joint printing projects, both nations used their presses to support shared political goals and to reinforce their independence from global superpowers [13].

2.4. Chronological Connections Between Croatia and Egypt in the World of Printing

Croatia and Egypt, though geographically distant, share notable parallels in the development of their printing industries. In the late 15th century, Croatian printing was deeply influenced by Italian centers, especially Venice. Croatian pioneers like Dobrusko Dobricevic and Andrija Paltasic worked in Venetian print shops, producing texts in Latin and Glagolitic. The Glagolitic script held particular importance in preserving Church Slavonic traditions. Although the first Croatian printed book, Missale po zakonu rimskoga dvora (1483), was long believed to be printed in Venice, new findings suggest that Kosinj in Croatia may have been the actual site—highlighting Croatia's early local capability and ambition in print culture [14].
By the early 19th century, both Dalmatia and Egypt experienced the cultural and technological impact of French rule. Napoleon's forces not only brought military campaigns but also the printing press, used as a tool for propaganda and modernization. In Dalmatia, the Il Regio Dalmata newspaper appeared during French occupation, expanding the region's printed discourse. Meanwhile in Egypt, the French established some of the first presses to print in Arabic, setting the stage for Egypt's own publishing industry. Though Croatia already had a printing tradition by this time, the French helped revive and redirect it in Dalmatia, while in Egypt, they introduced printing altogether. The mid-20th century brought the most ideologically significant convergence between Croatia and Egypt. Under Tito and

Nasser, the two nations shared a vision of independence through the Non-Aligned Movement. In both contexts, printing was co-opted as a powerful state instrument. Egypt's press, under Nasser, produced materials to foster Arab unity and socialism, while Yugoslavia's press echoed Tito's brand of self-managed socialism and international neutrality [15]. Though there's no concrete evidence of joint printing initiatives, the ideological synergy between the two leaders created similar media landscapes—centralized, state-driven, and focused on political education. This period marked a shared chapter in the history of printing as a force of political influence and national identity [16].

3. EXPERIMENTAL

This section analyzes six Croatian documents collected in Hrelić, Croatia, ranging from 1939 to 2002. The goal is to determine the predominant printing method and whether the documents use chromatic (colored) or a-chromatic (black and white) inks. The analysis is also applied to Egyptian documents, allowing for statistical comparisons between Croatian and Egyptian printing methods from the early to late 20th century.

3.1. Used materials and equipment

Dino-Lite, a leading brand in digital microscopes, was used for this analysis. These pen-shaped devices offer magnification from 10x to over 200x, allowing detailed inspection of print and paper fibers. They feature high-resolution CMOS or CCD sensors, with some models reaching up to 5 megapixels. Adjustable LED lighting ensures clarity, and USB/Wi-Fi connectivity allows for easy image capture. The software, compatible with Windows and Mac, supports image capture, measurement, and annotation.
Inks: Of the six Croatian documents, three use chromatic (colored) inks, and three use a-chromatic (black and white) inks, meaning 50% of the documents feature color while the other 50% are black and white.

Printing Technique: All document covers and most inner pages (except for two) are printed using offset printing.

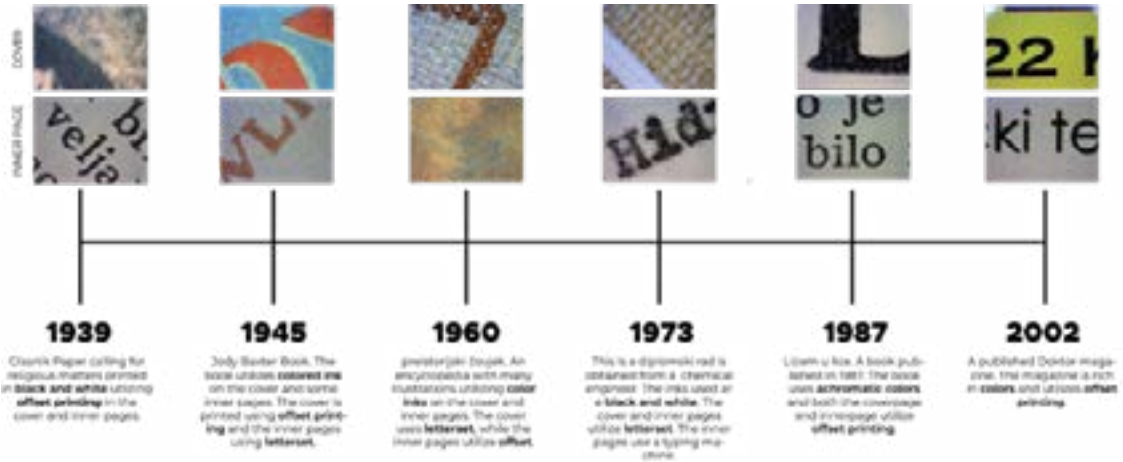


Figure 1: A timeline presenting the details of the six scanned Croatian documents is provided.

4. RESULTS

As noted earlier, the writer conducted an experimental analysis of six documents collected from Egypt, ranging from 1929 to 1994, obtained from Souq-Al Asbakiya. The goal of this

analysis was to identify the types of printing techniques used and determine whether the documents were printed in chromatic or achromatic colors using Dino-Lite.

4.1. Inks Analysis

The analysis revealed that 83.3% of the six documents examined were printed in chromatic inks (full color), while only 16.6% of the documents used strictly black and white inks.

4.2. Used printing techniques

All the covers (except two) and inner pages (except one) of the Egyptian documents analyzed were printed using offset printing. Offset printing is a commonly used method for high-volume, high-quality printing.
The scanned documents are organized on a timeline, highlighting key details and providing insights into the evolution of the printing techniques and ink usage across the years. This timeline serves as a visual representation of the changing trends in printing in Egypt between 1929 and 1994.

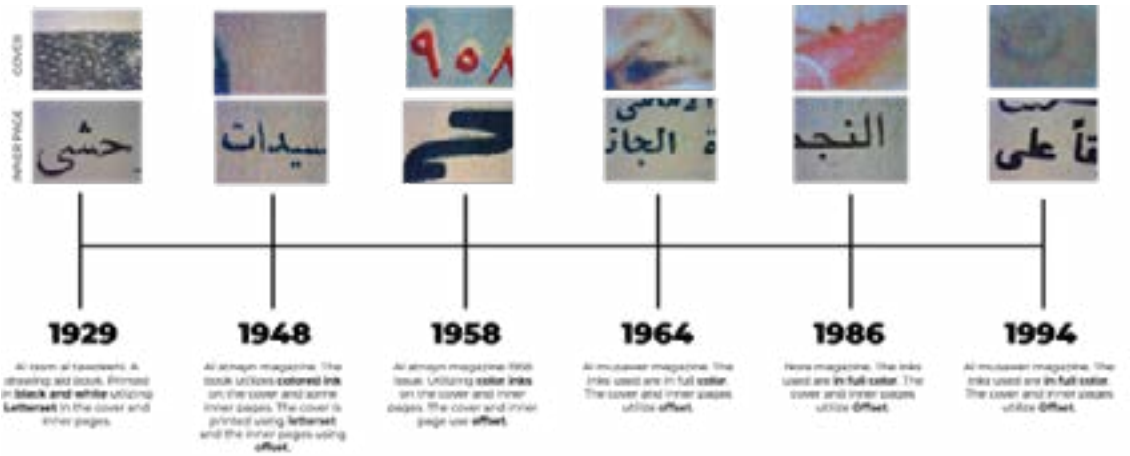


Figure 2: Visual representation of the changing trends in printing in Egypt between 1929 and 1994.

GLASNIK SV.FRANJE 1939.

JODY BAXTER 1945.

PREISTORIJSKI 1960.

DIPLOMSKI RAD. ZORAN RAŠIDKADIĆ 1973.

LICEM U LICE 1987.

DOKTOR 2002.

Figure 3: Documents pertain to Croatia, varying from 1939 to 2022.

AL-RASM AL TAWDEEHI 1929.

AL ATNAYN MAGAZINE 1948.

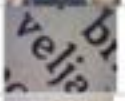
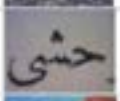
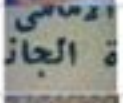
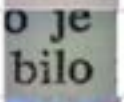
AL MUSAWER 1958

AL MUSAWER 1964.

NORA 1986.

AL MUSAWER 1994.

Figure 4: Documents pertain to Egypt, varying from 1939 to 2022.

Title of Document	Date	country	Photo	Type of printing	Document numbering
Glasnik/ Cover	1939	Croatia		Offset	Document 1-Croatia
Glasnik/ Page 1	1939	Croatia		Offset	
Al rasm el tawdeehi /cover	1929	Egypt		Letterset	Document 1-Egypt
Al rasm el tawdeehi / page 3	1929	Egypt		Letterset	
Jody Baxter / Cover page title	1945	Croatia		Offset	Document 2-Croatia
Jody Baxter/ inner page	1945	Croatia		Letterset	
Al-atnyan magazine cover	1948	Egypt		Letterset	Document 2-Egypt
Al-atnyan magazine / page 4	1948	Egypt		Offset	
Al-atnayn magazine cover	1958	Egypt		Offset	Document 3-Egypt
Al-atnayn magazine page 3	1958	Egypt		Offset	
preistorijski čovjek / cover	1960	Croatia		Letterset	Document 3-Croatia
preistorijski čovjek / Page 50	1960	Croatia		Offset	
Al-musawer magazine cover	1964	Egypt		Offset	Document 4-Egypt
Al-musawer magazine page 5	1964	Egypt		Offset	
Diplomski rad/ cover	1973	Croatia		Letterset	Document 4-Croatia
Diplomski rad/ page 4	1973	Croatia		Letterset	
licem u lice cover title	1987	Croatia		Offset	Document 5-Croatia
licem u lice page 5	1987	Croatia		offset	
Nour magazine /cover	1986	Egypt		Offset	Document 5-Egypt

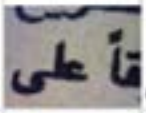
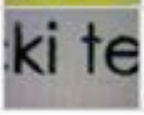
Nour Magazine /page 3	1986	Egypt		Offset	
Al-musawer / cover	1994	Egypt		Offset	Document 6-Egypt
Al musawer /page 9	1994	Egypt		Offset	
Doktor Magazine /cover	2002	Croatia		Offset	Document 6-Croatia
Doktor Magazine /page 6	2002	Croatia		Offset	

Figure 5: Used printing techniques

5. CONCLUSION

This research highlights the deep and multifaceted historical connections between Egypt and Croatia in the world of printing, drawing attention to the shared influences, cultural intersections, and technological developments that shaped both nations across centuries. Beginning with the early adoption of printing in Croatia in the late 15th century—heavily influenced by Italian craftsmanship and typographic traditions—we see how the Glagolitic script became a symbol of Croatian religious and cultural identity. Meanwhile, Egypt's entrance into the printing era, though later, was catalyzed by the French expedition of 1798, which introduced printing technology and democratic ideals, leaving a lasting imprint on Egypt's intellectual and political landscape. The 19th century marked a turning point for both regions. While Croatia was refining its print tradition, Egypt, under the rule of Muhammad Ali, transformed the printing press into a cornerstone of educational and administrative reform. Both nations benefited from European knowledge—Croatia through its Venetian ties, and Egypt through French and Italian experts—showing how transnational exchange fueled local advancements in print culture. Perhaps most compelling is the ideological convergence of the mid-20th century, when Egypt under Nasser and Yugoslavia under Tito forged strong political and cultural bonds as co-founders of the Non-Aligned Movement. In both countries, the printing press evolved into a state-controlled medium, instrumental in shaping public discourse, spreading socialist ideology, and reinforcing national identity. The press became more than a technological tool—it was a strategic instrument of governance, education, and unity. These chronological and thematic connections reveal that printing in both Egypt and Croatia was never an isolated phenomenon but part of a larger global narrative of knowledge exchange, political change, and cultural preservation. Printing served not only as a means of communication but also as a vessel of identity, a mirror of power structures, and a bridge between nations. Understanding these shared histories enriches our appreciation for how deeply intertwined technological progress and cultural evolution can be, particularly in regions with such distinct yet overlapping historical paths.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

CURRENT LEVELS OF ACCESSIBILITY ON THE WEB: ACHIEVEMENTS AND ONGOING CHALLENGES

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ABSTRACT

The web is the digital canvas that enables content creators to publish content using the simplest way to reach a global audience. Often, web page authors forget that not all audiences they address have the same capabilities. This is where web accessibility, as an important communication tool, comes into the picture. Web accessibility ensures that everyone can use and interact with websites and applications, including individuals with disabilities, such as those with visual, hearing, motor, or cognitive impairments. Accessibility means different things to different people, but it is not just a single thing. We can broadly divide it into three pillars: emotional, functional, and technical. Each pillar must be accessible in itself, but all must be considered together. People with disabilities navigate the web in various ways, encountering various barriers. This paper examines web accessibility from multiple perspectives. It evaluates the European Union's Web Accessibility Directive (Directive (EU) 2016/2102) and its implementation, exploring the current accessibility status.

Keywords: web, accessibility, diversity, communication, disability

1. INTRODUCTION

The UN Convention on the Rights of Persons with Disabilities defines persons with disabilities as 'those who have long-term physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others'[1]. Around 87 million people in the EU have some form of disability. Many persons with disabilities in Europe do not have the same chances in life as other people. Schools or workplaces, infrastructures, products, services, and information are not all accessible to them [2].

Accessibility is defined as meaning that people with disabilities have access, on an equal basis with others, to the physical environment, transportation, information and communications technologies and systems (ICT), and other facilities and services. There are still major barriers in all of these areas. For example, on average in the EU-27, only 5% of public websites comply fully with web accessibility standards, though more are partially accessible. Many television broadcasters still provide few subtitled and audio-described programmes [3].

In today's increasingly competitive and digital world, the internet serves as a vital gateway to information, services, education, and social interaction. For the web to indeed be inclusive, it must be accessible to everyone, including individuals with disabilities. Over the past decades, significant strides have been made in promoting web accessibility—driven by advancements in technology, evolving design practices, and the enforcement of legal frameworks. This paper examines the current state of web accessibility, exploring

both the progress made and its current status.
The potential of technology and artificial intelligence (AI) to connect people and provide access to education has never been more remarkable or more rapidly changing. Communication technologies and new media promise to revolutionize our lives by breaking down barriers and expanding access for people with disabilities. Yet, it is also true that technology can create unexpected and under-critiqued forms of social exclusion for disabled people.
Key Aspects of Web Accessibility are [4]:

- Perceivable – Content must be presented in a way that users can perceive it (e.g., text alternatives for images, captions for videos, readable text).
- Operable – Users must be able to interact with the website using different input methods (e.g., keyboard navigation for those who cannot use a mouse).
- Understandable – Information and navigation should be clear and intuitive, with features such as readable fonts, logical structure, and clear error messages.
- Robust – Content must be compatible with assistive technologies, such as screen readers, voice commands, and alternative input devices.

The European Union's Web Accessibility Directive (Directive (EU) 2016/2102) came into effect on 22 December 2016. The Republic of Croatia has implemented and regulated the European Union's Web Accessibility Directive (Directive (EU) 2016/2102) through two Acts: The Act on the Accessibility of Websites and Software Solutions for Mobile Devices of Public Sector Bodies [5] and the List of Bodies of Public Authority [6]. According to it, the law entered into force in the Republic of Croatia on 23 September 2019. Public sector bodies were required to bring software solutions for mobile devices into line with the provisions of this Act by 23 September 2021.

2. EXPERIMENT

The research was conducted online on 126 entities of higher education institutions in the Republic of Croatia. The source of the list of 126 higher education institutions in the Republic of Croatia is available on the official website of the SRCE University of Zagreb University Computing Centre [7]. The research was conducted in period 10. -14. March 2025. In the research, all 126 websites of higher education institutions were evaluated through metrics:

- Does the website have an accessibility function
- What is the level of accessibility
- University – institution is part of one of the universities
- Accessibility symbol – what kind of symbol is used

This was the first research on this subject in the Republic of Croatia.

3. RESULTS AND DISCUSSION

On a sample of 126 websites from higher education institutions, 66.67% have an accessibility function on their website, while 33.33% do not (Table 1). Such results provide insight into the status of accessibility function penetration in this segment and what has been done since the European Union's Web Accessibility Directive (Directive (EU) 2016/2102).

Table 1: Results of the availability of the accessibility function

METRIC	POSSIBLE ANSWERS	RESULTS %
Does the website have an accessibility function?	YES	66,67
	NO	33,33

From the observed 84 websites, i.e., 66.67% that have an accessibility function, two major segments were identified based on the level of accessibility (Table 2):

- Minimum level - has 1 or 2 accessibility functions
- Standard level - has 3+ accessibility functions

Table 2: Results of the status of the level of accessibility

METRIC	FINDINGS	RESULTS %
What is the level of accessibility?	MINIMUM	10,7
	STANDARD	89,3

These 84 websites (66.67%) with accessibility functions are distributed across major universities in the Republic of Croatia (Table 3).
The "OTHER" category includes higher education institutions, with 18 of them (21.5%) located throughout the country in Dubrovnik, Pula, Slavonski Brod, Zadar, Vukovar, Knin, Ivanić-Grad, Gospić, Rijeka, Zaprešić, Zagreb, Bjelovar, Karlovac, Virovitica, and Velika Gorica.

Table 3: Results of the accessibility function per University

METRIC	POSSIBLE ANSWERS	RESULTS %
Is the institution part of one of the universities?	UNIVERSITY OF ZAGREB	25
	UNIVESITY OF RIJEKA	19
	UNIVERSITY OF SPLIT	13
	UNIVERSITY OF OSIJEK	21,5
	other	21,5

In the research, various symbols were identified as being used for accessibility features on the web pages of these 84 websites (66.67%) with accessibility features (Table 4).
The "Accessibility Icon", a symbol of a web accessibility function, is typically represented by a stick figure (human) with outstretched arms and legs, usually inside a circle.
The wheelchair symbol, also known as the International Symbol of Access (ISA), represents physical accessibility for individuals with disabilities. It indicates facilities, services, or features accessible to people who use wheelchairs or have mobility impairments.
The symbol AA, with one smaller and one larger letter A, is commonly used to represent text size or font size accessibility options.
The symbol of a stylized eye with a slash through it, which universally indicates that something is hidden or not visible. Sometimes, it is used in accessibility tools to control visibility settings, such as hiding interface elements for simplicity or to maintain focus.
The symbol, a stylized, abstract figure, potentially represents a person or a dynamic shape with a circular element above it; however, its relation to accessibility is unclear.
The symbol with two elements, half black, half white circle (this usually toggles between dark mode and light mode) and small and large "T" (this typically adjusts the text size either increasing or decreasing font size for accessibility) These controls are commonly found in web applications, reading platforms, or accessibility toolbars.

Table 4: Results of the symbol usage

METRIC	FINDINGS	RESULTS %
What kind of symbol is used?		65,5
		20,1
		7,2
		3,6
		3,6

Various websites offer different accessibility menus (Figures 1 and 2). On some pages, the accessibility menu is in Croatian despite the chosen language, for example, English (Figure 2). It shows that some institutions merely fulfilled the obligation without fine-tuning as it should have been done.

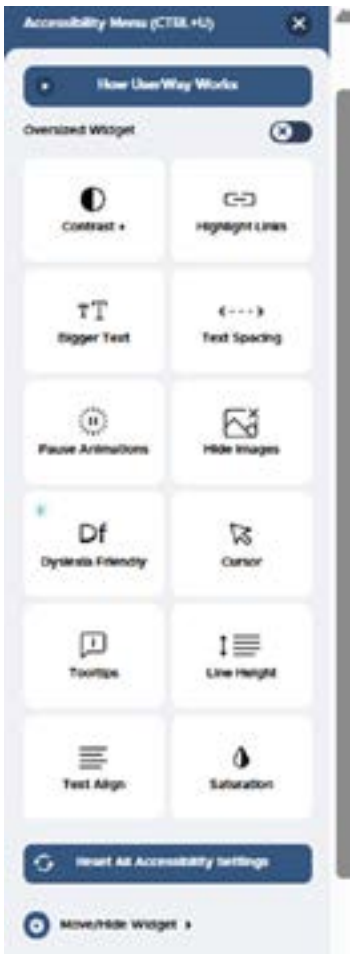

Figure 1: Accessibility menu 1

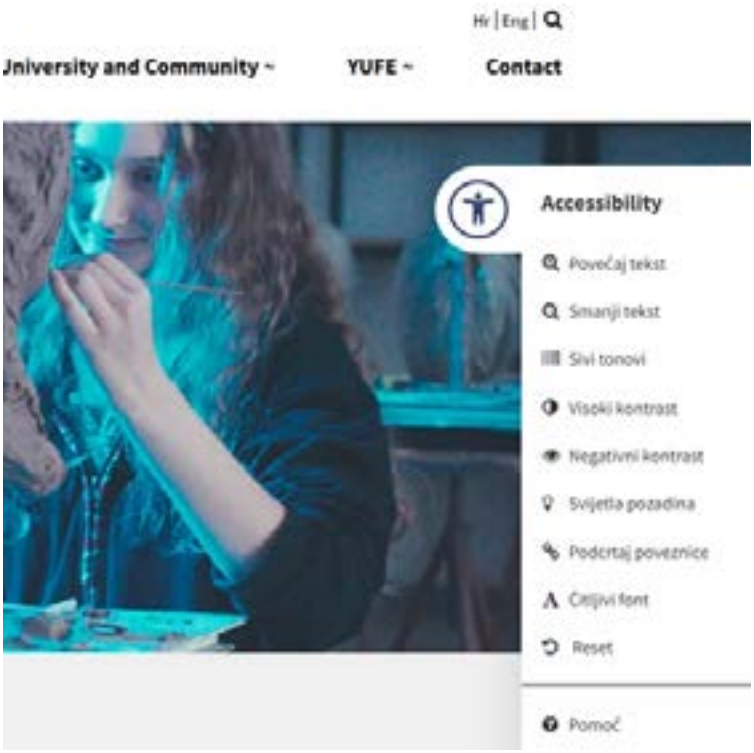

Figure 2: Accessibility menu 2

4. CONCLUSION

As this was the first research on this subject in the Republic of Croatia, the findings will serve as a foundation for further studies in the field of web accessibility. No research has been conducted on this topic even at the international level.

Although the law on web accessibility in the Republic of Croatia came into force on 23 September 2019, over the past six years, web accessibility has been implemented on 84 websites (66.67%) of higher education institutions. As there is no data on web accessibility penetration in higher education institutions in other countries of the European Unit, it is impossible to make any comparison. The reason for such a rate of implementation can be the subject of another research. Even though Croatian law also has misdemeanour provisions, in terms of financial amount, not a single penalty has been imposed for punishment so far.

It is expected that new technologies, such as artificial intelligence (AI), will contribute to the development of web accessibility tools and their application in everyday life, making life and access to information more manageable for people with disabilities.

Artificial intelligence (AI) has been integrated into various aspects of everyday life for a considerable period, often operating imperceptibly within systems regardless of the user's awareness and knowledge of it. It has changed human communication and behaviour, creating incredible opportunities in human lives. Web accessibility has a long way to go, and it will significantly influence design standards, legal frameworks, and technological innovations that will improve digital access for millions of users with disabilities.

This paper marks the first step in promoting web accessibility within the Republic of Croatia, examining its achievements and regulatory framework.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

PROFESSIONAL PAPER

CREATING POSTERS IN RISOPRINT STYLE

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ABSTRACT

Digital Risoprint is a contemporary approach to reinterpreting the classic printing process of risograph printing through the use of digital tools such as Adobe Photoshop. The aim of this method is to digitally simulate the specific characteristics of risograph printing, such as grainy textures, colour layers and overlaps, with minimal technical cost. In this article, the digital Risoprint process is presented through a practical task: creating a poster on the subject of "Life and Death". The posters were created by students of Information Design studies at the Zagreb University of Applied Sciences as part of the "Digital Image" course. The focus is on the analysis of the image editing process, the use of colours and the application of layers and textures in order to faithfully recreate the aesthetic identity of the risograph print. The theoretical part gives an overview of the history and development of the technique, while the practical part demonstrates how the visual impact of traditional printing can be achieved using purely digital methods. The paper opens up space for further research into the digital reinterpretation of classical printing processes and their role in contemporary design and educational contexts. It also highlights the importance of digital literacy and creative freedom when working with visual content to encourage innovation and experimentation in design practise. Particular emphasis is placed on the potential of this approach for future multidisciplinary projects that combine technology, art and communication.

Keywords: Risoprint, risograph, digital simulation, image processing, design

1. INTRODUCTION

Risoprint is an analog printing technique that has gained popularity due to its special aesthetic properties — grainy textures, staggered layers of colour and unique pigmentation. This printing process, also known as risograph printing, is characterized by its raw, organic appearance, which is characteristic for non-industrial, experimental design. Originally, the process was not only used in art, but was developed at the end of the 20th century for fast and inexpensive printing in the educational and administrative sectors. Over time, especially with the growing interest in independent publishing, Risoprint found its place in contemporary art, graphic design, illustration and visual communication. Due to the limited availability of risograph machines, inks and the specialty papers required for printing, carrying out physical Risoprint projects in educational institutions or smaller studios is often not feasible. These limitations have led many designers and visual artists to reinterpret and simulate the effect using digital tools and software — particularly Adobe Photoshop.

Numerous artists and tutorials explore how to digitally replicate the Risograph printing style using Photoshop. For instance, illustrator Asahi Nagata has created a detailed step-by-step guide available through Adobe's platform and Help Centre, demonstrating how to achieve the distinctive Riso aesthetic [1]. Additional resources—such as Liz Nugent Illustration and Alex Clem in the Shutterstock blog—offer alternative methods and creative tips for mimicking the signature textures, colours, and imperfections of Risograph prints [2,3].

Digital simulation allows users to achieve a visually similar result without the need for

physical equipment, making the process more accessible, faster and much more environmentally friendly. In addition, digital processing offers more flexibility, repeatability and the ability to experiment without material costs. The emergence of digital Risoprinting as a form of creative expression in educational programs, including in the field of information design, provides an opportunity to explore the relationship between traditional and modern media. Students and young designers gain insight into the mechanics of analog reproduction through hands-on work with digital tools while developing an understanding of composition, layering, colour and texture. Successful digital simulation requires an understanding of Risoprint principles — how colours are applied in individual layers, how pigments overlap and interact, and how visual imperfections contribute to the distinctive character of the print.
This article will cover both the theoretical framework, which includes the history, characteristics and development of Risoprinting, and the actual practical process of creating a digital poster in the Risoprint style. It will show how this effect can be achieved digitally in Photoshop, focusing on layer processing, use of textures, imitation grain and layering of colours. The process of poster creation will be analysed, including its aesthetic qualities and potential applications in educational and design contexts. With this approach, we aim to show how analog traditions can be successfully transferred and reinterpreted in contemporary digital environments while maintaining their authentic visual language.

2. THEORETICAL PART

Digital printing, as a substitute for traditional methods, enables faster production, easier distribution and often a significant reduction in costs and waste. To digitally simulate the Risoprint effect, one must understand how the physical technique works — how colours are applied, how layers overlap, and how the imperfections of the process become its visual signature. These aspects — colour, texture and layering — are critical to creating a digital Risoprint simulation. By using appropriate textures, blending modes and layer processing techniques in Adobe Photoshop, a very convincing result can be achieved. This method not only encourages experimentation, but also brings the aesthetic values of the Risoprint into the digital world.

2.1. Risoprint

Risoprint, also known as risograph printing, emerged in the late 1980s as an affordable and fast technology for the mass reproduction of graphic content. The process was popularized by the Japanese company Riso Kagaku Corporation whose founder is Noboru Hayama, which developed the machine of the same name as an alternative to photocopying and offset printing devices [4].
Risoprint machines work on the principle of stencil printing (mimeographs), in which a master stencil made of thin paper is wrapped around a drum and the ink is pressed through the cut-out areas of this stencil. Each colour is applied separately, which means that multicoloured prints require the preparation of several stencils and a layered print. The visual aesthetics of Risoprint result directly from the process itself — colour shifts, slight imperfections and textural effects created by the absorption of the ink on uncoated paper. These so-called “imperfections” are considered to be one of the greatest values in contemporary design [5].
The inks used are intense or semi-transparent and allow for unpredictable and interesting results when colours overlap. This creates multi-layered compositions where new shades are created by mixing existing colours directly on the paper. The paper plays a crucial role in this process, as its structure and porosity influence how the ink penetrates the surface and forms the final print impression. Recycled or uncoated paper is most commonly used, which enhances the characteristic “live” look of risograph prints [6]. A successful

Risoprint requires solid knowledge of file preparation, colour separation, working with halftones and layer registration. Due to the complexity of preparation and limited access to risograph equipment, many designers and students are now turning to digital alternatives [7]. Digital Risoprint simulation allows users to achieve similar visual results without the need for physical machines [8]. Tools such as Adobe Photoshop offer a wide range of features to mimic layers and textures — with masks, blending modes, colour-separated layers and the addition of textures such as grain and paper.
With digital imitation, each colour is created as a separate layer and the blending method is set to mimic the semi-transparency of the ink in the real print. Colour overlap effects are achieved with modes such as "Multiply" or "Screen," while textures add depth and a tactile feel. Rasterization and halftone simulation provide even more realism. While the end result is technically different from physical Risoprint, the visual and aesthetic value can be highly authentic [9]. In this way, digital technology makes the Risoprint design accessible to a wider audience, particularly in the educational and experimental contexts, where flexibility, speed and low cost are key advantages. This approach offers the opportunity to reinterpret the analog technique in a modern digital form, thus preserving the tradition and transferring it to new media.

2.2. Blend Modes: "Multiply" and "Screen"

In digital design and image editing, blending modes are important tools that determine how the colours of one layer interact visually with those of the layer below. The correct use of blending modes enables the creation of interesting visual effects, realistic lighting, depth and the simulation of print techniques such as Risoprint. The most commonly used blending modes include "Multiply" and "Screen", which work almost as opposites.
The "Multiply" blend mode is used to darken an image. It literally multiplies the colour values of the applied layer with those of the layers below. The result is always darker, except when using white — white becomes invisible in "Multiply" mode as it has no effect on the layer underneath. Black, on the other hand, remains unchanged and has the strongest darkening effect. "Multiply" mode is often used to simulate a layered print where the colours visually mix and create new shades. In Risoprint, for example, overlapping two colours with the "Multiply" effect, you can create the impression that two colours are mixing to form a third colour which exactly what happens in real printing. On the other hand, "Screen" mode works in the opposite way. It lightens the image.
Internally, this mode also calculates colour values, but in reverse order: it inverts them, multiplies them and inverts them again. The result is a brighter image in which black becomes invisible while white remains dominant. The "Screen" mode is often used to simulate light effects, e.g. reflections, glow or transparent light on surfaces. It is also very useful for photo retouching or emphasizing highlights in a design. To better understand the difference between these two blending modes, consider the following: "Multiply" mode mimics the behaviour of ink so as more layers of colour are layered, they become darker and more complex. "Screen" simulates light, so more layers result in a lighter composition. The characteristics of these two modes are explained in Table 1.

Table 1: "Multiply" and "Screen" mode behaviour; source: author

	Multiply	**Screen**
Effect	Darkens	Lightens
Black in layer	Stays black	Disappears
White in layer	Disappears	Stays white
Real-world sim.	Ink layering, shadows	Light overlays, glow

Common in	Print effects, risograph emulation	Retouching, light leaks, gradients

When working with multiple layers, as is the case when creating Risoprint compositions, it is recommended to use the "Multiply" option for all coloured layers so that the colours overlap naturally [10]. Each layer should have its own colour and remain separate, while "Multiply" mode allows you to blend their shades in a way that resembles traditional printing. Understanding how the blending modes work allows to be creatively free and better control the visual identity of design. "Multiply" and "Screen" modes are simple to use, but their effects can be very powerful, whether we want to add depth to design, simulate a realistic print or simply add a touch of light and contrast.

3. PRACTICAL PART – CREATING A POSTER USING THE DIGITAL RISOPRINT TECHNIQUE

In the practical part, posters were created on the subject of "Life and Death" using the digital Risoprint technique in Adobe Photoshop. The aim was to faithfully recreate the aesthetic characteristics of traditional risograph printing — a graphic technique known for its specific colour overlaps, grainy textures and limited but bold colour palette. The digital approach made it possible to simulate this visual language using modern tools and methods. The process began with the creation of a new document of any size; in the case of the students at the Zagreb University of Applied Sciences, A3 format was used. The colour mode of the document was set to CMYK in order to achieve a more accurate colour representation compared to the standard RGB mode, which is especially important when simulating printed materials. Once the workspace was prepared, visual elements on the themes of life and death were selected. The images were sourced from the internet and imported into the document. The "Object selection tool" was used to select the most important parts of each image and unwanted backgrounds were removed using the "Layer Mask" technique. This process was repeated for each motif, enabling precise isolation and further editing. Each subject was then recoloured using the "Color Overlay" effect from the "Layer Styles" menu (as shown in Figure 1).

In the initial editing phase, a specific colour was selected for each layer and the blend mode was temporarily set to "Screen" allowing a lighter appearance and easier colour separation. Once all subjects were shaped, the "Blend Mode" for all layers was changed to "Multiply". This step is crucial for achieving Risoprint's signature colour overlap effect, where different colours blend together to form new shades — similar to the behaviour of ink layers in physical printing.

Figure 1: Using "Color Overlay" effect on multiply layers; source: author

To further improve the texture and print image, several texture layers were added. First, a grain texture was applied using the "Soft Light" blend mode, followed by a second texture layer using "Overlay", and a paper texture set to "Multiply" blend mode in between. This layering and choice of blend modes helped the textures appear organic and consistent with hand printing techniques. If required, the number of texture layers could be increased to achieve an even finer result. The process of adding textures and using "Soft Light" blending mode is illustrated in Figure 2. Due to the influence of these textures, the motifs appear slightly lighter and more "washed out" in the final stage.
To further emphasise certain elements and restore visual contrast within the composition, the "Burn Tool" and "Dodge Tool" in Adobe Photoshop were strategically employed which resulted in greater contrast and image depth. The „Burn Tool" was used to darken selected areas of the design that required increased visual weight or tonal depth, thereby enhancing the overall sense of spatial layering. This technique mimics traditional darkroom methods, where parts of a photographic print are intentionally darkened to draw attention or increase dimensionality. Conversely, the „Dodge Tool" was applied to lighten darker regions of the image, thereby revealing hidden details and creating stronger contrast between highlights and shadows. This approach improved image clarity and accentuated focal points within the design, guiding the viewer's eye toward key visual components.

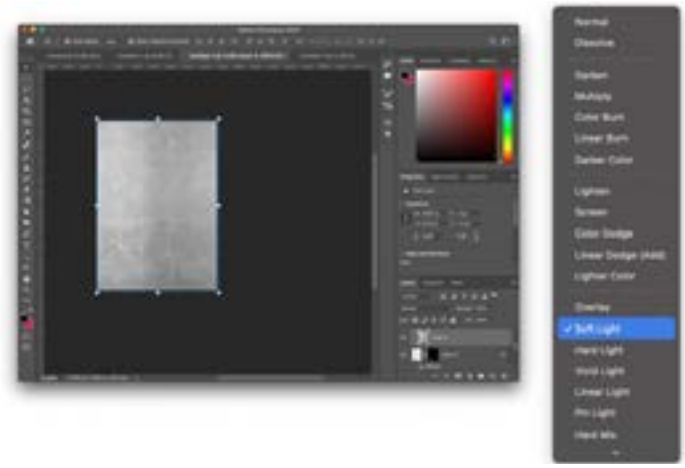

Figure 2: Adding texture layer and using "Soft Light" blend mode; source: author

As a final touch, text was added to the design where required. It is important to note that the text layer had to be placed below the texture layers so that the same visual effects could be applied to it. The blend mode of the text was also set to "Multiply" to give the impression that the text was "printed" into the design and not simply placed on top of it. Integrating text into the design by using "Multiply" blend mode is shown in Figure 3. The combination of carefully selected motifs, colours, textures and tools for localized contrast correction, created a visually rich, thematically layered and aesthetically balanced poster — a successful reinterpretation of the Risoprint aesthetic through a digital medium.

Figure 3: Integrating text layer by using "Multiply" blend mode; source: author

4. STUDENT SOLUTIONS FOR RISOPRINT POSTERS

During the process of creating the posters on the theme of "Life and Death" a number of important design solutions emerged as crucial for a high-quality and aesthetically convincing end result. The thematic framework required a thoughtful visual narrative, so motifs, colours and compositional relationships were carefully selected to convey the contrast and connection between two universal concepts - existence and its end.

First and foremost, special attention was given to the selection of appropriate colours for each layer. The colours were chosen to overlap effectively while maintaining the visual clarity and legibility of the motifs, even in areas where multiple layers overlap. In addition to colour selection, working with textures was an important part of achieving an authen-

tic look. Textures that mimic the graininess of traditional printing and the surface of paper were used to enhance the visual connection to classic Risoprint techniques. Equally important was the deliberate use of blending modes. By applying these modes, the layers maintained a sense of transparency while also allowing the creation of new colours through overlapping. This method added depth and dynamism to the composition and gave each subject an additional dimension through its interaction with other elements. In addition to the technical aspects, the project also placed great emphasis on layer organization. The layers were structured in a way that allowed flexible edits and adjustments without compromising the already completed work. This approach provided creative freedom, encouraged experimentation, facilitated the iteration of ideas and enabled quick adjustments during the design process.

The combination of these solutions resulted in creative work that was not bound by the limitations of physical equipment, while the final visual outcome was comparable to the results achieved using traditional Risoprint methods. The student work produced using this method can be seen in Figure 4 and Figure 5. They clearly demonstrate the quality of colour blending, texture layering and overall visual coherence of the posters, which interpret the theme of "Life and Death" in a symbolic and aesthetically rich way.

Figure 4, entitled "A sticky situation"," shows an illustrative nature scene depicting a chameleon catching a fly with its long, sticky tongue. The upper part of the picture shows twigs and leaves in which the chameleon is hidden, while the lower part captures the moment of the hunt. The blue and orange colours typical for the Risoprint technique emphasise the contrast between life and death and capture a moment of the natural struggle for survival. The layering and grainy texture enhance the impression of movement, while the centrally placed title "A Sticky Situation" adds an ironic touch to the scene.

Figure 5 with the title "Quit bugging me!" interprets the theme of mortality in a humorous way through an everyday action — stepping on a bug. The dominant pink of the foot and sneaker, combined with green and darker abstract elements, suggests a moment of violence that contrasts with the seemingly playful design. The beetle is depicted in a highly stylized form that is partially obscured to symbolise its vulnerability. The typographic element "Quit bugging me!" is a play on words that emphasises the double meaning of the theme: an everyday annoyance and the symbolic end of a life.

Both images effectively capture the coexistence and conflict of life forces through the Risoprint aesthetic, using a limited colour palette, layering, and visual irony to convey their message.

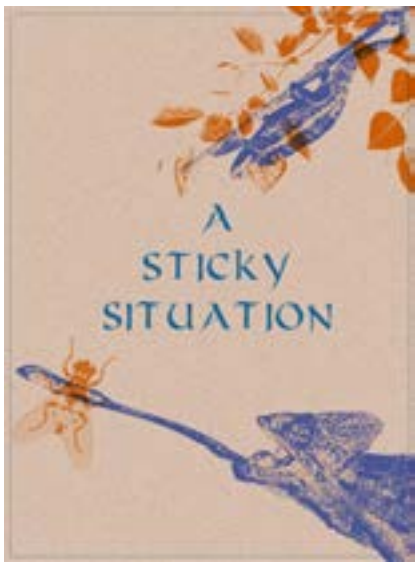

Figure 4: "Life and Death" Risoprint poster by student Anel Ibrahimović; source: Author

Figure 5: "Life and Death" Risoprint poster by student Mia Junković; source: Author

5. CONCLUSION

The digital Risoprint represents a successful synthesis of tradition and modern technology. Through the use of widely available digital tools, it is possible to reproduce the visual and tactile qualities of the classic Risoprint, opening up new possibilities in the field of design and visual communication. While the digital version is no substitute for the physical technique, it offers numerous advantages — accessibility, speed of execution and sustainability. This project has shown how the aesthetic value and heritage of a printing technique can be preserved and reinterpreted in a digital environment. The resulting posters illustrate how the creative potential of Risoprint can be transferred to new media without losing its distinctive visual character.

Analysis of the Risoprint as a technique has highlighted its uniqueness in visual expression — colour layering, organic halftones and imperfect colour registration are not technical flaws, but rather intentional aesthetic devices. Digital simulation allows precise control of these effects while maintaining the same experimental freedom as the analog process. Adobe Photoshop was used to achieve results that convincingly replicate the traditional printing process through the use of layers, textures, blending modes such as "Multiply" and "Screen", and additional refinements with tools such as "Burn" and "Dodge".

The educational and experimental value of digital Risoprint in an academic environment is important. Through this project, students developed a sense of composition, layers, colour, visual balance, and narrative while learning about both traditional printmaking techniques and modern digital production. This experience enabled a deeper understanding of the relationship between medium and message, as well as the importance of a design language that transcends purely technical execution. The student work presented in this project demonstrates how the theme of "Life and Death" can be interpreted through clear visual metaphors, while respecting the aesthetic principles of Risoprint. Each work represents an individual approach to the theme while maintaining technical consistency in the use of layers, textures and colour choices. Through this process, students have not only reproduced the Risoprint style but also, they have understood, adapted and critically reflected upon it.

The digital Risoprint is not the end of a process, but the beginning of a new approach to design— that combines craft aesthetics with digital possibilities. Its greatest value lies not

in the mere imitation of the Risoprint look, but in the continuation of the spirit of the print tradition into the modern context. In this way, it pushes the boundaries of visual communication and provides designers with a tool that is both nostalgic and innovative. Ultimately, this project confirms that digital technology shouldn't be in conflict with analog tradition, but rather it can serve as its extension.

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PROFESSIONAL PAPER

COMPARATIVE ANALYSIS OF LOW-CODE/NO-CODE TOOLS FOR BUILDING VIRTUAL AI AGENTS

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ABSTRACT

Low-code and no-code platforms are transforming the landscape of artificial intelligence development, making it more accessible to individuals and organizations without extensive programming expertise. These platforms enable users to design, build, and deploy virtual AI digital agents with minimal coding effort by leveraging intuitive graphical interfaces, pre-built AI models, and automation frameworks. This shift democratizes AI development, allowing businesses to create intelligent assistants that enhance customer service, automate workflows, and improve user interactions across various industries.

This paper conducts a comparative analysis of leading low-code/no-code platforms designed for virtual AI agent development. The comparison is based on key criteria such as usability, AI capabilities, scalability, integration with third-party applications, and overall performance. The paper explores how different platforms cater to diverse user needs, from small businesses seeking cost-effective solutions to large enterprises requiring robust and scalable AI-driven automation.

Through evaluation and testing, we highlight the strengths and limitations of each tool, providing insights into their suitability for various applications. Paper findings offer recommendations tailored to different use cases, helping organizations select the most appropriate platform for their AI-driven initiatives.

Keywords: digital, artificial intelligence (AI), agents, chatbot, low-no-code

1. INTRODUCTION

Artificial Intelligence (AI) has become a key technology when it comes to digital transformation. Building AI-based solutions required expertise and knowledge in machine learning, natural language processing (NLP), and software development. Technical expertise was a requirement that was a barrier for many potential users/creators, until the emergence of tools that enable the creation of low-code and no-code (LCNC) applications. When LCNC tools emerged, they also democratized the use of AI, allowing users with limited technical skills to create and deploy virtual AI agents such as chatbots, voice assistants, and process automation robots [1].

LCNC tools simplify the development process by enabling visual programming, drag-and-drop interfaces, and easy integration with existing AI services. This allows a wide range of users, from business analysts to professional developers, to create new AI agents for customer service automation, sales, marketing, healthcare, financial services, or other sectors.

This paper provides an overview and evaluation of selected LCNC tools for AI agent devel-

opment, comparing their functionalities, user experience, and application performance to determine their relative strengths and weaknesses.

2. METHODOLOGY

The comparative analysis in this paper is based on a combination of literature review [2] [3], product documentation, and hands-on testing of the platforms. The platforms selected for analysis include:

1. Microsoft Copilot
2. Google Dialogflow CX
3. IBM Watson Assistant
4. Salesforce Einstein Bots
5. Kore.ai XO Platform
6. Voiceflow

Each platform was evaluated using the following criteria:

1. Usability: Interface design, learning curve, and user support.
2. AI Capabilities: Built-in NLP features, training flexibility, and support for contextual understanding.
3. Scalability: Performance under load, deployment options, and enterprise readiness.
4. Integration: Compatibility with third-party tools, APIs, and external data sources.
5. Performance: Response time, accuracy, and maintenance features.

Platforms were tested using standardized scenarios involving conversational flows, API integration, and deployment on web and messaging platforms. Each scenario simulated a typical customer service use case, including multi-turn dialog handling, conditional logic, API calls, and fallback strategies.
The testing was conducted collaboratively by a research team of two researchers from CITUS and the University of Zagreb.
Quantitative performance metrics included: average response time (ms), intent recognition accuracy (%), and Task completion success rate (%).
Usability was assessed using: System Usability Scale (SUS), task completion time, and error frequency.
Six test users from CITUS and the University of Zagreb, with varying technical backgrounds (from business analysts to professors), participated in usability testing to ensure the evaluation reflected diverse user profiles.

3. COMPARATIVE ANALYSISS

3.1. Microsoft Copilot Studio

Copilot Studio is a conversational AI platform that empowers people to create agents using natural language or a graphical interface. It enables easily designing, testing, and publishing agents that suit any needs for internal or external scenarios across an industry, department, or role. It allows building a standalone agent or publishing to Microsoft 365 Copilot [4].

- Usability:
  - Deeply integrated into Microsoft 365, making it very accessible for users already within that ecosystem.
  - Interface is designed to be intuitive within familiar applications.
  - User support is strong, leveraging Microsoft's extensive resources.

- AI Capabilities:
  - Strong in content generation and contextual understanding within Microsoft 365.
  - Growing rapidly in general AI capabilities, utilizing large language models.
  - Contextual awareness within the Microsoft ecosystem is a key strength.
- Scalability:
  - Leverages Microsoft's cloud infrastructure, providing strong scalability.
  - Enterprise-ready, with robust security and compliance features.
- Integration:
  - Excellent integration within the Microsoft ecosystem.
  - Expanding API capabilities for broader integration.
- Performance:
  - Generally strong performance, with ongoing improvements.
  - Accuracy and response times are continuously being refined.

3.2. Google Dialogflow CX

Dialogflow CX provides advanced NLP powered by Google's machine learning models. It features a state-based approach to dialog management, making it suitable for complex conversations. Its integration with Google Cloud services and other Google tools enhances scalability [5].

- Usability:
  - Visual flow builder can be complex for beginners, but powerful for advanced users.
  - Learning curve is steeper than some no-code platforms.
  - Strong documentation and community support.
- AI Capabilities:
  - Highly advanced NLU, with robust intent and entity recognition.
  - Excellent for building complex conversational flows.
  - Strong contextual understanding capabilities.
- Scalability:
  - Google Cloud-based, offering excellent scalability.
  - Enterprise-grade infrastructure and security.
- Integration:
  - Strong integration with Google Cloud services and various channels.
  - Robust API for custom integrations.
- Performance:
  - High performance, with low latency and accurate responses.
  - Strong analytics and monitoring features.

3.3. IBM Watson Assistant

Watson Assistant excels in enterprise deployments with strong multi-channel support and deep integration with Watson Discovery for unstructured data. Its graphical interface allows intuitive design, and it includes advanced AI features such as intent disambiguation [6].

- Usability:
  - User-friendly interface with visual tools.
  - Good documentation and tutorials.
  - Offers both no-code and low-code options.
- AI Capabilities:
  - Powerful NLU with intent, entity, and dialogue management.
  - Good training flexibility and contextual understanding.
  - Strong at handling complex conversational scenarios.

- Scalability:
  • Scalable on IBM Cloud, with various deployment options.
  • Enterprise-grade security and compliance.
- Integration:
  • Good integration with IBM services and third-party applications.
  • Flexible API for custom integrations.
- Performance:
  • Reliable performance with good response times.
  • Strong analytics and monitoring.

3.4. Salesforce Einstein Bots

Einstein Bots cater primarily to existing Salesforce users. They offer excellent CRM integration and AI features tailored to sales and customer service. The interface is accessible but has limited flexibility for non-Salesforce environments [7].

- Usability:
  • Tight integration within the Salesforce ecosystem, making it easy for Salesforce users.
  • Relatively easy to use, with a visual builder.
  • Strong integration with Salesforce CRM data.
- AI Capabilities:
  • Focuses on customer service and sales use cases.
  • Good NLU for common customer interactions.
  • Contextual understanding within Salesforce data.
- Scalability:
  • Scalable within the Salesforce cloud.
  • Enterprise-ready, with Salesforce's security and compliance.
- Integration:
  • Seamless integration with Salesforce CRM and other Salesforce products.
  • API for external integrations.
- Performance:
  • Reliable performance within the Salesforce ecosystem.
  • Performance is strongly tied to the overall Salesforce platform performance.

3.5. Kore.ai XO Platform

Kore.ai offers a powerful LCNC interface with a strong focus on enterprise automation and omni-channel deployment. It supports advanced features such as sentiment analysis, voice AI, and integration with RPA platforms [8].

- Usability:
  • Comprehensive platform with a focus on enterprise-grade conversational AI.
  • Visual builder and low-code options.
  • It can have a steeper learning curve due to its extensive features.
- AI Capabilities:
  • Advanced NLU, dialogue management, and process automation.
  • Strong support for complex enterprise use cases.
  • Multi-lingual capabilities.
- Scalability:
  • Highly scalable, with flexible deployment options.
  • Designed for enterprise-level deployments.
- Integration:
  • Extensive integration capabilities with enterprise systems and third-party applications.

• Strong API and SDK support.
- Performance:
• High performance and reliability.
• Robust analytics and reporting.

3.6. Voiceflow

Voiceflow is a collaborative low-code platform designed specifically for designing, prototyping, and deploying conversational experiences such as chatbots and voice assistants. It supports both designers and developers through a visual canvas and modular structure. Originally focused on voice assistants like Alexa and Google Assistant, Voiceflow has evolved into a robust tool for multi-channel AI agent development [9].
Its intuitive interface allows users to create complex dialog flows without writing code, while also providing support for advanced logic, API calls, and integrations for power users. Voiceflow offers cloud deployment, version control, and team collaboration features, making it suitable for both prototyping and production-ready systems.
- Usability:
• Specifically designed for voice and conversational AI, with a very intuitive visual interface.
• Excellent for rapid prototyping and deployment.
• Very easy for beginners to learn.
- AI Capabilities:
• Strong focus on conversational design and voice interactions.
• Good NLU for voice-specific use cases.
• Strong tools for designing conversational flows.
- Scalability:
• Scalability depends on the deployment environment.
• Suitable for a wide range of applications, from small to large.
- Integration:
• Good integration with various voice platforms and APIs.
• Growing integration capabilities.
- Performance:
• Strong performance for voice applications.
• Focus on optimizing voice interaction performance.

4. CONCLUSIONS

Low-code/no-code tools have significantly lowered the barrier to entry for AI agent development. By abstracting technical complexity, they empower business users and smaller organizations to harness the power of AI. Based on chosen methodology we have evaluated 6 Low-code/no-code (LCNC) tools as show in (Table 1).

Table 1: COMPARATIVE ANALYSIS: Low-Code/No-Code AI Agent Platforms; The grades in the table are assigned from 1 to 5, where grade 1 indicates the lowest grade and grade 5 the highest grade.

#	Platform	Usability	AI Capabilities	Scalability	Integration
1	Microsoft Co-pilot	4	4	4	4
2	Google Dia-logflow CX	3	5	5	5

3	IBM Watson Assistant	4	4	4	4
4	Salesforce Einstein Bots	4	3	4	5
5	Kore.ai XO Platform	3	5	5	5
6	Voiceflow	5	3	3	4

However, choosing the right platform depends on specific business needs, technical capacity, and integration requirements, as (Table 2) shows below. This comparative analysis offers a framework to guide organizations in selecting the most suitable LCNC solution for their virtual AI agent initiatives.

Table 2: Recommendations for using LCNC tools based on use case

#	Use Case	Recommended Platform
1	Quick deployment in Microsoft stack	Microsoft Copilot Studio
2	Enterprise-grade scalability	Kore.ai or IBM Watson Assistant
3	Advanced NLP and flexibility	Google Dialogflow CX
4	CRM-focused chatbot for Salesforce	Salesforce Einstein Bots
5	Conversational design and rapid prototyping	Voiceflow

Acknowledgement:

Present research has been financed by the project financed by CITUS and in cooperation with researchers from University of Zagreb.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

PROFESSIONAL PAPER

ACCESSIBILITY IN USER INTERFACE DESIGN: THE ROLE OF CONTRAST

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ABSTRACT

This paper explores the role of contrast in user interface (UI) design, focusing on how different contrast levels impact the usability of digital products for users with varying visual abilities. The study includes a review of accessibility standards (WCAG and APCA) and a user survey with 39 participants. The research highlights key accessibility principles (i.e., perceivability, operability, understandability, and robustness) and compares how contrast is measured in WCAG versus APCA guidelines. Through case study and practical evaluation using screen variations on mobile devices with altered contrast, font weight, and size, findings show that poor contrast significantly reduces component visibility and text readability. Results confirm that APCA-compliant designs enhance the user experience by ensuring optimal contrast, especially for users with visual impairments. The study emphasizes that while contrast is the most influential factor in legibility, font size and weight are also contributing factors. The conclusions advocate for the broader implementation of evolving accessibility standards to create inclusive digital environments for all users.

Keywords: accessibility, user interface design, contrast, visual impairments, inclusive design, readability

1. INTRODUCTION

As defined by Office for Digital Accessibility (ODA) at the University of Minnesota [1], accessibility refers to ensuring that people with disabilities have the same opportunity to access information, participate in the same interactions, and enjoy the same services as people without disabilities, in an equally effective and integrated manner with the same ease of use.

Over 80 million individuals within the European Union experience some form of health-related impairment [2]. In relation to this, they represent a substantial portion of the user population that may be excluded when designers and software engineers fail to account for their needs during the digital product design and development process. For people with disabilities, the integration of accessibility features is essential not only for equitable use of digital products but also for enabling meaningful participation and contribution on these platforms. Inadequate accessibility results in the exclusion of millions of potential users whose engagement could enhance and enrich the product through their diverse perspectives and input.

Moreover, individuals with disabilities are not the only beneficiaries of accessible design. When accessibility considerations are integrated, the resulting design tends to be more user-friendly and effective for all users, thereby enhancing the overall usability and inclusivity of the product [3].

Furthermore, not all individuals who require enhanced accessibility have a diagnosed disability. Many users encounter other barriers when interacting with digital products. These challenges may include limited digital literacy, lower levels of education, or inadequate access to reliable devices and internet connectivity.

Given the above, this paper seeks to address the following research question:

RQ: How do different levels of contrast in user interface design affect accessibility for users with varying visual abilities, and how can this knowledge be applied to improve design for the benefit of all users?

The paper is organized as follows: Section 2 reviews key accessibility guidelines in user interface design, focusing on WCAG and APCA standards; Section 3 describes the methodology used in the user study; Section 4 presents the survey results; Section 5 discusses the findings in relation to accessibility principles; and Section 6 concludes with practical implications and suggestions for future research.

2. ACCESSIBILITY IN USER INTERFACE DESIGN

Designers employ a variety of practices to ensure that interface designs are accessible and user-friendly. These practices are comprehensively outlined in the Web Content Accessibility Guidelines (WCAG) [4], developed by the World Wide Web Consortium (W3C). The WCAG standards are internationally recognized and aim to make online content more accessible for people with disabilities. At the time of writing, the latest version was WCAG 2.2, published in October 2023. It consists of 13 principles that can be categorized into four groups: Perceivable, Operable, Understandable, and Robust (Table 1).

Table 1: WCAG principles [4]

WCAG principles	Description
Perceivable	• Provide text alternatives for non-text content and subtitles or alternatives for multimedia. • Ensure context is accessible, e.g., through tagging or extended audio descriptions. • Support users in seeing and hearing content, including through appropriate contrast.
Operable	• All functionalities must be accessible via keyboard. • Users must have sufficient time to read and use content. • Content must not cause physical reactions (e.g., epileptic seizures). • Users must be supported in finding and navigating content. • Operation with alternative input devices must be facilitated.
Understandable	• Text should be readable and understandable. • Content should be presented and behave in predictable ways. • Users should be helped to avoid and correct mistakes.
Robust	• Compatibility with current and future user tools should be maximized.

2.1. Contrast guidelines

According to WCAG guidelines, contrast measures how easily text can be distinguished from its background. It is quantified using a contrast ratio that compares the relative brightness of text and background colours, ranging from 1:1 (no contrast) to 21:1 (maximum contrast, black on white). The ratio is easy to calculate using clear mathematical formulas and is widely implemented in accessibility testing tools. However, it can be imprecise and has limitations, especially when applied to modern design aesthetics and complex colour schemes.

Although WCAG contrast guidelines are widely accepted and commonly used, they have notable drawbacks and have faced significant criticism. For instance, most websites fail to meet these standards. The 2025 WebAIM report found that 94.8% of home pages detected WCAG 2 failures [5]. The few websites that do pass are often those specifically engineered

to meet the guidelines, raising concerns about designs being optimized for compliance rather than for actual usability and user needs [6]. This raises an important question: Are websites poorly designed, or is the test itself flawed? Both may be true since web designers could place greater emphasis on usability and accessibility, while the development of a more accurate and realistic testing method may also be necessary.
In response to this need, the Advanced Perceptual Contrast Algorithm (APCA) [7] was developed and is currently under consideration for inclusion in the upcoming WCAG 3 guidelines. APCA is based on Lightness Contrast (LC), a value calculated from the minimum text size and colour pairings. Unlike simple brightness comparisons, LC is perceptual, meaning that an LC value of 60 represents the same perceived contrast, regardless of whether the colours are dark or light. Instead of a strict pass/fail model, APCA introduces a tiered system of compliance levels: bronze, silver, and gold (Table 2) [8].

Table 2: APCA compliance levels [8]

APCA compliance levels	Description
Bronze	• Bronze level is the minimum required. • Only the primary content text must comply. • Does not include disabled or placeholder text, which is referred to as other content text. • Minimum text size is not defined, and there's no requirement for font matching in size or weight.
Silver	• Silver level covers all text on the page. • Text that was considered "other content" in the bronze level is divided into fluent text, large fluent text, and sub-fluent text. • All texts have recommended colour contrast, as well as size and weight recommendations. For example, the minimum size for content text is 13 px with an x-height ratio of 0.5; the minimum for other text is 10 px.
Gold	• Gold level builds on the bronze and silver, and includes font comparison to a reference font. • Minimum content text size is 18 px with an x-height ratio of 0.5, and for other text, it's 12 px.

Considering all relevant parameters, Figure 1 provides a practical reference for accessible design.

Figure 1: APCA lookup table [9]

2.2. Contrast Guideline Equivalents in WCAG and APCA Approaches

The WCAG contrast scale defines values ranging from a minimum of 1:1 to a maximum of 21:1. In contrast, the APCA scale utilizes an LC metric, with values spanning from 0 to 106. Within the APCA framework, a LC value of 15 is generally imperceptible to some users, whereas a LC value of 90 is considered optimal for standard body text readability [10]. Table 3 presents a comparison of accessible contrast standards.

Table 3: Accessible contrast standards comparison

Standard	Purpose	Threshold
WCAG AA	Readable for good vision	4.5:1
WCAG AA (large text)	Readable for good vision (large text)	3:1
WCAG AAA	Stricter standard for poor vision	7:1
WCAG AAA (large text)	Stricter standard for poor vision (large text)	4.5:1
APCA LC 90	Ideal contrast for body text	LC 90
APCA LC 75	Minimum for body text	LC 75
APCA LC 60	Minimum for other text	LC 60

APCA LC 45	Minimum for large text	LC 45
APCA LC 30	Absolute minimum for any text	LC 30
APCA LC 15	Lower limit of visibility	LC 15

3. METHODOLOGY

To investigate and demonstrate the impact of contrast on accessibility, a survey was conducted with 39 respondents aged 18 to 33. The research was conducted through a Google Forms survey. Participants were selected using random sampling methods within the general population of Croatia. Of the participants, 23 identified as women and 16 as men. A total of 20 participants reported having some form of visual impairment, with the majority affected by refractive errors (n = 13), followed by astigmatism (n = 6). Other reported conditions included colour blindness (n = 2), strabismus (n = 1), and reduced vision in one eye (n = 1).

The study was structured into two main phases. In the first part, Screen A (Figure 2A) was developed as a baseline design with standard contrast levels. Screen B (Figure 2B) was then created as an identical copy of Screen A, except those certain areas had reduced contrast, deliberately adjusted based on WCAG contrast thresholds. Participants were asked to evaluate the visibility of these modified elements using a 5-point Likert scale, where 1 represented the lowest visibility and 5 the highest.

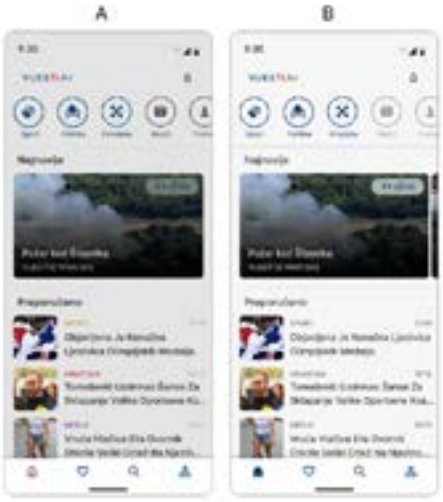

Figure 2: Screen A and Screen B

In the second part of the study, Screen C was designed featuring a large amount of text in various colours and sizes, all adhering to the ideal APCA guidelines. Several variations of Screen C were then produced to test different types of guideline violations. Screen D maintained the same structure but altered the font weight, resulting in non-compliance with APCA recommendations. Screen E similarly preserved the original layout but reduced the text size below the minimum recommended by the guidelines. Finally, Screen F kept the text size and font weight consistent but decreased the contrast between text and background, rendering it non-compliant with accessibility standards. These screens are depicted in Figure 3.

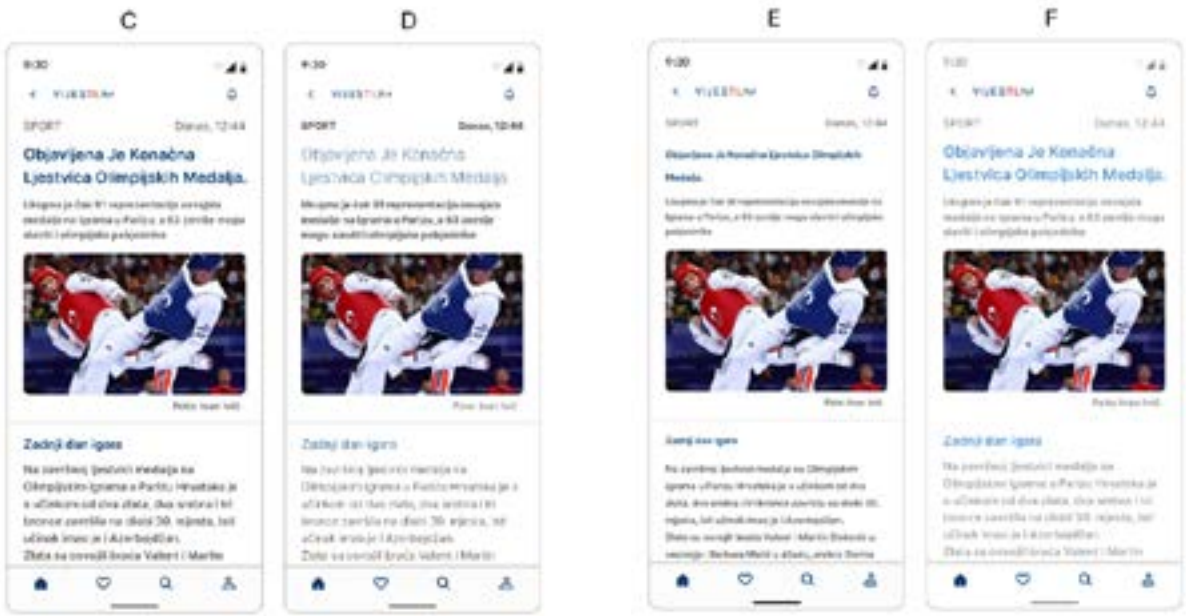

Figure 3: Screen C, Screen D, Screen E and Screen F (from left to right)

3.1. Survey design

Participants were presented with a series of screens and asked to evaluate the visibility and readability of specific elements using a 5-point Likert scale, where 1 indicated "very poorly visible" and 5 indicated "very well visible."
For Screen A, participants were shown the image and asked to assess the visibility of the following elements:

1. Identification of the current screen within the navigation interface,
2. Time of publication of the recommended news item,
3. The word SPORT within the recommended news,
4. The word HRVATSKA within the recommended news,
5. The word MEDIJI within the recommended news,
6. The tag located in the top right corner of the latest news item,
7. Distinction between active and inactive news items, as indicated by the circular icons at the top of the screen.

For Screen B, which featured reduced contrast levels in specific areas compared to Screen A, participants were similarly asked to assess the following elements:

1. Identification of the current screen within the navigation interface,
2. Time of publication of the recommended news item,
3. The word SPORT within the recommended news,
4. The tag located in the top right corner of the latest news item,
5. Distinction between active and inactive news items.

In the second part of the study, participants evaluated Screens C, D, E, and F. For each of these screens, a general question was posed: "Evaluate the readability of the text on the following screen," using the same 5-point Likert scale (1 = very poorly readable, 5 = very well readable).
This structured approach allowed for a direct comparison between screens designed according to accessibility guidelines (WCAG and APCA) and those with deliberate deviations,

to measure the impact of contrast, font weight, and text size on perceived readability and usability.

3.2. Survey results

To facilitate the analysis of the survey results, the mean value of participant responses was calculated for each question.
The results for Screen A were as follows: the average rating for identifying the current screen within the navigation interface (Question 1) was 3.09. The time of publication of the recommended news item (Question 2) received an average score of 3.23. The visibility of the word SPORT within the recommended news (Question 3) was rated 3.74, while the word HRVATSKA (Question 4) achieved the highest average visibility score of 4.26. The word MEDIJI (Question 5) was rated 4.03. The tag located in the top right corner of the latest news item (Question 6) received the lowest visibility rating, averaging 2.83. Finally, the ability to distinguish between active and inactive news items in the circular icons at the top of the screen (Question 7) had an average rating of 3.06.

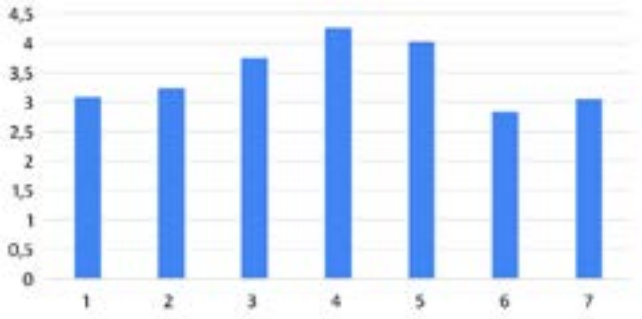

Figure 4: Visibility assessment results for Screen A

Similarly, the mean value of participant responses was calculated for each question on the visibility of elements on Screen B. The results show that the average rating for identifying the current screen within the navigation interface (Question 1) was 3.86. The time of publication of the recommended news item (Question 2) also received an average rating of 3.86. The visibility of the word SPORT within the recommended news (Question 3) was rated slightly lower, with an average score of 3.49. The tag located in the top right corner of the latest news item (Question 4) achieved an average rating of 3.83. Finally, the ability to distinguish between active and inactive news items in the circular icons at the top of the screen (Question 5) was rated at 3.71.

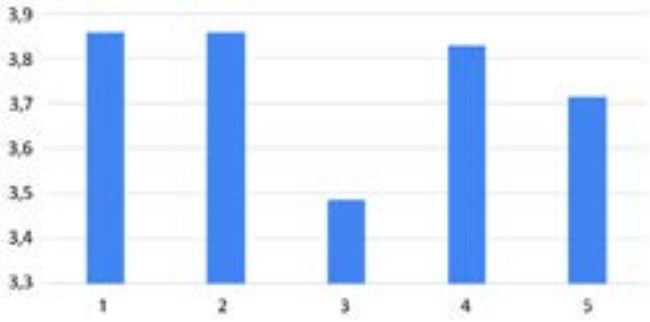

Figure 5: Visibility assessment results for Screen B

In the second part of the study, participants evaluated the readability of Screens C, D, E, and F. For Screen C, which was designed according to ideal APCA guidelines, the average readability rating (Question 3) was 4.2, indicating a high level of perceived text clarity. For Screen D, where the font weight was modified to no longer comply with APCA recommendations, the average readability score (Question 4) decreased to 3.43. In Screen E, where the text size was reduced below the guideline requirements, the average rating (Question 5) was 3.45. Finally, for Screen F, which featured reduced contrast between text and background, the readability rating (Question 6) further declined to an average of 3.11.

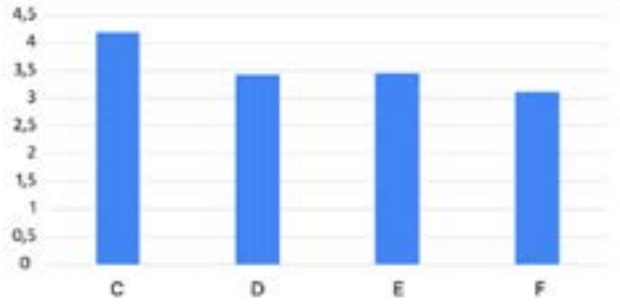

Figure 6: Visibility assessment results for Screen C, D, E and F

4. DISCUSSION

This study explored the impact of contrast, font size, and font weight on the visibility and readability of user interfaces. Before interpreting the findings, it is important to acknowledge that the study was conducted on a relatively small sample. Future research with a larger sample and more detailed statistical analysis will be necessary to draw more definitive conclusions.

In the first phase, Screens A and B, identical in design but differing in contrast, were compared. Survey results showed that Screen B, which featured enhanced contrast, received a significantly higher average visibility rating (3.86) than Screen A (3.09). These results might indicate that increasing contrast substantially improves user experience by facilitating the recognition of navigation elements, news items, and tags, thereby supporting more efficient interaction with the application.

The second phase evaluated Screens C, D, E, and F based on their compliance with APCA (Advanced Perceptual Contrast Algorithm) guidelines. Screen C, designed in full alignment with APCA recommendations (optimal font size, weight, and colour contrast), achieved the highest readability rating (4.2). This finding demonstrates the effectiveness of APCA standards in enhancing text legibility.

In contrast, Screens D and E, which introduced deviations from the ideal, altered font weight and reduced font size, respectively, received lower readability ratings (3.43 and 3.45). Screen F, which retained font size and weight but lowered contrast, was rated even lower (3.11). These patterns suggest that although font size and weight contribute to readability, adequate contrast has the most substantial individual impact.

Across both phases of the study, a consistent pattern emerged: improvements in contrast led to better visibility and readability, while reductions in contrast and deviations from APCA parameters impaired user experience. Specifically, reduced contrast hindered the ability to distinguish secondary text, navigate within the application, and differentiate between active and inactive news items. Thus, contrast is critical not only for the readability of body text but also for the effective differentiation of interface elements.

Overall, the results emphasize that strict adherence to contrast guidelines, such as those

recommended by APCA, greatly enhances user interaction by improving text readability and the visibility of navigational components. Among the factors tested, insufficient contrast had the most detrimental effect on perceived readability, underscoring its primary role in user interface design.

5. CONCLUSION

A significant portion of the global population experiences some form of visual impairment, making the accessibility of digital content an essential priority. As digital media becomes increasingly integral to daily life, it is critical to ensure that interfaces are designed to be inclusive for all users.

This study confirms that varying levels of contrast have a substantial impact on interface accessibility, particularly for users with diverse visual abilities. Key findings include:

- Optimal contrast enhances accessibility: Applying contrast in accordance with established guidelines, such as APCA or WCAG standards, significantly improves both readability and visibility. Enhancing contrast benefits all users, not only those with visual impairments.
- The role of text size and weight: Alongside contrast, factors such as text size and font weight are crucial for accessibility. A holistic approach that combines adequate contrast with appropriate text characteristics leads to a substantially better user experience.

The results demonstrate that improving contrast in user interface design is a powerful way to enhance accessibility. Proper implementation of established guidelines can make digital products more usable for all individuals, regardless of their abilities.

Designers and developers play a pivotal role in shaping the user experience. Therefore, the availability and adoption of clear, actionable accessibility guidelines are essential. While effective standards already exist, they must continue to evolve alongside technological advancements to remain relevant and impactful.

It is also important to recognize that accessibility guidelines should not be applied as isolated, pass-or-fail checklists. Instead, they should be integrated within the broader context of accessible design. For instance, contrast alone is insufficient if the text is too small or too thin to be legible. Accessibility should be approached as a comprehensive design philosophy, where multiple factors work in synergy to ensure digital inclusivity.

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REVIEW

INK TRAPS: BEYOND FUNCTIONALITY AND INTO EXPRESSION

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ABSTRACT

Ink traps are details in the character design of certain typefaces. They originated from the need to control ink overflow during printing, especially when using lower-quality paper or when printing on materials that are more absorbent. Nowadays, with advancements in technologies and materials used in printing, there is less need for ink traps to prevent detail loss due to ink bleeding; however, they have not disappeared from typeface design. In contemporary usage, instead of serving only as a technical adjustment, they often become a stylistic detail that adds character and recognisability to a particular typeface, especially when used at larger sizes. This paper provides an overview of various ways of designing ink traps. It also analyses examples of characteristic design details of letterforms in typefaces that use ink traps, ranging from those specifically designed for problematic printing conditions to those for which ink traps serve as a dominant stylistic characteristic. An example of typical letterforms of a typeface with ink traps has been designed; they are subsequently employed to redesign a prominent logo, illustrating the influence of ink traps on the visual expression of the brand's typeface.

Keywords: ink traps, typeface design, typography, visual expression.

1. INTRODUCTION

Typography has always been a complex interplay between function, form, and aesthetics, evolving alongside technological innovations in printing, typesetting and digital display. Among the myriad of technical solutions developed to address the inherent challenges of reproducing sharp, legible text, the concept of ink traps stands out for its dual role in both practical application and stylistic expression. Originally conceived as a technical measure to mitigate ink spread and enhance legibility in low-quality printing conditions, ink traps have undergone significant transformation, shifting from purely functional features to prominent design elements that influence a typeface's character and visual identity. Today a functional need remains for thoughtfully designed typefaces with ink traps, particularly when it comes to microtext on product packaging labels or when designing security graphics. This multifaceted evolution underscores the importance of ink traps in shaping both the technical and aesthetic dimensions of typography across history and within the contemporary digital contexts.

This article aims to provide an overview of the history, development, and current applications of ink traps, tracing their origins from early technological challenges to their recent reimagining as stylistic devices. We examine the significance of early uses and explore changes that came with technological advances such as phototypesetting and typography on the screen. Furthermore, the emergence of variable fonts and digital design has expanded the potential for dynamic and expressive use of ink traps, embedding them into the contemporary typographic practice. This article highlights how the initial technical purpose of ink traps has grown into a specific visual vocabulary, contributing both functional clarity and stylistic character.

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2. THE EVOLUTION OF INK TRAPS

In typography, the strategic implementation of ink traps is primarily aimed at enhancing the openness within the letter strokes, thereby improving both clarity and function. This is particularly evident in areas where two or more strokes join, such as inner corners or junctions within characters, which are prone to ink accumulation. During the printing process, especially with absorbent paper, ink naturally spreads and is absorbed, potentially leading to blurring, smudging, and loss of fine details. By incorporating ink traps, designers ensure that any ink overflow is directed into strategically placed gaps. This not only prevents ink from spreading beyond the intended outlines but also protects the integrity of the typeface's design and maintains the legibility of the text [1].

2.1. The beginnings of ink trap development and the Linotype Excelsior font

One of the first instances of mentioning ink traps in the context of typeface design is an advertisement for the Linotype Excelsior typeface (Figure 1), published in 1931 in the American printing technology magazine "Editor & Publisher" [2]. The advertisement clearly highlights the design advantages of the promoted typeface, emphasising the openness of its forms as a solution for preventing smudging during printing. The term ink traps appeared as a description of the problem of certain letter shapes which 'trap' ink, in contrast to its contemporary usage. The ink traps which we refer to today, shaped as incisions at critical junctions of strokes, are not strongly featured in this typeface [3].

Figure 1: Advertisement for the Linotype Excelsior typeface, from the magazine "Editor & Publisher", 1931. [2]

2.2. The significant applications of ink traps — the Bell Centennial font

One of the most well-known examples of a typeface using ink traps is Bell Centennial (Figure 2), which has been included in the collection of The Museum of Modern Art (MoMA,

New York). The Bell Centennial typeface was designed between 1975 and 1978 by Matthew Carter of Mergenthaler Linotype Company for AT&T Corporation (formerly The American Telephone and Telegraph Company) on the occasion of their 100th anniversary (hence the name "Bell Centennial") [4]. The typeface was created for printing AT&T telephone directories and is composed of four different weights: "Bell Centennial Address", "Bell Centennial Caption", "Bell Centennial Name and Number" and "Bell Centennial Bold Listing" (Figure 2). It is exceptionally functional and readable at very small sizes, especially when text is printed on absorbent paper, due to careful planning of details such as ink traps. The new design was introduced as a modern replacement for the previously used Bell Gothic typeface (Figure 3), aiming to solve various technical and visual problems arising from Bell Gothic's design in conjunction with challenging printing conditions.

Figure 2: Bell Centennial typeface [4]

Figure 3: Bell Gothic typeface [4]

Due to the high volume of small, densely packed text printed with relatively low-quality ink on thin paper, significant technical challenges such as ink spread, stroke merging, smudging, and diminished legibility arose. To address these issues, Carter aimed to create

a typeface that not only possessed a modern appearance but also prioritised maximum readability at small sizes, particularly at 6 points (Figure 4). Special attention was given to the design of numerals, notably ensuring that similar characters like 5 and 6 or 3 and 8 were visually distinct. Achieving this goal involved designing highly open letterforms and implementing modifications such as exaggerated openings at corners and junctions, which helped prevent ink distortion and maintain clarity. Overall, these interventions combined technical precision with thoughtful aesthetic adjustments, resulting in a typeface optimised for challenging printing conditions while maintaining a contemporary look.

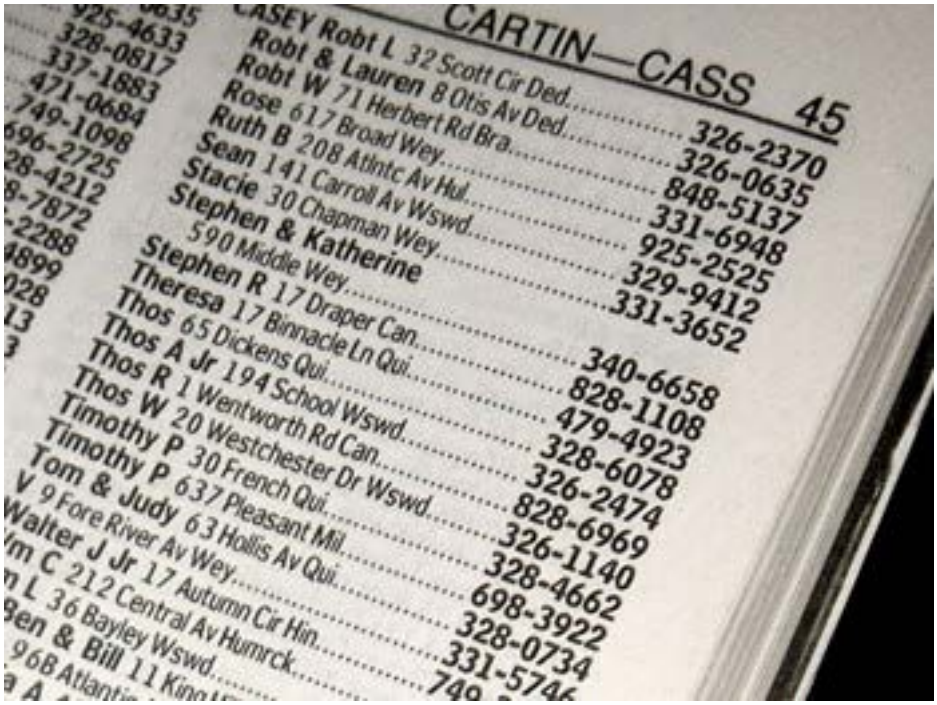

Figure 4: The AT&T phonebook showing typeface Bell Centennial in use [4]

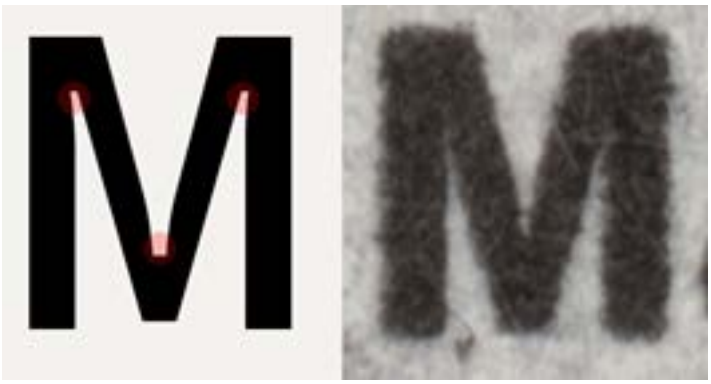

Figure 5: Design of the uppercase M and a print at a size of 6 points [4]

Despite making the letterforms appear quite unusual in their original design, these modifications effectively mitigated print distortion (Figure 5), ensuring that, even under low-quality printing conditions, the letters remained clearly defined and legible in the final print. [4]

2.3. Visual impact of ink trap design in different font weights

While the design of ink traps can differ based on the design concept or the intended use of

the typeface, certain patterns emerge from optical adjustments made across various font weights. Typically, as the weight becomes more expressive, the ink traps become more prominent within the typeface. Different weights of the Whyte Inktrap typeface (designed in 2019 by Johannes Breyer, Fabian Harb and Erkin Karamemet at Dinamo, a Berlin-based type foundry) are illustrated (Figure 6) – Extra Light, Book, Medium, Heavy, and Super.

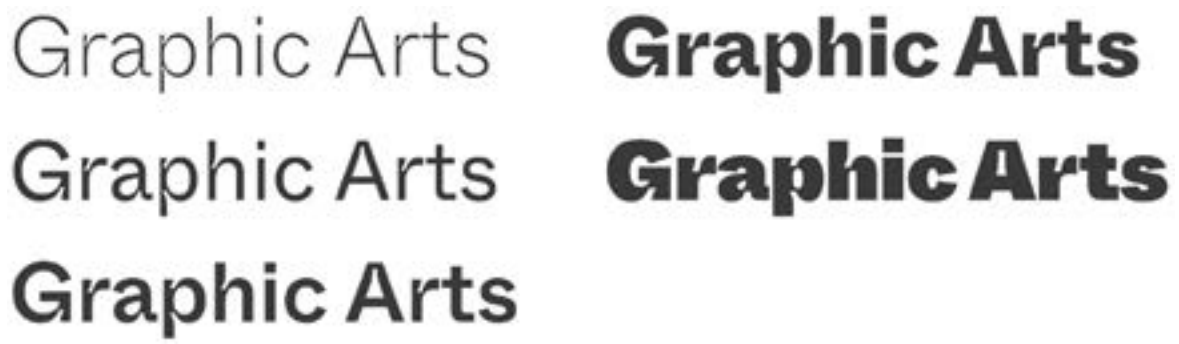

Figure 6: Example of ink traps in various widths of Whyte Inktrap typeface.

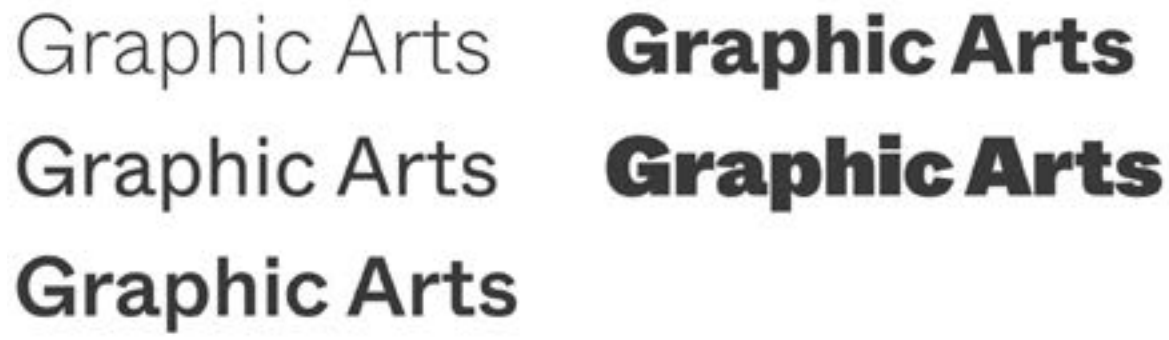

Figure 7: Example of text set in the same widths of Whyte typeface, without inktraps.

The differences in visibility and visual impact of the ink traps are distinctly apparent across different weights, particularly when contrasted with the identical text set in Whyte, the original typeface devoid of ink traps (Figure 7).

3. INK TRAPS TODAY

Despite various design approaches and purposes of ink traps, which originated from different technological contexts, and acknowledging that many issues inherent to older printing technologies are no longer relevant in modern practice, the geometric and stylistic forms developed through these adaptations continue to retain significance. Certain complex letterforms, notably those involving wide junctions such as the letters M and W, feature stroke connections that can appear visually heavier or bulkier due to the increased concentration of black in these areas. These optical effects can sometimes hinder overall legibility or visual harmony. To mitigate such visual weight, typographers and designers may employ techniques such as separating stroke junctions to spread out the black surface, thereby widening the entire character — a solution which, while effective, may not always be desirable. Alternatively, incisions at the junctions can serve as an optical correction, minimising perceived heaviness without altering the overall proportion of the letterform. Although originally devised as technical solutions to address ink spreading and smudging issues in traditional printing, these modifications today predominantly function as optical adjustments, enhancing the visual balance and readability of typefaces

across various uses and sizes [5].
Beyond their original functional purpose, ink traps in contemporary typography are increasingly employed as stylistic elements. Especially in display typefaces, they serve as prominent visual features which contribute to the overall look and feel of the design, highlighting their evolution from technical solutions to intentional aesthetic accents.
The application of ink traps as a purely aesthetic element has become increasingly prominent in the context of logo design, where their visual impact often serves as a distinctive stylistic feature. An illustrative example is the AVU Custom typeface [6], which employs ink traps as a fundamental element within its design framework, directly influencing the formation and recognition of the logo mark (Figure 8).
This typeface was designed within the Heavyweight Digital Type Foundry in 2019 explicitly for the rebranding of the visual identity of the Academy of Fine Arts in Prague, on the occasion of the 220th anniversary of the Academy [6]. In the previous logo, a heart motif was incorporated, embodying a core symbolic element, which the design team sought to preserve in the redesign and systematically integrate into the entire visual communication system, beginning with the logo itself (Figure 9).

Figure 8: AVU Variable typeface, by Jan Horčík and Filip Matějíček at Heavyweight Digital Type Foundry [6]

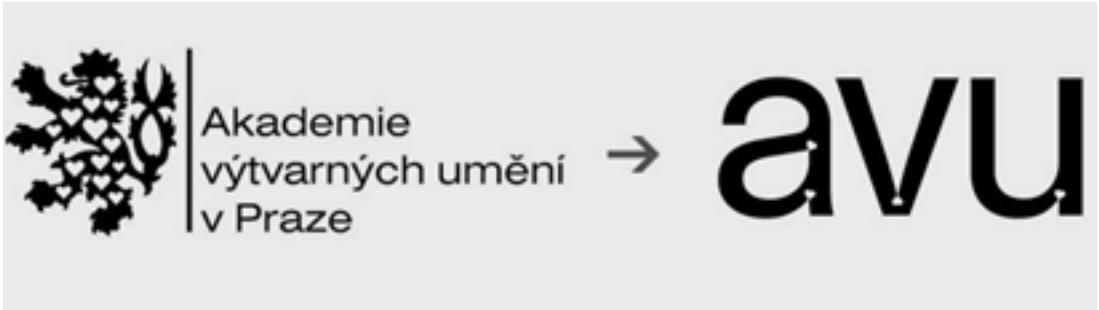

Figure 9: Redesign of AVU logo, with the retention of heart motif [6]

Figure 10: Characteristic typographic details [6]

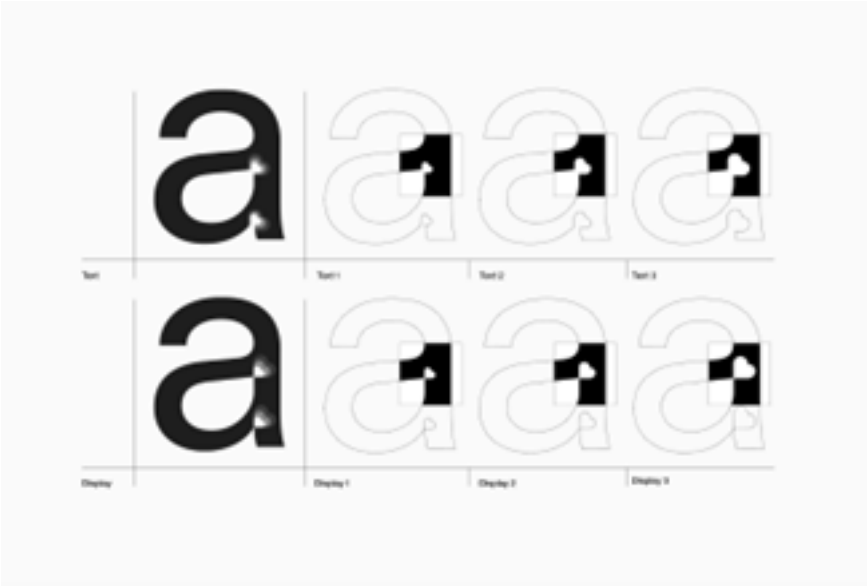

Figure 11: Characteristic typographic details in various size variations, intended for use in different situations and applications [6]

The innovative solution involved modifying the letterforms to include ink traps shaped as hearts (Figure 10), which remain visually identifiable at larger font sizes, intended for use in various situations and applications as a variable font (Figure 11). At reduced scales, although the specific heart shape becomes less immediate, the ink traps still function as compelling visual highlights, contributing both to the aesthetic appeal and the identity coherence of the overall brand system [6].

4. INDIVIDUALISED INK TRAP TYPEFACE DESIGN IN THE EXPERIMENTAL WORK

For the purposes of logo design, a modern sans-serif typeface with emphasised ink traps was created (Figure 12). Figure 12 shows the redesign of the Franck company brand logo, using the designed typeface.

Figure 12: Redesigned logo for the Franck brand with individualised ink trap typeface design

The design of an individualised typeface for a logo featuring prominent ink traps is driven by both functional and aesthetic considerations. Designing a customised typeface with strategically integrated ink traps ensures optimal print quality by minimising ink bleed and preserving sharpness and clarity at various sizes and printing techniques.

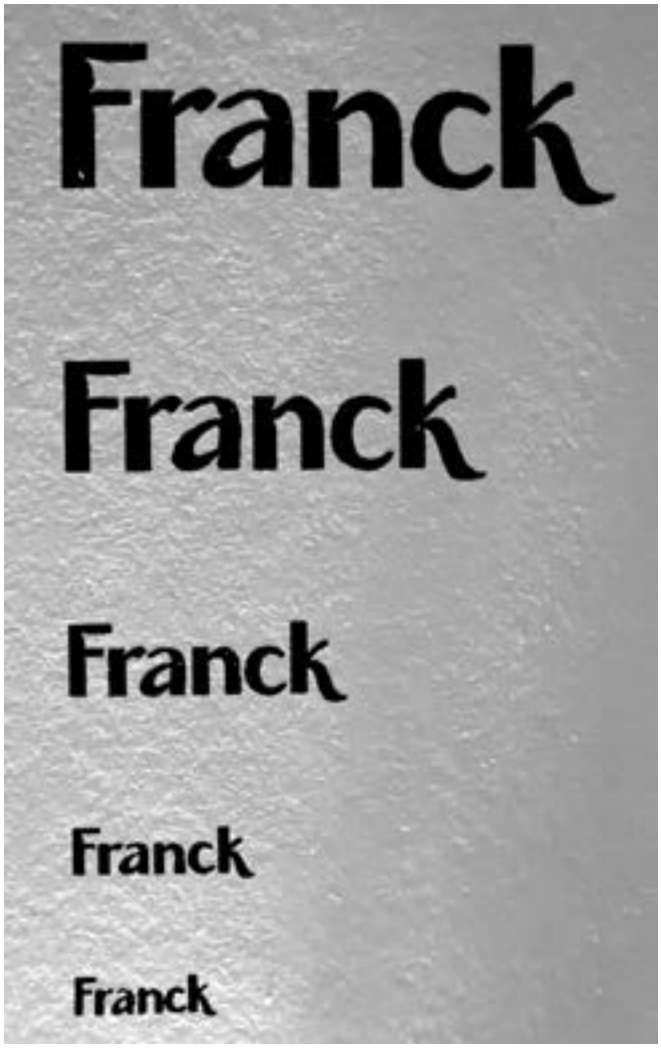

Figure 13: The legibility testing of the designed typeface at the 10 pt, 8 pt, 6 pt, 4 pt and 2 pt font sizes

In the experimental part of the work, the legibility testing of the typeface for the 10 pt, 8 pt, 6 pt, 4 pt and 2 pt font sizes was carried out on a digital press Konica Minolta BIZHUB C3321i, on plain 80 g/m^2 paper (Figure 13).

5. RESULTS AND DISCUSSION

The experimental part — the readability assessment of the individualised typeface for the rebranding of the Franck logo across various typographic sizes (10 pt, 8 pt, 6 pt, 4 pt, and 2 pt) — demonstrated the potential for application of custom-made typography in contexts where legibility may be compromised yet remains crucial, such as on packaging labels and declarations. It is evident that at sizes of 6 pt and smaller, ink traps virtually disappear, thereby improving readability and reducing text smudging. At sizes of 8 pt and larger, ink traps remain visible, maintaining their role as stylistic design elements.

Tailoring the typeface to include ink traps enhances the logo's visual distinctiveness, integrating functional necessity with brand identity. This approach allows for a harmonious balance between technical performance and aesthetic appeal, resulting in a unique, reliable typographic solution which sustains its legibility and visual integrity across diverse printing conditions.

One of the specific situations where the usefulness of typographic fonts with ink traps becomes evident is in the use of microtext. The integration of microtext within packaging design serves as an advanced security feature aimed at combating counterfeiting and unauthorised reproductions [7]. Microtext enhances packaging security by incorporating tiny, magnification-only legible fonts that are difficult to reproduce, relying on precise typographic design and high-resolution printing techniques.

When combined with strategically integrated ink traps, these features help prevent ink bleed and spreading at small sizes, ensuring sharpness, clarity, and legibility under magnification. Ink traps also reduce visual noise and improve contrast against complex backgrounds, facilitating accurate verification. This combination creates a subtle but highly effective security element that maintains aesthetic appeal, boosts anti-counterfeiting measures, and ensures durability across various printing substrates.

6. CONCLUSION

The findings of the article Ink traps: Beyond Functionality and Into Expression highlight that ink traps play a significant role in the design of typefaces, not only within the historical context of printing but also in contemporary typography. Although originally developed to control ink spread and improve legibility on lower-quality papers, ink traps have evolved into aesthetic elements which contribute to the character and recognisability of fonts. Analysing different approaches to ink trap design reveals how they can serve as technical tools in challenging printing conditions, as well as stylistic details shaping the identity of typefaces. The analysed typefaces exhibit a diverse array of ink trap applications, ranging from functional implementations across different typographic sizes in packaging to artistic interpretations. In contemporary design contexts, ink traps augment functionality while simultaneously enhancing the visual appeal of text. Consequently, they remain relevant in modern typography, encouraging designers to think creatively and innovate. Ultimately, their role extends beyond a technical fix to become an important component in the formal and aesthetic dimensions of type design.

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PROFESSIONAL PAPER

SUSTAINABLE REDESIGN OF FRUIT DRINK PACKAGING ON THE SLOVENIAN MARKET

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ABSTRACT

Packaging plays a crucial role when entering the market, as it is a key factor in attracting consumers and making the brand recognisable. In the fruit juice industry, effective packaging must not only attract attention but also communicate the contents of the product clearly and attractively. Graphic elements have a major impact on the consumer's perception of freshness, quality and taste. This study analyses the current state of fruit juice packaging on the Slovenian market, focusing on the materials and shapes used and the prevailing trends in packaging design. The findings from this analysis were used to develop a comprehensive packaging solution for a newly created fruit juice brand. The research process included a market analysis and the design of a brand identity that had to follow the right steps and settings of graphic prepress. The focus was on creating a visually appealing and recognisable design that aligned with the brand's values. In addition, environmental aspects were an integral part of the project to ensure that the packaging reflected a commitment to sustainability and environmental responsibility. The result of this study is a range of fruit juices with innovative and sustainable packaging designs. These solutions are not only aesthetically pleasing but also address environmental challenges and show how effective packaging can combine market competitiveness with sustainable development.

Keywords: fruit juice packaging, sustainable design, graphic prepress, brand identity.

1. INTRODUCTION

In contemporary society, consumers are becoming increasingly aware of the negative effects of fast-paced and stressful lifestyle on overall health [1]. As a result, there is a growing emphasis not only on regular physical activity but also on maintaining a diet rich in fruits and vegetables. One popular dietary choice that fits in with this trend is the consumption of fruit juices, which are recognised as valuable sources of important nutrients and vitamins. Although fruit juices are sometimes criticised for their sugar content, it is important that consumers continue to perceive them as healthy and tasty options. When consumed in moderation, fruit juices provide important vitamins and minerals that support general health and well-being [2]. They also contribute to hydration and provide a convenient way to increase daily fruit intake. This growing health awareness is reflected in packaging design, which plays a crucial role in attracting consumer attention and influencing purchasing decisions [3]. Packaging that effectively emphasises the product's natural ingredients – such as the absence of added sugars and preservatives – is essential for communicating health-related benefits. Clear communication of attributes such as high vitamin content, freshness, and natural flavour is crucial to appeal to health-conscious consumers. The beverage industry is one of the leading sectors experiencing significant investment aimed at expansion and technological progress. The packaging of still and carbonated beverages is a technically demanding segment within the packaging industry. Recent technological innovations in this area have enabled the development of more sustainable and functional

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packaging solutions [4, 5]. These advances not only improve the freshness and quality of products, but also help to reduce the environmental impact of packaging. In addition, improved packaging technologies play a key role in preserving the nutritional value and flavour of beverages, thus increasing consumer satisfaction. The aim of this research was to analyse the current state of fruit juice packaging in the Slovenian market, focusing on the materials and structural forms used and the prevailing trends in packaging design. Therefore, the research focused on developing a visually appealing and recognisable packaging design that aligns with the brand's values while taking into account environmental aspects to reflect a strong commitment to sustainability – resulting in a range of fruit juices with innovative and eco-friendly packaging solutions. New, sustainable packaging solutions were designed based on the analysed packaging on the Slovenian market.

2. EXPERIMENTAL

2.1. Materials and methods

A Lenovo IdeaPad S540 computer (Lenovo Group Limited, China) with Microsoft Word and PowerPoint software (Microsoft Corporation, United States of America) was used to conduct this study. In addition, a Wacom Intuos graphics tablet (Wacom Co,. Ltd., Japan) and an iPad (Apple Inc., United States of America) were used, as well as computer programmes for designing the packaging such as Adobe Illustrator, InDesign and Photoshop (Adobe Inc., United States of America).

2.2. Market analysis

There is a large selection of fruit drinks from various brands on the Slovenian market. The first step was to identify the key brands that are highly recognisable and most popular with consumers. After analysing data from stores in Slovenia such as Spar, Mercator and the Slovenian Consumer Association, the following brands were identified for 0,5 l and 1l packaging: Fructal fruit juice (Fructal d. o. o., Slovenia), Dana fruit juice (Dana, proizvodnja in prodaja pijač, d. o. o., Slovenia), Rauch Fruchtsaft (Rauch Fruchtsäfte GmbH & Co OG, Austria, P.E. RAUCH, Slovenia), other fruit juices from store brands (Mercator d. o. o., Slovenia and SPAR Slovenija d. o. o.) were shortlisted and analysed. First, the data on the packaging types were collected and categorised (type of packaging for each quantity of fruit, e.g. glass, tetrapack, PET, etc.). Then each packaging sample was analysed in terms of the use of colour schemes, placement of brands or logos and typographic elements. The analysis was carried out on 30 samples. Based on the insights gained from this analysis, the design process for our own brand logo was initiated, as described in the following subchapter.

2.3. Designing the brand logo and packaging label

Before the juice packaging was designed, a brand was created under which the product would be sold. Although the name Gloria was initially considered, market research revealed that this name was already in use in the beverage industry abroad, so the company was renamed "Zvezda". The name, which means "star", was chosen to symbolise prestige, elegance and excellence – values that were to be reflected in the product. Customers should feel that every sip of the juice is unique and of high quality. The brand communicated a commitment to premium taste and sustainability. Eco-friendly, recyclable packaging was used, and emphasis was placed on environmentally sound practises to reduce impact and preserve the planet for future generations. The logo design process began with sketches and font selection (Figure 1), aiming for a typographic brand mark consisting of only let-

ters. Once the desired font was selected, slight adjustments were made, and the logo was redesigned. The result was a clean, minimalist logo that would appeal to consumers.

Figure 1: Examples of typography for designed brand

CATEckmann in the Regular version was chosen as the font for the brand logo. General Sans Variable in the Regular, Semibold and Bold versions was used for the secondary font. The final logos and the typography used for the brand are shown in Figure 2.

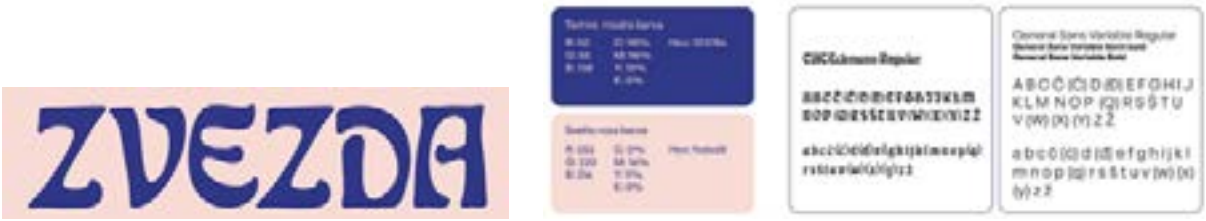


Figure 2: Selected typography and basic colours for designed brand

3. RESULTS AND DISCUSSION

3.1. Results of the market analysis

The analysis of fruit juice packaging in Slovenia covered four brand categories: Fructal, Dana, Rauch and store brands. It focussed on the materials used in plastic, cardboard, glass and metal packaging, as well as laminated branded packaging such as Tetra Pak. Fructal, Dana, and Rauch use polyethylene (PET) for its durability and recyclability, while other brands use plastic less consistently. For carton packaging, cardboard with polypropylene (PP) is common for all brands. Fructal and Dana offer glass packaging in combination with other packaging materials such as paper and steel, while Rauch does not. Aluminium cans are used by Fructal, Dana and Rauch, but not by store brands. Overall, the market prefers recyclable materials such as PET, Tetra Pak and aluminium, reflecting the trend towards more sustainable packaging.

3.2. Final designs, packaging and brand identity

As the company focuses on ecological development, recycling and reuse, the packaging was designed accordingly. First, the drink was developed the name, the colour palette, the flavour of the drink and the packaging types were chosen. The product carried the same brand name to increase recognition and used consistent fonts and colours. A clear, linear font conveys clarity and elegance. Every design element – from the materials to the col-

ours – was carefully chosen to reflect quality. Bright primary colours stood for freshness, while secondary colours provided sophistication, all united by black to symbolise prestige.

a) b)

Figure 3: Final label designs for the Zvezda brand a) apple drink and b) strawberry drink

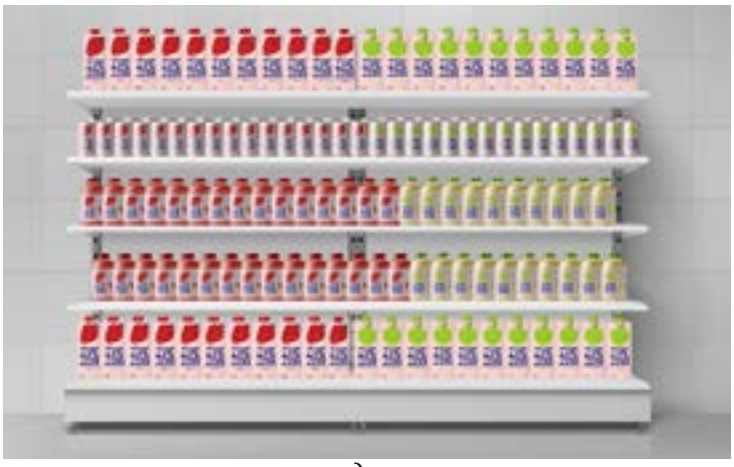
The final packaging label design followed the current colour trends and was designed to stand out on store shelves and attract consumers (Figure 3). As the brand was designed for the Slovenian market, the language on the labels is Slovenian.

a) b) c)

d) e) f)

Figure 4: Final packaging for the Zvezda brand a) apple drink can, b) apple drink cardboard packaging, c) apple drink glass packaging, d) strawberry drink can, e) strawberry drink cardboard packaging and f) strawberry drink glass packaging

Figures 4 (a–f) show the final packaging of the Zvezda brand. The Zvezda drink is also designed to attract customers' attention on the shelf (Figure 5a). With unique packaging, a refreshing flavour and a clear message of sustainability (Figure 5b-c), we will inspire consumers and encourage them to buy.



a)

b)

c)

Figure 5: a) Zvezda products on the store shelf, b) examples of advertising designed brand on the street and c) advertising on social media

4. CONCLUSION

Research in the Slovenian fruit drink market shows a growing consumer preference for brands that demonstrate sustainability and offer quality products. Companies need to focus on innovative packaging solutions that appeal to consumers while contributing to environmental protection. Whilst plastic continues to dominate due to its flexibility and cost efficiency, there is an increasing shift towards sustainable alternatives, particularly Tetra Pak cartons, which help to reduce environmental impact. Cans and bottles are also widely used, with packaging design incorporating elements such as bright colours, minimalism and retro accents, as well as technological innovations such as QR codes. Fructal is leading the way in offering diverse, consumer-friendly packaging, while Spar and Dana could improve their designs even further. Our own packaging concept follows the principles of sustainability and combines minimalism, retro ambience and intelligent functionality. By

using four primary colours, we wanted to evoke a sense of calm and elegance and ensure that our product stands out on the shelf and appeals to consumers.
Although the research provides valuable insights into packaging trends in the Slovenian fruit drink market, several limitations must be acknowledged. Firstly, the results are context-specific and may not be transferable to other markets with different cultural, economic, or regulatory conditions. Secondly, the analysis focussed primarily on visual and structural aspects of the packaging, which may have overlooked deeper consumer motivations such as brand loyalty, perceived product quality or environmental awareness beyond the packaging. Furthermore, the research was based on observational data and secondary sources rather than direct consumer feedback or quantitative metrics, which could limit the robustness of the conclusions. Finally, the rapid development of sustainable materials and packaging technologies suggests that current trends can change quickly, requiring ongoing research to maintain relevance.

Acknowledgement:

The authors acknowledge the financial support from the Slovenian Research Agency (research core funding No. P2-0450).

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ORIGINAL SCIENTIFIC PAPER

THE FRAGILITY OF COLOR MEMORY: FACTORS INFLUENCING RECALL AND RECOGNITION

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ABSTRACT

Colour is a psychophysical property that influences all aspects of daily human life. Since it is deeply rooted in human psychology, colour perception varies from person to person, directly influencing how it is stored in memory. The widespread use of colour and its many advantages drive research on colour memory and fuel interest in its improvement. While people can easily distinguish even subtle differences between adjacent colours, recalling a specific shade becomes challenging when colours are separated either temporally or spatially. This suggests that human colour memory is relatively weak and susceptible to various external influences. This study aimed to investigate the factors affecting colour memory, examine how people remember colours, and determine what reference points they rely on most during recall. Through three experiments, the research explored the memory for background colours with displayed information, the memory of multi-colored patterns, and the recall of familiar colours after a time delay. The findings indicate that colour memory is inherently weak, deteriorates over time, and often relies more on recognising patterns than accurately recalling the perceived colour itself.

Keywords: colour memory, colour perception, visual cognition

1. INTRODUCTION

Everything based on perception and personal experience cannot be the same for every individual, and the same applies to color [1]. Each person perceives and describes color in their own unique way. Depending on the aspect from which colour is considered—physical or psychophysical—it can be viewed either as a physical stimulus, representing visible radiation, or as a psychological experience of color that arises as a result of converting the initial light signal into a neural signal, which is then processed in the brain [2]. The key elements involved in the perception of color include the light source, the object, and the observer. Color is commonly described using three standard attributes: hue, saturation, and lightness [3]. When a person observes a color, even the slightest difference between it and another color—no matter how similar—can be noticed. However, difficulties arise when these colors are separated in some way, whether in time or space, making it challenging to recall the exact shade previously seen [4]. Based on this, it can be concluded that human color memory is relatively weak and is undoubtedly influenced by various external factors. Some of these include visual perception and attention, as well as memory, which is generally divided into three stages: working memory, short-term memory, and long-term memory. Additionally, human biology—such as genetic predisposition, age, and intelligence—plays an important role, as do external factors like environment, lighting, and background. Previous research has also highlighted the importance of fatigue and drowsiness in the context of color memory, showing that lack of sleep leads to reduced levels of attention and concentration, making it harder to focus and stay alert [5]. The aim of this paper is to investigate how people remember colors and how the hue itself influences that process. The results will reveal what people rely on most when recalling colors and provide deeper insight into the mechanisms behind color memory. Through practical

experiments divided into three parts, the following will be explored: color memory of a sample with a time delay, color memory of UNO game card backgrounds and color memory of brand logo backgrounds.
Based on the theoretical background and previous research, we assume that the accuracy of color memory tends to decrease when there is a time delay between the observation and the reproduction of the color sample. It is also expected that certain hues—especially those with higher saturation or stronger contrast—will be more easily remembered than others. In addition, individual factors such as fatigue, attention, and prior exposure to color stimuli are likely to influence how well colors are recalled. Finally, it is assumed that people rely not only on the physical characteristics of color but also on subjective impressions and contextual cues when trying to remember what they have seen.

2. EXPERIMENTAL PART

The experiments were conducted on a group of 55 participants. The participants were undergraduate students from the University of Zagreb Faculty of Graphic Arts, divided according to their program specialization — 39 in design and 16 in the technical-technological field. All participants previously completed the Farnsworth-Munsell 100 Hue Test in order to assess their ability to distinguish between color hues, which is crucial for the reliability of the research results. Based on the test results, participants were categorized into two groups: 26 superior (with exceptionally high precision in distinguishing color hues) and 28 average (with a standard level of hue discrimination ability).
All materials used in the first experiment were prepared using Adobe Illustrator. The second experiment utilised UNO game cards, while the third was prepared using Adobe Illustrator, Google Forms, and Adobe InDesign. The first two experiments were conducted under D50 lighting in an X-Rite The Judge II Viewing Booth. D50 lighting was used to simulate daylight conditions. The third experiment was digitally prepared and also conducted in the same booth for its neutral grey background, but without lighting, to minimise the reflection of external light on the laptop screen that participants observed. The materials for the first two experiments were previously printed and physically presented on paper, while the third experiment was displayed on the same MacBook Air laptop to eliminate differences in monitor calibration.

3. RESULTS AND DISCUSSION

3.1. Colour sample memory with time delay

It is assumed that when faced with the task of memorizing a set of information, people seek patterns or associations to facilitate memory retention. There is also a certain suspicion that some colors attract more attention than others. Beyond the memorization strategies themselves, a key question is how long this information can persist in our minds and whether it depends on the passage of time.
The aim of this experiment is to identify patterns in how people memorize a specific color arrangement, to examine whether certain colors significantly attract more attention from observers, and to explore how the passage of time influences the accuracy of memory. The experiment consisted of two predefined color grids, one empty grid, and 9 color squares (green, orange, brown, blue, pink, yellow, purple, gray, and red).
The specific arrangements of the two color grids were not based on a theoretical model or prior empirical findings, but were instead designed to meet several practical and methodological criteria: (1) to ensure a balanced distribution of colors across positions, (2) to avoid any recognizable pattern or symmetry that could facilitate memorization, and (3) to maintain visual complexity at a comparable level in both grids. This approach was chosen

to support the primary research goals while minimizing confounding variables.

Participants were first shown Grid 1 (Figure 1) for 10 seconds in a controlled booth, with clear instructions to memorize the color layout that they would later need to reconstruct. After 10 seconds and the removal of the grid, they were given an empty grid and 9 cut-out colored squares matching those from the observed layout. Their task was to place the squares in the same arrangement they had seen 10 seconds earlier. There was no time limit for this task. Next, Grid 2 (Figure 2) was shown for 10 seconds, after which participants had to wait for one minute. Following the delay, they were given the same empty grid and color squares and asked to reconstruct the arrangement of Grid 2 from memory.

Figure 1: Grid 1

Figure 2: Grid 2

The following tables (Tables 1 and 2) show the total number of errors made by participants in Grid 1 and then in Grid 2, where:
• E indicates the total number of errors made in the grid,
• P indicates the number of participants who made that number of errors,
• % indicates the percentage of participants who made that number of errors.

Table 1: Total number of errors in Grid 1.

E	**0**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
P	16	14	7	11	5	1	1	0	0
%	29,09	25,45	12,73	20	9,09	1,82	1,82	0	0

Table 2: Total number of errors in Grid 2.

E	0	2	3	4	5	6	7	8	9
P	6	12	6	7	5	9	1	3	6
%	10,91	21,82	10,91	12,73	9,09	16,36	1,82	5,45	10,91

The Grid 1 was accurately recreated by 16 participants, or 29.09%, while the second grid was accurately recreated by 6 participants, or 10.91%. Some of the most common responses to the question of how they memorized the grid pattern included: by columns, by rows, corners, counting rhymes, hot–cold strategy, with the most frequent response being "three by three." The majority of participants who did not recall all elements correctly stated that they had memorized a specific square, which then helped them infer the surrounding or opposite ones. This was usually the first square, the center, or a square with a distinctive color. Two participants reported that three squares in the first grid reminded them of the German flag, while one participant said she remembered that in the Grid 2 "the colors on the left were ugly and on the right were pretty." In the Grid 1, the gray square was most frequently remembered, while in the Grid 2, it was the red one. The color with the fewest correct answers in the Grid 1 was blue, and in the Grid 2, yellow.

3.2. Memory for the background colour of UNO Playing Cards

It is assumed that people tend to give preference to warm colors over cool ones, but this remains scientifically unproven and can therefore only be considered speculation. We can also assume that individuals categorise information in certain ways to aid memory. Since each person processes information differently, it is interesting to examine which strategies people use in different situations. When attention is directed toward a specific type of information, as in this case—the number—the question arises as to how much, or even whether, individuals can focus on the background [6,7].

The aim of this experiment is to investigate the influence of background colour on memory and to determine to what extent it affects perception when a sequence of numbers is presented on different backgrounds. In addition, the impact of the response options will be examined. The advantage of using UNO cards lies in their identical design, differing only in background colour. This increases the likelihood of a participant being misled by a card with the same colour but a different number, or vice versa. Furthermore, the experiment will explore the assumption that warm colours are favoured over cool colours.
The experiment consisted of a deck of UNO cards, eight of which were pre-selected and arranged into a specific sequence to be observed. The sequence included cards numbered from 1 to 8, with each of the four existing colours appearing twice. Cards with the numbers 1 and 6 were blue, numbers 2 and 5 were green, numbers 3 and 4 were yellow, and numbers 7 and 8 were red. The remaining cards were organised by number, and for each number, all four colour variations—red, yellow, blue, and green—were prepared.
During the experiment, participants were presented with a randomly shuffled but always identical predefined sequence of eight cards (1 to 8). They observed this sequence for 15 seconds. Afterwards, the cards were removed, and participants were shown, one number at a time, four cards of that number in all four colour variations. The cards were presented sequentially from 1 to 8. For each number, participants were asked to identify which of the four cards had appeared in the previously observed sequence.

Figure 3: Observed sequence of cards

The following table (Table 3) shows the total number of correct responses for the entire sequence of cards, where:

- C denotes the total number of correct responses,
- P denotes the number of participants who achieved that number of correct responses,
- % indicates the percentage of participants who achieved that number of correct responses.

Table 3: Total number of correct answers in the UNO card sequence.

C	0	1	2	3	4	5	6	7	8
P	1	3	4	5	10	4	6	7	15
%	1,82	5,45	7,27	9,09	18,18	7,27	10,91	12,73	27,27

An analysis of the results from the second experiment (Table 3) shows that 15 participants, or 27.27%, accurately recalled the entire sequence of cards. Seven participants made only one mistake. Six participants correctly remembered 6 cards, four participants remembered 5 correctly, ten participants remembered 4, and five participants remembered 3. Four participants had only two correct answers, three had just one, and one participant did not correctly recall a single card.

When asked about their memorization strategy, more than 80% of participants reported that they paired numbers based on color. For example, for the blue color, they remembered either 1 and 6, or combinations such as 16 or 61. Another commonly reported strategy was a counting rhyme or a sequential approach from 1 to 8; several participants even asked which color was mentioned last while responding, in order to recall where they had stopped. The only memorization-related answer recorded apart from these two or their variations was "I don't know." In other words, some participants were not even aware of how exactly they remembered the sequence, and those individuals tended to have partially correct results.

3.3. Memory for brand background color

It is assumed that when multiple shades of a color are presented simultaneously in the same location, people can easily perceive the differences between them. However, when these shades are separated in time or space, distinguishing between them becomes more difficult. Thus, when a particular shade is initially observed and later presented among other, similar shades, many people may struggle to correctly identify the original one. This experiment also relies on the assumption that warm colors are better remembered than cool ones. Additionally, it can be assumed that familiar shades are more easily recognized, especially those we have encountered more frequently.

The aim of this experiment is to investigate the recognizability of a brand's signature color. In the field of design, this information can be highly valuable for marketing pur-

poses, brand recognition, and attracting clients. The study will examine patterns in brand color recognition and assess how easily a brand color can be identified once its logo and associated elements are removed. The experiment is conducted digitally, reflecting the contemporary trend of content consumption on screens, meaning that any potential design will primarily be viewed in digital format. Therefore, the recognizability of color on screens is being examined. The experiment was implemented as a Google Forms survey, featuring colors from three different brands: Coca-Cola (Figure 5), Tiffany & Co. (Figure 7), and Barbie (Figure 9). Each question was structured so that the first page displayed a photo of the brand logo on its signature background color. On the following page, participants were shown that color along with four similar shades in square swatches, and were asked to select the color they had observed for 10 seconds on a laptop placed in a darkened booth. The colorimetric difference, or ΔEab, represents the difference between colors in the CIE color system [7]. It is calculated as the distance between the coordinates of two colors being compared. This value is derived from the mean difference in the L*, a*, and b* values of the two colors. The resulting values are interpreted as follows:

- ΔE < 0.2: invisible difference
- ΔE = 0.2–1: perceptible difference
- ΔE = 1–3: visible difference
- ΔE = 3–6: clearly visible difference
- ΔE > 6: obvious difference

Measurement of the three brand colors (Figures 6, 8, and 10) shows that the differences between the original brand color and the alternative shades fall within the ranges of clearly visible and obvious differences.

Figure 4: Coca-Cola logo on the background

Figure 5: Shades of red options, the correct answer is Option 4.

Figure 6: Tiffany & Co. logo on the background

Figure 7: Shades of blue options, the correct answer is Option 5

Figure 8: Barbie logo on the background

Figure 9: Shades of blue options, the correct answer is Option 3.

The following table (Table 4) shows the total number of responses for all three brands:

- S denotes the selected option from the five provided,
- % indicates the percentage of participants who chose that option.

Table 4: Total number of correct answers for brands

S	1	%	2	%	3	%	4	%	5	%
Coca-cola	0	0	5	9,1	16	29,1	31	56,44	3	5,5
Tiffany & CO	12	21,8	0	0	1	1,8	22	40	20	26,4
Barbie	1	1,8	3	5,5	9	16,4	31	56,4	11	20

From Table 4, it is evident that 31 participants, or 56.4%, selected the correct option for the red colour. Option 1 was not chosen by any participant. Option 2 was selected by 5

participants (9.1%), option 3 by 16 participants (29.1%), and option 5 by 3 participants (5.5%). For the blue colour associated with Tiffany & Co., the correct option was selected by 20 participants, representing 36.4%. Option 1 was chosen by 12 participants (21.8%), while option 2 was not selected by anyone. Option 3 was chosen by 1 participant (1.8%), and option 4 by 22 participants, accounting for 40%. Regarding the pink colour, only 9 participants selected the correct option, which accounts for 16.4%. Option 1 was chosen by 1 participant (1.8%), and option 2 by 3 participants (5.5%). Option 4 was the most popular, with 31 responses (56.4%), while option 5 was selected by 11 participants (20%).

4. CONCLUSION

The first experiment confirms the hypothesis that human colour memory is quite weak, as the majority of participants—70.91%—were unable to accurately recreate the grid after just 10 seconds. Furthermore, when comparing the total errors between the first and second grids, the experiment also supports the assumption that the more time passes, the weaker our colour memory becomes. While 29.09% of participants successfully recreated the first grid, only 10.91% managed to recreate the second one, which means that only 37.5% of those who were successful in the first attempt remained successful. Additionally, the results suggest that attention and colour preference play an important role in colour memory, as most participants remembered specific parts of the grid that had caught their attention. It can also be concluded that people rely more on patterns and associations when trying to remember a set of colours than on the colours themselves.

The second experiment confirms the assumption that people categorise information—that is, over 80% of participants grouped numbers of the same colour together, making it easier to remember the sequence. When comparing results between individual colours, no significant difference was found between warm and cool tones. On average, blue performed best, followed by red, with green and yellow scoring equally. The strong result for blue may be attributed to the fact that the number 1 card was also blue, and it had the highest success rate. It could be assumed that other colours placed in that position might also lead to better memorisation. According to participants' comments, yellow and green were often confused and perceived as interchangeable, while blue and red left a stronger impression and stood out more. The offered card selection further confused several participants; some initially selected the correct answer but ultimately changed it to an incorrect one. Interestingly, all such participants eventually chose the red card, even though it was incorrect.

The third experiment confirms the assumption that human memory for specific color shades is quite poor, and when a shade is placed among similar ones, very few people can easily identify the correct one. Results show that the Coca-Cola red was significantly more accurately recognized than the other two brand colors. This can likely be attributed to the fact that participants had encountered it more frequently in everyday life prior to the experiment, and also to the fact that red is generally considered the most eye-catching and appealing color.

The aim of this study was to expand knowledge and stimulate interest in the complex topic of color memory. The results clearly demonstrate that various factors influence color memory, which, by nature, is highly subjective and complex. Consequently, it remains difficult to determine with precision how color memory functions for each individual. Despite the existing body of knowledge and the experiments conducted in this study, much about color memory remains unknown, leaving significant room for further research and development. Future studies could explore how different environments and situations influence color memory, as well as examine how color memory may vary between individuals with color vision deficiencies or those with different cognitive abilities.

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ORIGINAL SCIENTIFIC PAPER

THE IMPACT OF BACKGROUND COLOR AND TRANSPARENCY ON TEXT READABILITY

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ABSTRACT

The choice of text color and its background plays a key role in enhancing the overall impression and readability of the text. The perception of contrast between the background and the text is significantly influenced by the background's transparency. Transparency of elements in design plays a crucial role in achieving balanced and effective visual communication. The purpose of this paper is to investigate how different levels of background transparency, which also affects the contrast between text color and background color, influence the user's ability to read textual content in printed media, specifically in a catalog. For the purpose of the research, a catalog smaller than A5 format, with exact dimensions of 13.4 x 17.5 cm, was created. The catalog consists of eight pages, including the cover. Participants read excerpts from the catalog aloud while positioned approximately 30 centimeters away from it. The analysis showed that transparency had a varying impact on readability depending on the text color, with examples of white text on a blue background being overall a more readable combination. All collected data was processed on a PC using Microsoft Word, Excel, and DaVinci Resolve 18. The obtained results can improve the readability of textual content in printed media and provide guidelines for graphic designers on how to format textual content in printed media.

Keywords: transparency; contrast; text; reading speed; readability

1. INTRODUCTION

In graphic design, the terms „transparency" and „opacity" are used as synonyms. However, opacity measures how much light can pass through an element. The level of opacity of an element is directly related to how transparent the object is. In other words, transparency measures how „see-through" an object is. The more „see-through" an object is, the higher its transparency. [1]

Transparency is important in graphic design because it adds depth and allows layered placement of elements (typography, photos, shapes). It also enables interaction between design elements. [2] There are many examples of designs that use transparency very successfully, both in digital and printed media.

When a color's transparency is increased, it becomes less intense and more influenced by the color or image beneath it. This way, colors blend and create new shades and effects. [3][4] All colors have positive and negative effects on people. Usually, brighter and vivid tones are seen as positive, while darker tones are seen as negative.

The modern theory of colors was described by Sir Isaac Newton in the 17th century. He made his discovery by passing white light through a prism, and the output light was split into a spectrum of colors. [5] Color is also part of human consciousness and subconsciousness and can significantly affect us and our behavior. [6] The foundation of visual communication in design consists of color and typography, as color emphasizes text but also impacts the readability of typography.

Typography is the art and science of shaping written characters, such as letters and symbols, and arranging them to create readable, attractive, and functional textual content.

With the development of technology, typography has also evolved and is now applied in various fields like the graphic industry, graphic design, and video games. [7] The goal of typography in interface design is to evoke a specific reaction or convey a certain message to the user, while the designer's aim is to ensure the interface's readability and clarity. [8] When designing text, it's important to follow certain rules. It's recommended to use two fonts: one for headings and another for the main text. Combining different fonts can be aided by mixing font types, such as pairing a serif font with a sans-serif font. [9] Numerous studies show that optimal text design can increase reading speed both on paper and on screens.

Hall and Hanna [10] examined how text and background color combinations on web pages influence readability, retention, aesthetic perception, and user behavior. Their results showed that higher contrast colors improved readability, while color combinations did not significantly impact information retention. Preferred colors such as blues and other chromatic tones were rated more aesthetically pleasing and were associated with a greater intention to purchase, with aesthetic quality strongly related to behavioral intention.

Liao and Tsai [11] investigated how different combinations of text lightness and background color affect visual comfort, recognition, and user preference on packaging labels. They found that recognition improves with greater lightness contrast, while visual comfort and preference are highest with medium levels of contrast rather than very high or very low. Their results suggest that extreme lightness differences can reduce comfort and preference, and that comfort and preference are strongly correlated with recognition performance.

Gong et al. [12] explored how background colors in digital educational materials affect comprehension and user preference among native and non-native English speakers. While background color did not significantly influence comprehension performance, preferences varied notably between groups, with native speakers favoring blue and purple and non-native speakers preferring yellow and blue. The study highlights that although comprehension remains stable across color conditions, aesthetic preferences can impact learner engagement and should be considered in the design of inclusive digital learning environments.

Cheng et al. [13] examined how font and background color combinations influence text recognition efficiency on LCD screens. They introduced the concept of Primary Color Difference (PCD) and found that greater color differences, especially green text on a black background, led to faster recognition. The study suggests that maximizing contrast through careful color selection can enhance legibility in LCD-based user interfaces.

Jiménez et al. [14] studied the impact of text and background color combinations on eye accommodation and pupil response during reading on LCD screens. They found that blue-on-red increased accommodative response, while low luminance contrast, such as white on yellow, reduced perceived legibility. Despite these effects, text-background color did not significantly affect reading speed, highlighting the importance of color selection for visual comfort in digital design.

2. EXPERIMENT

The aim of this research was to examine how different transparency values affect text readability in printed media. The assumption is that lower background transparency enables faster reading and fewer errors.

For the purpose of the research, an eight-page catalog of equal paper weight was created. The first and last pages are the catalog covers, while the six inner pages are used to test text readability. Each page consists of black or white text on a blue background. Three pages have black text on a blue background, and three pages have white text on a blue background. Besides the black or white text, the variable parameter is the background

transparency. One background has a transparency value of 0%, another 20%, and the third 50%.

2.1. Catalog design for research purposes

The catalog was created using Adobe InDesign, a tool used for designing materials such as flyers, brochures, magazines, newspapers, and books.
The catalog measures 13.4 x 17.5 cm, smaller than A5 format, and has eight pages, including the covers (Figure 1). The six inner pages contain text excerpts on the topic of internet safety.

Figure 1: Catalog's inner pages with different transparencies

The CMYK color model was used because it is primarily used in printing. The lighter background color of the catalog is C7%, M2%, Y13%, K0%, and it was used as a neutral background to test the impact of element transparency without additional influence from the background color.
The background color behind the text is blue, with C99%, M72%, Y19%, K5%, and its transparency varies, making it the main factor affecting text readability.
The red color used for icons of various objects (bug, computer, mobile phone, cloud, envelope, etc.) in the catalog's background is C8%, M100%, Y100%, K2%.

The colors used for the textual content are black (C0%, M0%, Y0%, K100%) and white (C0%, M0%, Y0%, K0%). The text color of the first, second, and third paragraphs is white, while the text color in the fourth, fifth, and sixth paragraphs is black.

2.2. Textual content in the catalog

When creating the textual content for the catalog, attention was paid to the number of words in each paragraph and the complexity of the text. Each paragraph consisted of 180 to 185 characters. The text was written in the Verdana font, size 17 pt, with a line spacing of 20 pt. The theme of all paragraphs was internet safety.

2.3. Participants and conducting measurements

This research involved 64 second-year undergraduate students from the Department of Multimedia, Design, and Application. Of the total number of participants, 29 were male and 35 were female. Selecting participants without dyslexia was crucial for this research, as their reading results could affect the final outcomes.
A printed catalog (Figure 2) was used in the testing, from which participants read the texts. Their reading was recorded using a smartphone, MIUI Global 14.0.9, with the „Recorder“ app installed on the device.

Figure 2: Printed catalog used for reading

Each participant read all six texts aloud, one after another. Two parameters analyzed were the time needed to read the texts and the number of errors during reading. After the testing, all collected data was processed on a personal computer using Microsoft Excel and DaVinci Resolve 18.

3. RESULTS AND DISCUSSION

During the testing, six different combinations of text color and background color were used, as shown in Table 1. The fourth paragraph, consisting of black text on a blue background with no transparency, proved to be the most readable combination. While reading this paragraph, participants had the fewest errors and read the text the fastest. The third paragraph, with a background transparency of 50%, had the same number of errors. It was unexpected that the results would be so good, considering that graphics visible beneath the text slightly distracted the participants. The third and first paragraphs also showed, based on average reading time, that they were combinations of text and background that were read quickly.

Table 1: Number of errors and average reading time per paragraph

Paragraph	Text and background color combination	Background transparency	Display	Average reading time	Total number of errors
Fourth	Text: Black color, Background: Blue color	0%	internet	00:10:26 s	20
Third	Text: White color, Background: Blue color	50%	internet	00:10:48 s	20
First	Text: White color, Background: Blue color	0%	internet	00:10:55 s	22
Second	Text: White color, Background: Blue color	20%	internet	00:11:55 s	25
Fifth	Text: Black color, Background: Blue color	20%	internet	00:11:24 s	32
Sixth	Text: Black color, Background: Blue color	50%	internet	00:11:05 s	34

The results of this research (Figure 3) provide significant insight into the impact of transparency on text readability in different color combinations. The analysis showed that black text on a blue background with no transparency was read the fastest and had the fewest errors. However, when black text on a blue background had some level of transparency, readability was much lower, as seen from the many errors during reading. The assumption is that the red background elements affected the participants and somehow distracted their attention.
Still, the results for white text on a blue background, which are also significant in this research, should not be overlooked.

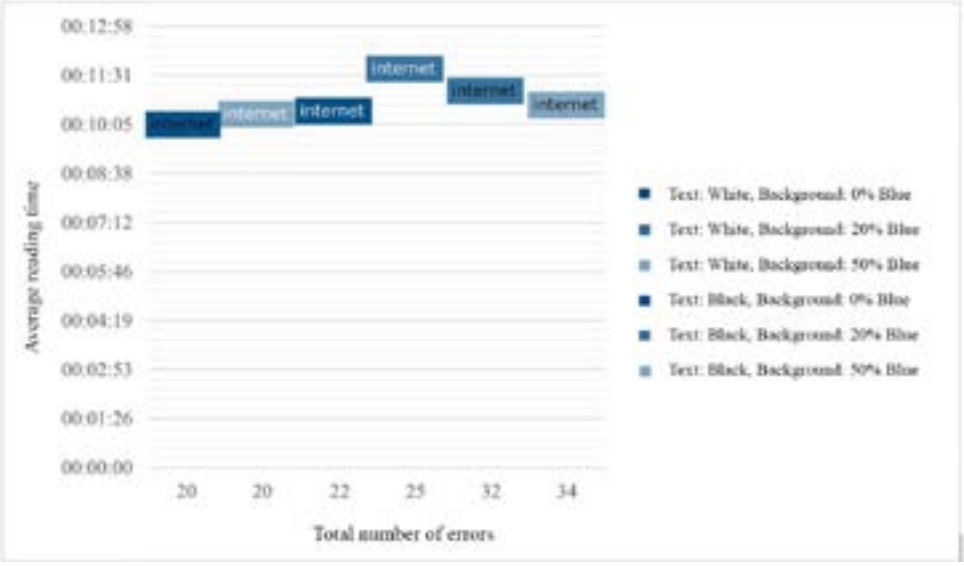

Figure 3: Relationship between average paragraph reading speed and number of errors

For this reason, an analysis was conducted in which all three white texts were grouped separately and all three black texts were grouped separately. Paragraphs with white text on a blue background had an average of 22.33 errors, while examples with black text on a blue background had 28.66 errors. This means that white text on a blue background proved to be the combination where participants made fewer errors. Results supporting white text on a blue background are presented in the dissertation [15], where, out of ten combinations of text color and background color, white text on a blue background was noticed the fastest.

4. CONCLUSION

The aim of this research was to determine the impact of background transparency on the readability of textual content. Contrary to expectations, the paragraph with the lowest contrast between text and background proved to be the most readable. Participants made the fewest errors when reading black text on a blue background and read it the fastest on average. This text and background combination had no applied transparency.
In cases where black text on a blue background had some level of transparency, readability was much lower, as evident from the many errors during reading. The assumption is that red background elements affected the participants and somehow distracted their attention.
From the analysis where all three white texts were grouped separately and all three black texts were grouped separately, it is clear that participants made fewer errors when reading white text on a blue background compared to black text on a blue background.
This advantage of white text can be attributed to its better visibility on a blue background and lower sensitivity to transparency variations.
The results confirm that background transparency significantly affects the perception of the text placed on it. Transparency of elements in design plays a major role in achieving balanced and effective visual communication. Excessive transparency can hinder the reader's ability to clearly perceive and read content without errors.
Given these findings, further exploration of transparency's role in text readability is essential to support more informed and effective design decisions.

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PROFESSIONAL PAPER

THE IMPACT OF COLOR IN LOGO DESIGN: A SURVEY-BASED STUDY OF PUBLIC OPINION ON BRAND RECOGNITION THROUGH COLOR

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ABSTRACT

This paper explores the role of color in logo design, with a particular focus on its psychological effects and impact on brand perception. The study analyzes the colors used by well-known brands as well as those most used in visual identities, considering how different hues can elicit specific emotional responses in consumers. Colors are examined not only as aesthetic elements but also as communicative tools capable of conveying a brand's values, messages and character. Special attention is given to the comparison of colors used by prominent brands in order to assess their effectiveness in establishing brand recognition and emotional connection with the target audience. As part of the research, a survey was conducted to investigate whether and to what extent, respondents could recognize selected Croatian and international logos based solely on their color. The aim of the research was to evaluate the extent to which color contributes to faster and more accurate brand identification in everyday life.

Keywords: color, logo, design, visual perception, brand

1. INTRODUCTION

Colors have long been recognized as one of the most powerful elements of design, and their importance in creating visual recognition and emotional connection with consumers is becoming increasingly evident [1]. In the context of branding, colors are not merely aesthetic components they exert a deep psychological influence on brand perception. Colors can evoke certain emotions, associations or even cultural meanings that are linked to specific hues, which can significantly shape how consumers experience and recognize brands [2].

One of the most important aspects of color use in design is its impact on logos, as logos are often the first visual contact consumers have with a brand. Through carefully selected colors, logos can communicate the brand's personality, values and mission, while simultaneously eliciting an emotional response that can enhance consumer loyalty [3, 4]. Red may evoke feelings of energy and passion, blue can symbolize trust and professionalism, while green often conveys calmness and ecological responsibility [2].

Colors play a crucial role in branding due to their strong psychological and emotional impact on consumers, shaping their impression of the brand, its values, and the products or services it offers. In today's competitive market where consumers make decisions based on visual and emotional factors color becomes an essential tool for brand differentiation. Properly chosen colors can increase brand recognition, foster emotional connections with consumers and positively influence their attitudes toward the brand and its offerings [5]. The science that examines the impact of color on human emotion and behavior is known as color psychology and research in this field has shown that colors can trigger specific emotions and responses that directly influence how people perceive brands. These emotional associations enable brands to create tailored experiences for their users and shape consumer perceptions [6, 7]. In branding, color selection is not arbitrary but strategic and carefully considered to reflect a brand's values, mission and vision. Colors can play a deci-

sive role in brand recognition, communication with the target audience, and the creation of a strong visual identity that is easily noticed and remembered [4, 5, 6].
Research in psychology and neuromarketing shows that colors can elicit specific emotions, shape attitudes and influence memory and brand recognition [5, 6, 8]. Studies suggest that up to 90% of consumer product assessments may be based solely on color, depending on the context. Color also plays a key role in brand differentiation consistent use of colors can increase brand recognition by as much as 80%. However, it is important to note that the meaning of colors can be culturally conditioned, so effective color branding requires thorough research of the target market [2, 4, 5, 7].

2. THE PSYCHOLOGICAL IMPACT OF COLORS IN BRANDING

Colors have a powerful impact on how we perceive the world around us, and in the context of design, their influence becomes even more significant. In today's competitive market environment, where competition between brands is constantly increasing, color is used as a key tool for building brand recognition and emotional connection with consumers. This paper explores the importance of color in design, with particular emphasis on its impact in logo creation and how it shapes brand perception. Special attention is given to a comparison of colors in the logos of well-known global brands that use color as a hallmark of their identity. Through the analysis of different colors and their psychological effects, it examines how selected colors can evoke specific emotions and associations in consumers, thereby influencing a brand's success and recognition.

Red [2, 8]
Psychological effect: Increases excitement, energy, and a sense of urgency. It can stimulate quicker decision-making.
Neurobiological aspect: Elevates heart rate and blood pressure.
Application: Used in sales promotions, warnings, urgency cues, and to convey passion.

Blue [2, 5]
Psychological effect: Evokes feelings of trust, security, and calmness. It is associated with intellect and professionalism.
Application: Common in banking, corporate branding, and technology.

Green [1, 2]
Psychological effect: Symbolizes nature, balance, health, and renewal. It has a calming and refreshing effect.
Neurobiological aspect: Stimulates the parasympathetic nervous system, helping to reduce stress.
Application: Often used in brands related to ecology, health, and sustainability.

Yellow [2, 4]
Psychological effect: Promotes optimism, happiness, and creativity, though it can cause anxiety in large doses.
Neurobiological aspect: Due to its brightness, it can lead to eye strain.
Application: Attracts attention (e.g., warning signs, children's products).

Purple [2, 4]
Psychological effect: Combines the stability of blue and the energy of red. It symbolizes luxury, creativity, and spirituality.
Application: Used by brands seeking to convey exclusivity or innovation.

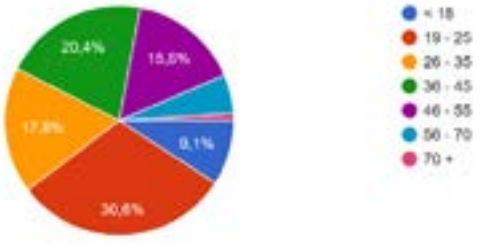
Black [2, 4]
Psychological effect: Denotes power, elegance, luxury, and authority—but can also suggest mourning or fear, depending on the context.
Application: Found in luxury and fashion brands, as well as in formal and serious communication.

White [2, 4]
Psychological effect: Associated with purity, simplicity, and neutrality. Frequently linked with freshness and modern design.
Application: Commonly used in healthcare, technology, and cosmetics.

3. SURVEY RESULTS

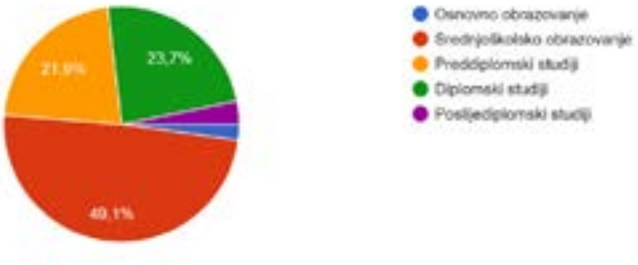
In the experimental section of this paper, a survey was conducted to examine the recognition of well-known logos based solely on their colors. This research approach provides insight into the actual effectiveness of color as a key element in the branding and visual identification process. Given the importance of color in creating emotional connections and shaping brand perception, the aim of this experiment was to investigate how well consumers can recognize logos based solely on their color schemes, without the presence of additional visual elements.
Logos of globally recognizable brands, primarily Croatian, that use specific colors as a hallmark of their identity were selected. Participants were asked to identify the logos based on the displayed color combinations and to associate them with the corresponding brand. The results of this survey provide valuable information about how colors can facilitate or hinder brand recognition, and how important color is in establishing visual identity.
The experimental component also allowed for an analysis of how different demographic groups (age, gender, education) may respond differently to colors in the context of logo recognition, offering a deeper understanding of the psychological impact of color on consumers.
Each survey question displayed specific color combinations, and participants were asked to select the brand that those colors most strongly reminded them of. A total of 602 respondents participated in the survey, which provides a high level of reliability for this analysis and enables the drawing of more in-depth conclusions regarding the relationship between color, perception, and brand identity.

Graph 1: Graph shows age of participants



A total of 602 respondents from various age groups completed the survey. The largest age group was 19–25 years (30.6%), followed by the 36–45 age group (20.4%), then 26–35 years (17.8%) and 46–55 years (15.6%). Respondents under the age of 18 accounted for 9.1%, while those aged 56–70 made up 5.5%, and participants over 70 years represented 1%. This distribution indicates that all generations—from the youngest to the oldest—were represented in the survey, allowing for a broader interpretation of the results.

Graph 2: Graph shows participants level of education

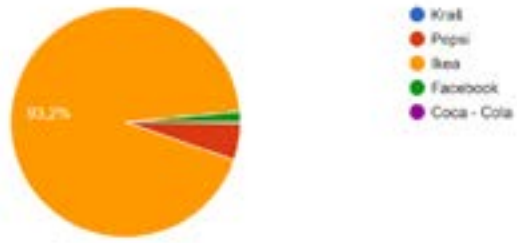


The largest proportion of respondents, 49.1%, have completed secondary education. They are followed by individuals with a master's degree (23.7%) and those with a bachelor's degree (21.9%), while 3.2% of respondents have completed postgraduate studies and 2.2% have primary education. This educational structure provides insight into the attitudes and responses of participants from a broad educational spectrum.

3.1. Question 1. IKEA

Figure 1: Sample of blue and yellow color combination that represent IKEA brand

Graph 3: Graph shows how participants reacted to the colors of IKEA brand displayed in survey



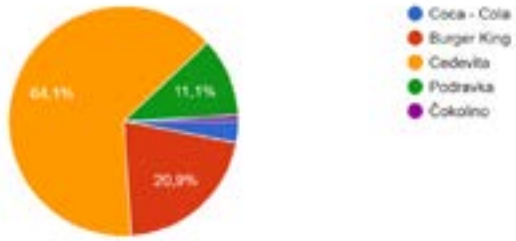
It was expected that the display of the blue and yellow color combination (Figure 1) would immediately evoke associations with the IKEA brand among most respondents, due to their long-standing and consistent use of these colors in their visual identity. The results (Graph 3) confirmed this assumption as many as 93.2% of participants correctly identified IKEA. The remaining answers included Pepsi with 5.1% and Facebook with 1.5%, suggesting that only a small percentage of respondents instinctively associated this specific shade of blue with other globally recognized brands.
An analysis of the results by age and education level revealed no significant deviations, indicating that IKEA's brand colors are equally recognizable across all surveyed demographic groups. These findings further emphasize the importance of consistency in the application of visual elements, especially color, in branding strategies. The successful and continuous use of specific colors can significantly contribute to a high level of brand rec-

ognition among consumers.

3.2. Question 2. Cedevita

Figure 2: Sample of orange and white color combination that represent Cedevita brend

Graph 4: Graph shows how participants reacted to the colors of Cedevita brand displayed in survey

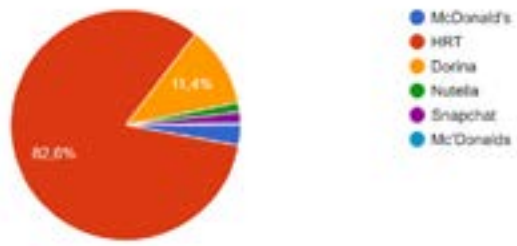


In second question (Graph 4) 64.1% of respondents associated the presented colors (Figure 2) with Cedevita, which confirms that many clearly recognized its brand identity and long-standing market presence. 20.9% of respondents selected Burger King and 11.1% selected Podravka, while Coca-Cola (3%) and Čokolino (0.8%) received significantly lower shares. Interestingly, some respondents associated the same colors with Burger King or Podravka, likely due to similar shades used by these brands in their communications. There were no noticeable differences among age and education groups; all groups predominantly associated the colors with Cedevita.

3.3. Question 3. HRT

Figure 3: Sample of gray and red color combination that represent HRT brand

Graph 5: Graph shows how participants reacted to the colors of HRT brand displayed in survey

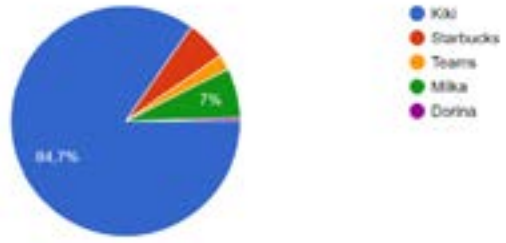


Third question (Figure 3) 82.6% of respondents selected HRT, while 11.4% preferred Dorina. McDonald's received 2.8%, but at the same time, another 0.3% of respondents selected McDonald's again from the repeated offer. Snapchat and Nutella received only 1.5% and 1.3% of the votes, respectively. The results (Graph 5) show that the majority of respondents were confident in their choice. There were no noticeable differences between different age and education groups.

3.4. Question 4. Kiki

Figure 4: Sample of purple, white and red color combination that represent Kiki brand

Graph 6: Graph shows how participants reacted to the colors of Kiki brand displayed in survey



The majority of respondents 84.7% selected the correct color combination (Graph 6) and associated it with the Kiki product (Figure 4), which was in line with expectations, given the product's long-standing presence on the domestic market and its highly recognizable color palette. A smaller number of respondents chose Milka (7%), Starbucks (5.6%), Teams (2.2%), or Dorina (0.5%), likely due to the partial similarity of some of the shades used.

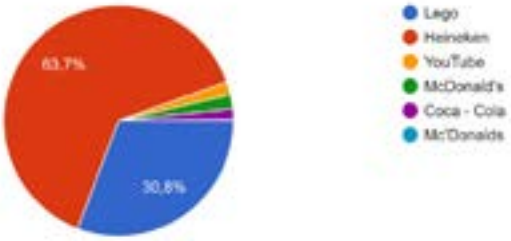
From these results (Graph 6), we can conclude that Kiki, despite being part of a broader Kraš product range, has successfully developed its own visual identity and high brand recognition among consumers over the years. There were no significant differences between

age and education groups, indicating the brand's equally strong presence across different generations and consumer groups.

3.5. Question 5. Heineken

Figure 5: Sample of red and green color combination that represent Heineken brand

Graph 7: Graph shows how participants reacted to the colors of Heineken brand displayed in survey

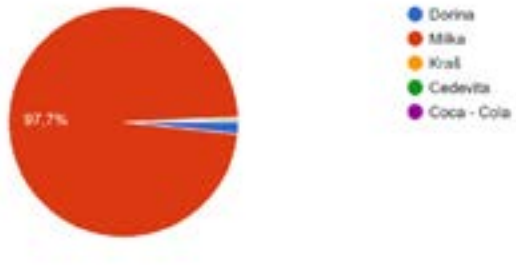


In fifth question 63.7% (Graph 7) of respondents associated the brand colors (Figure 5) with Heineken, indicating strong recognition of its identity among the majority of participants. However, as many as 30.8% of respondents selected Lego, which is an unusually high percentage for a "wrong" brand likely due to certain associations or shared elements that respondents link to the Lego brand. McDonald's (2%), YouTube (1.8%), and Coca-Cola (1.5%) received the remaining responses, meaning only a smaller number of participants associated these brands with the task. A comparison of different age groups and education levels revealed no significant differences, all groups predominantly selected Heineken.

3.6. Question 6. Milka

Figure 6: Sample of purple and white color combination that represent Milka brand

Graph 8: Graph shows how participants reacted to the colors of Milka brand displayed in survey

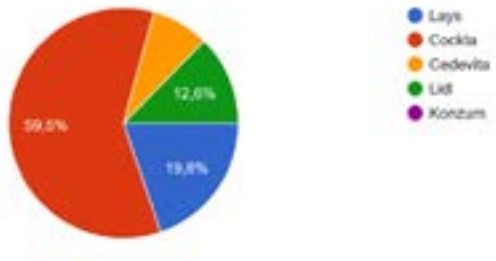


As many as 97.7% of respondents associated showed colors (Figure 6) with Milka, confirming that the brand has an exceptionally high level of recognition. Only 1.7% of participants selected Dorina, and 0.3% chose Cedevita, further highlighting how strongly Milka is "engraved" in consumers' minds. A comparison of different age groups and education levels showed very similar results, with an exceptionally high percentage in all groups correctly associating the brand.

3.7. Question 7. Cocta

Figure 7: Sample of cyan and yellow color combination that represent Cocta brand

Graph 9: Graph shows how participants reacted to the colors of Cocta brand displayed in survey



The majority of respondents 59.5% (Graph 9) associated the colors (Figure 7) with Cockta, indicating that the brand is still well embedded in consumers' memories. 19.8% linked them to Lays, 12.6% to Lidl, and 8.1% to Cedevita. Although certain groups of respondents were uncertain, choices based on age and education levels show a similar pattern Cockta holds a convincing lead as the most common response.

Insights have been gained from valuable results that explain the survey outcome through specific design segments. For example, when we look at the segment of color consistency over time, brands like IKEA, Milka, and Cedevita, known for their unchanged color palettes and strong marketing presence, recorded the highest accuracy levels. This suggests that

the long-term use of the same colors greatly facilitates recognition and recall.
In the case of simple color schemes (one to two distinct colors), participants more easily associate them with a specific brand. It was noted that multi-colored or more diverse visual identities can cause greater confusion and, consequently, dilemmas, especially when colors are shared by multiple brands such as the orange and white used by Cedevita or Podravka.
If we focus on significant local or global presence, although global brands like Heineken, Milka and IKEA are often at the top of the recognition scale, local brands with a long tradition such as Kiki or Cockta also recorded high rates of accurate responses, confirming the importance of continuous advertising and presence in the daily lives of local consumers.
The results of comparisons between age and education groups show that there are no drastic differences in color recognition accuracy, however, certain variations exist for brands that may be more specific to particular generations or interests. It was found that participants with a higher level of exposure to a brand, whether through personal use or frequent media consumption, are more likely to accurately recognize the brand's colors.
Some participants may hesitate with shades that are similar to those used by brands sharing a palette of red, orange, or green. Therefore, the consistent use of characteristic tones (e.g., the exact shade of purple used by Milka) is one of the most important elements for clearly distinguishing brands from their competitors.

4. CONCLUSION

This study underscores the significant role that color plays in brand recognition and consumer perception, particularly in logo design. The survey results highlight the powerful connection between color and brand identity, revealing how specific hues can foster emotional connections and influence consumer behavior. Brands that maintain consistency in their color usage, such as IKEA, Milka, and Cedevita, were more easily recognized by respondents, demonstrating the value of long-term color consistency in reinforcing brand recognition.
Moreover, the findings emphasize the impact of simple color schemes, with one or two distinct colors enhancing ease of identification. In contrast, more complex or multi-colored logos can introduce confusion, especially when brands share similar color palettes, as observed with Cedevita and Podravka's use of orange and white.
The study also revealed that while global brands like Heineken and IKEA dominate recognition scores, local brands such as Kiki and Cockta exhibit similar levels of brand recall, reinforcing the importance of maintaining a strong local presence and continuous brand exposure in the market. Furthermore, demographic factors such as age and education had little influence on color recognition accuracy, suggesting that once a brand achieves widespread recognition, its color identity becomes ingrained across diverse consumer groups.
This research suggests that the consistent and strategic use of distinct shades such as Milka's signature purple helps brands clearly differentiate themselves from competitors, particularly in a marketplace where similar colors may be shared by multiple companies. The results of this study contribute valuable insights into the strategic use of color in branding, emphasizing its crucial role in fostering recognition, emotional engagement and brand loyalty among consumers.

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ORIGINAL SCIENTIFIC PAPER

INTEGRATION OF AUGMENTED REALITY IN AN ENVIRONMENTALLY THEMED EDUCATIONAL BROCHURE

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ABSTRACT

The research addresses the challenge of integrating digital technologies into educational materials for children, focusing on how such tools affect learning quality and engagement. The aim was to develop an interactive brochure on climate change for primary school pupils, available in both printed and digital formats. Designed as a teaching aid, the brochure incorporated augmented reality (AR) to boost motivation, interactivity, and learning outcomes. In the theoretical part, we examined the role of information and communication technology (ICT) and AR in education, highlighting their advantages, limitations, and relevance in environmental topics. We also applied child-centered design principles to ensure age-appropriate content and structure. In the practical part, we developed the brochure and its digital counterpart, creating graphics and animations that were connected to target images using Unity. The final result includes a printed and digital AR-enhanced brochure and an Android app for displaying the AR content. Testing showed strong technical performance and positive user feedback. Children found the brochure engaging and easy to use when paired with the app, confirming its value as an educational tool.

Keywords: augmented reality, interactivity, education, climate change, user testing.

1. INTRODUCTION

1.1. Information and Communication Technology in Education

Information and communication technology (ICT) is an essential part of the educational system [1]. While the traditional model, where the teacher lectures and learners take notes, still exists, it is most often supported by digital tools such as tablets, smart boards, and virtual classrooms. The focus has shifted towards the learner (learner-centered), with the teacher acting as a guide in an interactive learning process. Learners are closely connected with ICT as they manage effectively their own learning [2, 3]. While teachers generally accept ICT positively, they tend to use ICT oriented tools less frequently [4]. Successful implementation of ICT requires proper knowledge, suitable equipment, support, and readiness for pedagogical changes [5]. ICT increases motivation, supports personalized learning, and encourages student engagement. Online communities, video lectures, and simulations offer additional explanations [3]. Interactive presentations and 3D models make lessons more dynamic and improve understanding [3, 6]. The use of augmented reality (AR) and virtual reality (VR) enhances the learning of complex content [7].
On the downside, many teachers lack training and technical support, which may lead to reluctance towards ICT [8]. Devices in classrooms also raise concerns about focus, distraction, and addiction [3, 9–10]. Challenges include lack of funding, poor internet access, and digital safety issues [8].

1.2. Augmented Reality in Education

AR technology enables interaction between the real and virtual world, supporting the understanding of abstract concepts. This technology is especially effective in natural sciences and requires expert collaboration. Game-based learning (GBL) further boosts student motivation and attention [11]. Its purpose is not to replace traditional teaching but to enrich it [12]. Despite its advantages, AR still faces barriers such as high costs, lack of research, and limited educational content. AR has strong potential in environmental education. It raises awareness and helps students better understand environmental challenges [12].
Various AR apps have been developed, such as Sky Guide AR, PlantSnap, and Monash Rocks [13]. In the EcoMOBILE project, students explored ecosystems with mobile AR, enhancing engagement and understanding [14]. In India, the "Save the Earth" project visualized the effects of pollution and encouraged student interest [15]. In Greece, AR tools helped pupils grasp climate change and renewable energy concepts [16].

1.3. Child-Centred Design

Child-centered design (CCD) is based on child-computer interaction (CCI) principles, which respect children's developmental needs [17] so that the educational content is intuitive, simple, and engaging [18].
User interfaces should be adjusted to children's cognitive and physical development. Young children respond better to visuals and sound than text. Interfaces must be graphic, with minimal text, large icons, and simple interactions [19, 20].
As children enjoy exploring, interfaces must be safe. Game elements (gamification), such as points and rewards, enhance engagement. Interfaces should be colorful and clutter-free. Text should be in sans-serif fonts, and elements large enough for smaller hands [20, 21].

1.4. User Experience Testing with Children

User experience (UX) testing with children differs from that with adults. The testing environment must be friendly and familiar – ideally in the child's home. Parental presence can help but should not interfere with responses [21].
Tests should be short, varied, and start with easy tasks. Communication must be simple, avoiding abstract terms. Closed or comparative questions are more effective than open-ended ones. Visual emotion scales help younger children express feelings more easily than words [21].
This research aimed to design a physical and digital interactive brochure on environmental protection for primary school kids, enriched with augmented reality. Key goals included content planning, brochure design, interaction analysis, multimedia integration, digital content creation, and usability testing to ensure engaging, effective, and curriculum-aligned learning experiences. We set the following research hypotheses:

H1: An interactive brochure enhanced with augmented reality technology will increase learning success and efficiency, as reflected in higher levels of comprehension and memorization of the learning material.

H2: Kids prefer to learn with learning content that can be enhanced with augmented reality technology.
H3: The physical version of the booklet will be more popular with kids than its digital form.

The novelty of the research is demonstrated in the thorough review of the content of text-

books used in Slovenian primary schools with the aim of obtaining results on how the primary school curriculum covers the area of climate change and the development of interactive animated content for augmented reality. Such multimedia content was not included in the teaching materials of Slovenian primary schools before the study.

2. EXPERIMENTAL

The experimental part of the research focused on creating an educational brochure enhanced with AR technology. We began by reviewing the primary school science curriculum to select underrepresented environmental topics. The brochure was designed in Adobe InDesign, with illustrations made in Adobe Illustrator. Animations were storyboarded, illustrated, and animated using Illustrator and After Effects. Final edits were completed in Adobe Premiere Pro. Voiceovers were recorded and edited with Audacity. The result was an interactive learning tool combining printed content, animations, and augmented reality for children aged 8 to 12 that was carefully tested using a child-centered user experience approach.

2.1. Overview of curricula for primary school subjects

A review of primary school curricula (in Slovenia) showed strong environmental representation across subjects, though climate change is rarely addressed. Only Environmental Education, an elective from grades 7–9, explicitly mentions it.

2.2. Brochure Design

When designing and editing the brochure, we followed Mayer's principles [22] to reduce unnecessary cognitive load. We applied coherence by including only key information, signaling through highlighted text, and spatial contiguity by placing graphics close to related text. We also used segmentation, dividing content into clearly separated sections and paragraphs, and pre-training by introducing key concepts on the first page.
The brochure features a clean, simple layout with flat illustrations and no shading. We divided it into three color-coded sections: yellow for key concepts like climate change and greenhouse gases, orange for consequences, and calming green and blue for solutions. The cover uses complementary green and red to draw attention. We included playful curves and round shapes to make the content more appealing and child-friendly. Each paragraph has a supporting illustration. Target images are marked with a phone icon for intuitive AR use. The brochure also opens with brief instructions on how to use the app. For typography, we used Franklin Gothic Heavy (60 pt) for main titles, 18 pt for subheadings, and Tw Cen MT (14 pt) for body text. The brochure is A5-sized and contains 20 pages in total. Figure 1 shows the design progress from a simple draft to the final version.

Figure 1: Cover design

2.3. Animation design

When planning the animations, we applied Mayer's segmentation principle [22] to reduce essential cognitive load, opting for several short animations instead of one long one (Figure 2). After defining the brochure content, we selected five key animations: an introductory one on the greenhouse effect and Earth's warming, placed on the cover to immediately spark interest, followed by two animations illustrating the consequences of climate change, and two more presenting mitigation measures. We prepared detailed content plans, scripts, and storyboards for each, including all animated elements.
The animations were designed as 2D vector graphics using Adobe Illustrator and animated in Adobe After Effects.

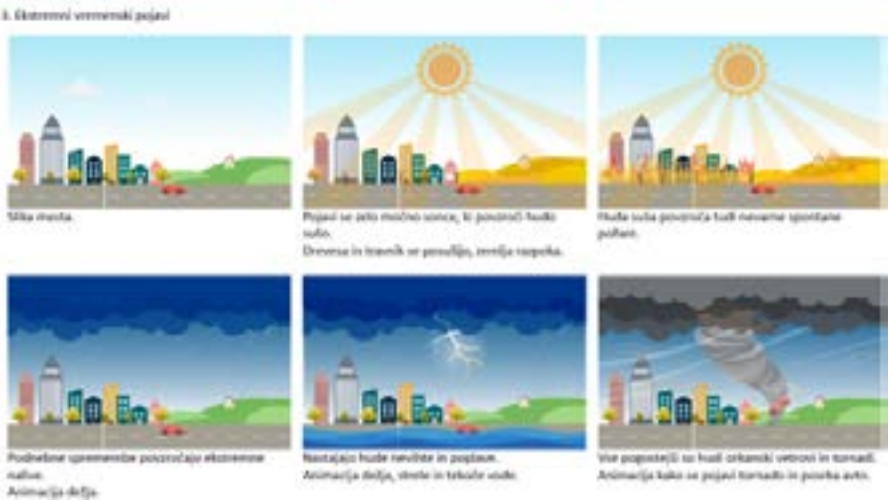
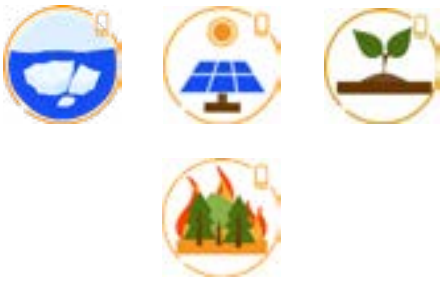


Figure 2: Example of scene planning (layout, movement, etc.) for the animation storyboard

Each scene was developed in Illustrator, ready for animation. We further segmented complex animations – for example, the melting ice animation includes three parts: the iceberg melting, the rising sea level flooding a city, and the general sea level rise – to maintain attention and motivation throughout.
To reduce cognitive load, we recorded voice-over narration to support animation comprehension, engaging both visual and auditory channels. Final editing was done in Adobe Premiere Pro, combining scenes, adding transitions, fade effects, ambient sounds, and adjusting volume.

To increase accessibility, we created a digital interactive PDF of the brochure. Due to PDF limitations, animations were also published on YouTube. Links were added in Adobe InDesign. Later, we exported an EPUB version and a more functional HTML5 format using the in5 plugin.
To develop the AR application, we used Unity and the Vuforia engine. We used illustrations from the brochure as target images (Table 1), uploaded them to Vuforia's Target Manager, and generated a database for Unity. We imported animations and connected video clips to image targets via video player components. To improve usability, we added buttons to control playback and scripted behavior for detecting targets, including audio/video pause when the image is lost. The interface is minimal, with only a red exit button. We exported the Android app and tested it on different devices (Table 1), checking performance and camera responsiveness.

Table 1: Testing devices with the version of Android system and camera resolution

Device	Version of Android System	Camera resolution	
Xiaomi 11T	13	108MP	
Pixel 6 Pro	14	50MP	
Redmi 6	9	12MP	
Galaxy A52s 5G	12	64MP	
Galaxy A33 5G	13	48MP	
Mi 11 Lite 5G	13	64MP	
Computer	Unity simulator	2MP	

2.4. User Experience Testing with Target Users

After confirming the app's technical functionality, we tested the user experience with six children (four girls, two boys), aged 8–12 (mean age 9.5). Each session lasted 30 minutes. We followed best practices for child-centered usability testing, ensuring comfort and understanding. The goal was to assess if the brochure and AR app were engaging, intuitive, and educational, and to identify any issues in content, design, or functionality. Testing was conducted in the children's home environment with parental consent. We combined performance metrics, issue-based metrics, and self-reported feedback. Example questions were:

Content aspect (performance metric, performance time 7 min): What is the brochure about?, Why is the earth warming?, What are the consequences of climate change?, How can I help prevent the consequences of climate change?, Find where in the brochure there is a description of extreme weather phenomena and watch the animation. Which extreme phenomena are a consequence of climate change? Which ones can we see in the animation?

Feelings when using (self-observation metric, 5 min): Were the animations interesting to you? Which animation did you like the most? Why?, Which illustration did you like the most?, Were any of the animations too boring, too long?, Would you use such booklets/textbooks/assignments at school?, Would you show the brochure to your friends?

The testing started with an informal introduction to create a relaxed atmosphere. Children were given the brochure and app to explore freely, allowing us to observe natural use and intuitiveness. Each task was introduced with clear instructions, followed by questions to assess comprehension. We examined usability (e.g., recognizing AR icons), technical aspects (e.g., video clarity and playback), design clarity (e.g., meaning of colors), and content understanding (e.g., climate change consequences). Finally, emotional responses were evaluated using questions and a visual scale of facial expressions. Tasks included identifying video content, using playback controls, understanding AR-enhanced pages, and discussing the meaning of key visuals and animations. This feedback was vital to refining the experience and ensuring both educational value and positive user engagement.

3. RESULTS AND DISCUSSION

3.1. Physical Brochure

The final result was an educational brochure in both physical and digital formats, designed for children from 4th to 6th grade and enhanced with augmented reality (AR) technology.

The printed brochure is shown in Figure 3 with the selected scenes from the greenhouse effect animation.

Figure 3: Final printed brochure and scenes from the Greenhouse Effect animation

To use the brochure, a mobile app called "AR brochure" (slo. AR brošura) is required, which runs on Android. The user opens the app and the camera launches immediately. By scanning marked images in the brochure (indicated with a phone icon), the app recognizes the target image and displays a video player. Tapping the play button starts an animation linked to the selected image. The player adjusts to portrait or landscape orientation. Tapping again pauses playback. When the target image is no longer visible, playback stops and the player disappears. To exit the app, the user taps the red X in the top right corner. Figure 4 shows screenshots of the app in action.

Figure 4: App in use on a mobile phone

Despite differences in camera quality, all tested phones detected target images and played animations smoothly within 1–2 seconds. Two issues occurred: on one lower-end device, playback was slow. We fixed this by adding a short delay before the video starts, allowing it to load properly. The second issue was incorrect recognition when parts of an illustration resembled a target image. We solved this by editing the image to remove similarities. Final testing showed the app is suitable for Android 8+ devices, and target detection and

deactivation worked reliably.

3.2. User Experience Testing Results

Key results of brochure testing are summarized in Table 2.

Table 2: Key user experience findings

Testing Aspect	Positive (+)	Negative (–)
Intuitiveness	Recognized phone icon quickly	Not all noticed animation on the cover
Usability	Enjoyed videos with text	Hard to use brochure and phone at once
Technical	Audio/video worked smoothly	Small exit button sometimes overlooked
Design	Clear color coding and layout	Possibly too simple for oldest users
Content	Understood material, answered correctly	Skipped reading full text when only watching animation

General Findings

The AR-enhanced brochure was well received. Users were enthusiastic and enjoyed the interaction. We noticed a clear difference between older and younger children. Older ones were more independent; younger ones needed guidance. Some were confused about where animations would appear, but once told to look for the phone icon, they used the app correctly.
For younger learners, especially in 4th grade, teacher involvement is key – demonstrating use and guiding them through steps.

Intuitiveness and Usability

Most users quickly linked phone icons with AR animations. They enjoyed having videos alongside the text and found the content more engaging this way. However, using both hands (for phone and brochure) was challenging. The solution was to place the brochure on a table during use.

Technical Aspects

Animations were clear even on small screens. Some asked about using it on a computer, so we explained the digital version and YouTube access. Tablets were suggested as an ideal alternative – larger screens but still mobile. Sound effects were recognized and appreciated.
Some users missed the app's exit button, instead pressing the phone's lock or home button, which still effectively closed the app.

Design and Content

Color-coded sections and illustrations were well understood. However, some children skipped reading and only watched animations, missing parts of the content. This highlights the need to encourage using the text and AR together for full understanding.

User Enjoyment

Children enjoyed using the app, and all but one said they'd like to use similar materials at school. One child, the oldest, was unsure – perhaps because the design felt too childish. Customizing versions for different age groups could improve engagement.
We also suggest expanding the app with more educational features – quizzes, challenges, and extra content – making it a standalone learning tool, not just a brochure extension.

Learning Outcomes

Children learnt the key terms by reading the text and watching the animation, whereby the animation supported the reading by showing the climate change in motion so that the children answered simple questions immediately (i.e. What are the consequences of climate change?). The problem that arose was that some subjects did not read the entire text, but only watched the animations.

4. CONCLUSIONS

We explored a modern method of delivering environmental education using ICT and augmented reality (AR), aiming to foster a dynamic and engaging learning environment. The result is an AR-enhanced educational brochure and app, tested technically and with users.

H1 was partially confirmed – AR improved understanding and recall, though further testing is needed.

H2 was confirmed – kids preferred AR-enhanced content for its engagement and accessibility.

H3 was partially confirmed – users favored the physical brochure with AR, but a small sample limits conclusions; broader testing is needed for definitive results.

Through developing the brochure and app, we gained valuable insight into the full design process and see potential for future enhancements, such as interactive quizzes or age-specific versions. In our opinion this type of educational material promotes greater awareness of environmental issues and inspires positive behavioral change for a sustainable future.
The study has some limitations, one of the most important of which is the small number of children included in the tests. A larger number would certainly give a deeper insight into the scope of the results and their relevance. In addition, standardized tests and multi-level tests could be included in the study to better define the learning outcomes.

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BLAŽ BAROMIĆ
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REVIEW

REVIEW OF CURRENT STATE OF BIOCOMPOSITE MATERIALS WITH POLYLACTIC ACID (PLA) BASE USED IN ADDITIVE MANUFACTURING

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ABSTRACT

Additive manufacturing (3D printing), particularly Fused Filament Fabrication method, is a technology that uses polymer materials with melting properties to produce physical objects. Environmental concerns have the aim to reduce all kinds of nondegradable plastic materials, thus lots of scientific research is done to create new composite materials with improved properties. This research was carried out with the aim of categorizing and summarizing the current state of fillers used in biocomposite materials with the base of polylactic acid (PLA) polymer. The use of organic materials as a source for the production of polymers has been used in the market for a long time. Small amounts of organic materials have already been successfully used as polymer fillers. In this way, a more cost-effective and sustainable filament materials are created. By mixing the various amounts of fillers with commercially available filaments, the potential of sustainable filament is evaluated and compared its' properties and printability.

Keywords: 3D printing, biocomposites, filaments, fillers, printability.

1. INTRODUCTION

Plastic pollution has become one of the major environmental concerns over the past decades.Due to their versatility and durability, plastic materials are used in many industries and everyday applications which ultimately burdens the environment and climate. . The packaging industry also relies heavily on various forms of plastic to contain and protect the products. According to data, in 2021 the packaging industry consumed almost 40% of the overall plastic material produced, but approximately 10% of post-consumer plastic was converted into recycled products in the European Union. At the same time, 90.2% of the new plastic produced comes from the non-renewable fossil-based sources [1].

Plastic materials are a collective term that refers to materials containing various types of polymers that are divided into three categories: thermoplastics, thermosets (duromers) and elastomers [2]. Thermoplastic polymers can be repeatedly moulded and shaped when heat is applied, under the influence of heat but retain their solid form after cooling. Conversely, the thermosets cannot be reshaped once the molecular structure has set during the cooling and hardening. Elastomers can be formed under applied pressure in their cooled state. Examples of thermoplastic materials that are currently mostly used in packaging industry include polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS) [3]. Such materials are mostly produced from fossil-based materials.

The need for global change is obvious and a more sustainable form of production and management is needed to resolve the problems arising from the fact that most common sources for the production of polymers are not renewable. Promising research is being done in the field of biopolymers using bio-based renewable sources and most importantly, such plastics promise good decomposition properties which are important in today's ecology.

The first generation of biopolymers aimed to reduce the landfill crisis by reducing the

amount of conventional polymer. This was achieved by mixing the conventional non-degradable polymers with degradable materials such as starch. These biopolymers were not entirely degradable, but they reduced in particle size when the starch or other added material was degraded. The second generation of biopolymers that could be entirely degradable are divided in two groups according to the starting material used for their production. These are synthetic petroleum-based polymers such as polycaprolactone (PCL), poly(butylene succinate) (PBS), poly(butylene succinate-co-adipate) (PBSA) or poly(butylene adipate-co-terephthalate) (PBAT). On the other hand, researchers are expolring new renewable sources for biodegradable polymers: starches, soy protein, cellulose and plant oils. The most researched biopolymers in this category are polylactic acid (PLA) and polyhydroxyalkanoates (PHA). They show similar characteristics to petroleum-based polymers.
This article describes current research on polylactic acid (PLA) and bio-composites of PLA and other materials. Biocomposite materials containing polylactic acid (PLA) are becoming increasingly popular for additive manufacturing (i.e. 3D printing) applications due to their advantageous mechanical properties, biodegradability, and sustainability. The potential of PLA-based biocomposites to replace traditional non-biodegradable materials has been highlighted by recent research [4].

2. ADDITIVE MANUFACTURING (3D PRINTING)

Fused filament fabrication (FFF) is one of the most widely used methods in additive manufacturing. This method includes melting a material called filament and building objects from it layer by layer. Therefore, it is based on the materials that have the property of melting at a certain temperature and solidifying when cooled. Thermoplastics are ideal for this purpose as they have the ability to be repeatedly remoulded. The creation of three-dimensional objects includes laying melted material from the nozzle of 3D printer onto the base according to coded instructions that move the printer head with the nozzle. Successive layers are fused together in this process, with the possibility to regulate layer thickness.

3. POLYLACTIC ACID (PLA)

Because PLA is affordable, eco- friendly and biodegradable, it is a popular biopolymer and ana important component in the development of sustainable products. The growing volume of PLA production makes it a promising option for commercial use, especially when considering ecologically responsible manufacturing [5].
PLA is environmentally safe because it is decomposed into water and carbon dioxide by hydrolysis. The time needed for degradation depends on various factors such as surface properties, pH, melting temperature, composition, crystallinity and molecular weight of the polymer [6] [7] [8].
We can define PLA as a linear aliphatic thermoplastic polyester derived from renewable sources [9]. The two most common processes of PLA synthesis are:

- Direct polymerization of lactic acid (polycondensation), and
- Ring-opening polymerization of lactide monomer (ROP)

With the latter being the preferred method as it offers better control over the reaction parameters [10].
The polymerization of PLA from lactic acid has its advantages in the fact that it is more affordable. Lactic acid can be produced by chemical or biological processes. Chemical reactions include the hydrolysis of esters or nitrile [11], but the large-scale production includes fermentation processes of plant material such as corn, beets, sugarcane, and other carbohydrates [12].

Although polylactic acid is environmentally friendly, bioplastics are considered to be a good alternative to petroleum-based polymers since they are highly biocompatible, easy to process, and require less energy [13]. The basic properties of 3D printed PLA parts, such as their low elongation at break, low toughness, and brittleness, limit their use in various applications [14]. Other sources also report that PLA exhibits brittleness, high absorption of moisture and low strength [5].

4. BIOCOMPOSITES

Composite materials are combinations of two or more materials that have different chemical and physical properties. They are heterogeneously mixed and maintain a structure that is different from its consisting components. Composites are made with a purpose of showing improved mechanical and functional properties than the individual materials. Strong bonds in the composites structure are achieved by reinforcements such as fibres or particles, plates or similar shapes together with a less rigid polymer matrix [15].
Fillers can be categorized according to a number of factors, such as their origin, chemical composition, shape, size, and aspect ratio, as well as by the impact they have on the matrix material (intended function) or their cost relative to the matrix polymer [16].
This article provides an overview of composite materials in which the main polymer matrix consists of polylactic acid (PLA), and the variety of added fillers i.e. biomaterials that can improve some mechanical properties of the basic polymer, while not affecting the degradation of the composite. By adding cellulose and other natural fibers to PLA-based biocomposites, their mechanical qualities can be improved [4]. Among the more intensively researched materials include wood, jute, sisal, kenaf and hemp as natural fiber reinforcements used to increase mechanical strength of the parts in automotive industry [17] Studies show that PLA with natural fiber composites can be used as an alternative to synthetic polymers [18]. When compared to their traditional counterparts, such as glass and carbon fibers, the main benefits of using natural fibers in polymeric composite structures are better stiffness-to-weight ratio, higher recycled content, good biocompatibility, insulation, and carbon dioxide neutralization. Strength and stiffness are often higher with very dense fibers than with less dense fibers. The tensile, impact, and bending strengths of natural fiber reinforced composites are influenced by fiber orientation. Generally speaking, natural fibers are far weaker in tension than synthetic fibers and offer different mechanical qualities [19].

4.1. Natural fiber fillers

To overcome the shortcomings of PLA, natural fibers are often added as reinforcements. These fibers are sourced from renewable plant material such as wood or fast-growing plants that are more sustainable than wood sources. Other sources include fibers obtained from animals or the environment [5]. Typically, natural fibers are used in the form of celluloses, nanocelluloses, fillers, and fibers [20]. The percentage of natural fiber in biocomposite - in weight percentage – best results from 1 – 10% (due to the lightness of the fibers, a low weight percentage can be a large volume percentage (i.e. 15% by weight vs. 55% by volume). One of the most important variables is particle size; larger particles result in a rougher printed surface, while smaller particles have a larger surface area which can lead to aggregation. Additives that improve the interfacial interaction between the polymer matrix and the added natural fibers, promote dispersion, and prevent particle aggregation can effectively address this issue. The viscosity of the biocomposite can also be increased with the help of additives. Variables like the layer thickness and nozzle diameter ratio can affect the mechanical properties of biocomposites when it comes to 3D printing. Another consideration is the quality of the fibrous fillers, which can negatively impact the composite's ability to bond. These fillers may contain lignin, pectin, or other substances

[21]. Filler quantity and different chemical treatments of fibers have a positive effect on stiffness and strength [22].
Some of the advantages that are highlighted in literature, such as biodegradability, carbon dioxide neutrality, and renewability, natural fibers, are the most beneficial to the environment. For example, using natural hemp fiber instead of glass fiber can reduce carbon dioxide emissions by three tons per every ton of material [23]. Effective thermal insulation is another benefit of natural fiber reinforced polymer composites.
Depending on the type of fiber, higher humidity absorption, poor permeability (hydrophilic fibers and hydrophobic polymer matrices), and often insufficient adhesion of the fiber-matrix interface, result in reduced mechanical properties. This can produce problems in manufacturing and new research is oriented toward improving these characteristics. In relation to the environment and growing conditions, the quality and properties of natural fiber might vary significantly. Studies also report low thermal conductivity compared to composite materials reinforced with glass fiber [19], thermo-oxidative deterioration of the biocomposite, which means that the melting point of the polymeric matrix needs to be relatively low. Natural fibers are hydrophilic, thus, must be carefully dried before processing to prevent the formation of water vapor or hydrolysis of the polymeric matrices that are susceptible to deterioration [22].
One of the major drawbacks of PLA polymer and the natural fiber fillers is high capacity of absorbing moisture. This characteristic enables faster degradation due to hydrolysis reaction that takes place in the bulk of material and not just the surface [24][25] It reduces the stability and durability of the products made with such biocomposites in humid and temperature environments [26]. The extensive research on changes in PLA polymer matrix in a range of relative humidity (RH) and in contact liquid was made by Rocca-Smith et. al. [27]. High hydrophilicity can cause problems during 3D printing process and usage of the final printed products such as swelling and dimensional changes, poor bonding of the 3D printed layers, susceptibility to rotting and degradation in outdoor applications.
In the following chapters, we will consider some of the sources of natural fibers that have been extensively researched and assess their advantages or shortcomings in the biocomposites for additive manufacturing.

4.2. Natural fibers derived from wood

The mostly used cellulose fibers are derived from softwood and hardwood – poplar, pine, aspen, paulownia, cork and others. Most reviewed papers do not contain information on the type of wood material used and only mention the group of materials wood fiber. One research [28] analysed six different amounts (0 to 50%) of wood filler combined with PLA pellets for filaments used for 3D printing. The density of filament was significantly reduced as the amount of wood filler in biocomposite increased. The addition of 10% wood particles improved the tensile resistance of the filaments. The filament's tensile resistance dropped when 50% wood particles were added. The research reports that wettability and surface roughness of 3D printed PLA/wood layers are directly influenced by the layer thickness.
To achieve sufficient interfacial adhesion and composite properties, polylactic acid-based wood plastic composite (WPC) needs to be extruded, injected, and compressed at a temperature much higher than PLA's melting point. There is also the problem of increased moisture absorption, which can cause problems with 3D printed objects. Research [5] +found out that PLA's tensile strength and crystallization were enhanced by the addition of wood pulp fibers. By its addition the composite's elasticity, the storage modulus, and even the crystallization of PLA have been successfully increased. On the other hand, no significant variations in crystallinity of PLA or the glass transition temperature of the composite were noted.

With the addition of cork [28], the tensile strength of the biocomposite was reduced, while the impact strength was increased. The ductility of the cork-reinforced PLA increased with higher cork content, while the mechanical properties declined, suggesting that only a maximum of 5% cork should be used.

4.3. Natural fibers derived from cereal straw

Some of the research was focused on rice straw [5] and rice husk [30] as a biofiller.
As the fiber content rises from 5% to 25%, the composite with rice straw's tensile strength and elongation decreases as the Young's modulus (the amount of elongation and deformation of the material) rises. The composites' increased flexural strength (14%) and enhanced tensile strength (20%) were much higher than those of pure PLA polymer.
In the research with rice husk [30], it was reported that the mechanical properties of biocomposites may be enhanced by the increased lignocellulose fiber strength caused by the high cellulose content. Rice husk can be processed at higher temperature compared to wood due to its cellulose and lignin content.
From the research on biocomposites with wheat straw [19][30][31] as the fiber content increased, the mechanical characteristics of the wheat composites became less susceptible to heat treatment.
Biocomposites with PLA and corn straw [5] showed that as the amount of fiber in the cornstalk rose, the mechanical parameters of the composites (tensile strength and elongation upon breakage) first increased and subsequently dropped.

4.4. Natural fibers derived from grasses

Grasses are also a highly researched source of natural fiber for the creation of biocomposites. The use of fibers derived from reed [31] has been observed to alter mechanical properties: a higher fiber content results in a higher flexural modulus (bending modulus). With increase of the amount of biomass, flexural strength either remained constant or declined. The inclusion of biomass increased the notch impact strength. There was a small improvement in Shore hardness D. Regarding heat and water absorption properties: the chemical composition of the filler affects the decomposition temperature; a higher decomposition temperature was associated with a higher proportion of pure cellulose in the filler.
The properties of bamboo fiber fillers combined with PLA polymer [28] showed poor thermal conductivity comparable to wood properties. Another research [19] showed increased mechanical properties - bamboo fibers were the best material for boosting tensile strength.

4.5. Natural fibers derived from other plant-based fiber

Research on hemp as a biofiller [5][30] has shown that hemp fibers, even in small amounts, speed up PLA degradation to a level comparable to that of water residue in undried pure PLA. A study of hemp combined with harakeke fibers [28] and mixed with PLA improved the tensile modulus. Use of hemp hurd as a filler in biocomposites [28] increased the flexural modulus. Parts that were 3D printed have improved dimensional accuracy and enhanced impact strength. According to a roughness study and scanning electron microscopy (SEM) examination, the roughness and corrugated form increase with the concentration of hemp hurd. Study also showed increased PLA crystallization and negligible variations in water absorption. For every Aligned Untreated Long Hemp Fiber (AUL) / Polylactic Acid (PLA), it was found that impact strength increased, and the Young's modulus, flexural strength, flexural modulus, tensile strength, flexural strength, and fracture sturdiness decreased.
Flax has also been studied [28][29] as a potential material for biocomposites and found that, compared to several other thermoplastic composites reinforced with flax currently

utilized in automotive panels, reinforced PLA composites that are easy to extrude and compress were shown to be 50% stronger. The combination of continuous flax fibers and PLA in biocomposites improve mechanical properties. Natural fibers that can match the young's modulus of synthetic fabrics include flaxseed, pineapple, and ramie [19]. Hybrid composites with banana and sisal fiber were found to have excellent mechanical properties [32].
Other researched materials such as cotton [30], coconut fiber [31], kenaf [33], jute [5] or sisal [34] were also found to give improved qualities to some mechanical properties, while also showing that significant improvement can be done in environmental impact compared to the use of pure PLA.

5. CONCLUSION

In recent years, extensive studies on biocomposites have emerged, showing promising results in material properties similar to those of conventional composites. Conventional composites reinforced with synthetic fiber may be replaced with biodegradable PLA composites reinforced with natural fiber. However, due to the hydrophilic properties of natural fibers, the combined effects of moisture and heat may cause hygrothermal aging of composites.
Additional treatments of natural fibers applied prior their mixing with the polymer matrix have been developed in different studies which can address negative properties like hydrophilic absorption. It has been demonstrated that the quality of biocomposites can be further enhanced by the impacts of additives on the composite materials, such as compatibilizers, plasticizers, hardness agents, and chemical treatment.

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BLAŽ BAROMIĆ
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ORIGINAL SCIENTIFIC PAPER

PLANNING AND VISUALIZATION OF A VIRTUAL TOUR THROUGH INTERIOR SPACES

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ABSTRACT

The aim of the research was to design and visualize an interactive virtual walkthrough of residential apartment interiors. In the theoretical section, we examined the software tools and core principles of photorealism necessary for high-quality visual rendering. The experimental part began with an analysis of architectural plans and the selection of materials for visualization. Basic geometry and objects were modeled in Blender, while more complex elements were imported from online libraries like BlenderKit and Poliigon. We applied physically based materials and HDR lighting to enhance realism. Final outputs were rendered as 360-degree panoramas and assembled into a virtual tour using 3D Vista. To improve user engagement, we developed a user interface and implemented virtual staging, allowing users to switch materials and personalize the apartment. Although the results approached photorealism, the process required substantial theoretical knowledge and practical experience. Optimization was essential: rendering only changeable components via alpha channels significantly reduced file sizes. Despite high-performance hardware, scene simplification in Blender remained necessary.

Keywords: virtual tour, architecture, 3D model, virtual staging, rendering.

1. INTRODUCTION

Conventional methods of property visualization, such as floor plans and static images, only offer a limited insight into the spatial dynamics and ambience of an interior. Virtual tours, on the other hand, overcome these limitations by offering a dynamic and interactive environment. Users can navigate through a digital twin of a residential property, giving them a realistic sense of size, light and flow. This innovative approach is not just a technological first, but meets a critical need for better understanding and informed decision-making in the property sector. Virtual tours offer an unprecedented level of detail and control, allowing users to engage with properties in a way that static visualizations simply cannot. Several professional fields are involved in the creation of virtual tours, including architecture, computer-aided 3D design and visualization, engineering and user experience. The paper focuses on the technical side of production, i.e. photorealism in interactive visualizations accessible to the user via online environments [1,2].

1.1. Principles of Photorealistic Rendering

Photorealistic rendering refers to the computer-based generation of images that, through the integration of geometry, simulate the physical and optical properties of materials and light, as well as their mutual interactions [3]. The resulting visual outputs are designed to be indistinguishable from real photographs. Achieving such realism requires more than just technical expertise; it also necessitates a deep understanding of design principles and meticulous observation of material surfaces [3]. Rendering must consider multiple criteria that contribute to photorealism. These parameters can be broadly grouped into three

essential categories: lighting, material optical properties, and camera optical characteristics [4].

1.2. Surface Imperfections and Real-World Realism

In everyday life, objects are arranged unevenly and surfaces exhibit a wide array of imperfections. Replicating material and object characteristics is critical for achieving visual authenticity, often relying on real-world references. Surface textures are not only visible but also tactile, and while all materials reflect light to varying degrees, the extent of reflectivity differs. No surface is flawless—traces such as dust, fingerprints, scratches, and surface roughness contribute to a material's identity. Although 3D software allows for the creation of perfectly sharp edges, real-world edges are almost always slightly rounded. Additionally, all modeled objects should be assigned appropriate thickness to enhance believability [3].

1.3. Lighting

Light interaction with matter enables the human visual system to perceive objects and their surroundings [5]. Material characteristics such as reflection and transparency determine how light behaves upon contact. While the material properties remain fixed, lighting conditions can be altered [5]. Lighting is a critical element that conveys information about scene geometry through light reflections. Rendering systems often offer global illumination, which simulates light behavior in real-world environments and on objects [6]. While in reality light rays reflect endlessly, practical constraints in computation limit the number of bounces. High Dynamic Range images (HDRi) are recommended as lighting sources, as they provide the closest approximation to natural illumination. It is also important to consider the color bleed effect, which results from the interaction of indirect or reflected light between objects in the scene [3,4,6,7].

1.4. Optical Properties of Material

The optical behavior of a material is determined by how light interacts with its surface—through diffusion, reflection, transparency, and scattering. Every material displays a specific combination of these interactions, contributing to its perceived appearance. For instance, smooth materials tend to reflect more light, while rougher surfaces scatter it diffusely. Physically-based rendering (PBR) maps are used to accurately simulate material appearance [6]. These maps may consist of photographic textures or procedurally generated patterns. The image maps are integrated into a BSDF (Bidirectional Scattering Distribution Function), yielding a realistic depiction of material properties such as reflectivity, bumpiness, and glossiness [8].

1.5. Camera Parameters

The camera defines the visible portion of a scene and simulates the functionality of a real camera. Parameters such as framing, depth of field, focal length, shutter speed, and lens type are essential to image formation [5]. For 360° panoramic rendering, a panoramic camera with equirectangular projection is used, and the image ratio is set to 2:1. A minimum resolution of 6000×3000 pixels is necessary to avoid visual artifacts. For consistency with human perception, the camera should be placed at average eye height to minimize perspective distortion [9]. 360° panoramas capture full horizontal and vertical views. Through stitching techniques, these panoramas can be mapped onto a sphere, enabling users to explore in all directions using mouse movements [10]. Virtual walkthroughs are constructed by linking multiple panoramas through "hotspots," allowing users to navigate

between different viewpoints. This method is increasingly used in tourism, education, and real estate. The experience is further enhanced with virtual reality (VR) headsets, allowing intuitive exploration through head movements [10,11].

This research aims to explore the integration of 3D modelling, rendering, and virtual walkthrough technologies into an interactive virtual apartment environment, located in the capital's residential area in Slovenia. In light of the rapid evolution of 3D computer graphics—transitioning within the last decade from basic models to highly photorealistic visualizations—this study situates architectural visualization as a valuable marketing tool for promoting new residential developments.
Before starting the research, we set the following hypotheses:

H1: Virtual staging enables space personalization through material variation.
H2: High-performance computing ensures seamless visualization rendering.

2. EXPERIMENTAL

The workflow was structured in the following steps: modelling the apartment in Blender based on a floor plan, including basic architectural features such as doors and windows; initial scene lighting using an HDR image; Importing complex models from online libraries and designing the interior layout; Assigning materials, shaders, and textures to 3D models; Designing the exterior surroundings; Additional lighting setup and camera placement; Rendering and post-production of 360 panoramas; Import and interconnection of panoramas in 3D Vista; Designing the user interface.
Most of the work was conducted in Blender, where we modelled primary and bathroom-specific furniture elements. To optimize the modelling process and the workflow, complex models were imported from BlenderKit and Poliigon. Lighting was created using HDR images along with additional lights for dim interior spaces. The 360 panoramas were rendered and imported into 3D Vista to be linked together into a cohesive experience. Individual material renderings with transparent backgrounds were exported from Blender for material customization in 3D Vista.
Preparation: We received the architectural floor plan for the interior and used it as the basis for modelling. To enhance visual accuracy, we were provided with reference images for exterior design and a list of materials used in the construction. Reference images were collected via Pinterest and organized using PureRef, which allowed for a clear and centralized overview. Images were grouped by rooms. The project's Swedish architectural theme significantly influenced our choice of visual references.
Apartment Modeling: Modeling commenced with the construction of walls according to the floor plan, ensuring dimensions matched real-world measurements. The apartment included a hallway, bathroom, storage room, bedroom, combined kitchen/living room, and a loggia. We used the Archimesh add-on (available by default in Blender) to generate elements such as windows and doors. This add-on allows precise dimensional input and further adjustments, making it ideal for architectural modeling (Figure 1).

Figure 1: Arrangement of the kitchen, dining room and laundry room

Lighting: HDR images from the free library Poly Haven were used, choosing one with medium contrast for soft shadows. We enhanced lighting intensity by duplicating the HDR image and separating visual and illumination roles between them, using node-based setup in Blender. While HDR light was used globally, artificial lights were added to poorly lit areas. Neutral white temperature (4700K) was selected. False Color filter was used to analyze light distribution and adjust exposure for visual balance.
Interior Design: We used the live preview render mode for real-time visual feedback during interior design. Although resource-intensive, this allowed immediate visual validation of changes. OptiX acceleration and denoising were essential for smooth performance. Most assets were imported from BlenderKit and Poliigon. Living Room – As the largest space, combining the kitchen and living room, this area received the most attention. Scandinavian-style elements such as a white sofa, light rug, and minimalistic coffee table were added. Wall decor, plants, floor lamps, and hanging lights completed the space. Kitchen – A suitable kitchen model was found in BlenderKit but required scale adjustments and material modifications to match the rest of the interior. A dining table and kitchenware were added for realism. Bedroom – Following Scandinavian design, the bedroom featured a white bed, cream rug, functional wardrobes, and sheer white curtains. The layout prioritized simplicity and light diffusion. Hallway and Storage – These areas required intensive lighting due to lack of windows. Lighting fixtures and storage elements were carefully arranged to avoid overfilling limited space. Bathroom – Custom lighting was essential here due to windowless layout. Fixtures were chosen based on client specifications, with some models adjusted or newly created. Functional elements such as mirrors and a washing machine were included.
Texturing Models: Stylized photorealism was the goal, with detailed material settings in Blender's Shading tab using the Principled BSDF shader.

2.1. Image-Based Materials and Procedural Materials

Material properties (color, roughness, normal, specular) were prepared using Photoshop. We ensured seamless texture tiling and created accurate maps using filters like Offset, Normal Map Generator, and Curves. Materials were linked in Blender using the Node Wrangler add-on (Figure 2). For simpler materials, procedural shaders were used (Figure 3). Noise, Wave, and Voronoi textures allowed creation of unique materials without image maps. Procedural nodes were optimized for small imperfections and surface realism.

Figure 2: Node for corrugated and smooth facade material.

Figure 3: Appearance of the rendering using the False Color filter, appearance of the basic rendering, and the corrected visualization.

Exterior Design and Landscape Design: Exterior surroundings play a major role in property marketing. We modeled adjacent buildings and landscape according to architectural plans, using references for material accuracy. Footpaths and fences were modeled using curves. A particle system simulated grass blades. RealTrees was used for background vegetation, using medium-quality assets to optimize performance.

2.2. Scene Optimization

Heavy use of complex assets led to performance issues. Optimization strategies included: Instancing repeating objects (e.g., alt+D in Blender); Decimating distant models; Reducing texture resolution to 1K and Linking object data across duplicates (ctrl+L).
Camera Setup (Figure 4): Cameras were placed at 1.35 meters for centered composition in 360° panoramas. Panoramic type with equirectangular projection was used. Resolution was set to 6000×3000 pixels. Up to 8 camera positions were placed to enable smooth navigation in the virtual space. Rendering used 2200 samples, with denoising applied in Blender's Compositing tab. Mix nodes were used to retain detail while removing noise.

Figure 4: Camera placement around the room from a bird's eye view

Material Export and Post-Production: To enable material customization without large panorama exports, only key objects were rendered separately with transparency. Visibility filters allowed indirect lighting influence while hiding non-essential objects. Rendered panoramas were upscaled using Photoshop's Preserve Details 2.0. Batch automation ensured consistency. Minor errors were corrected by rendering affected areas only and compositing them onto base images.

2.3. Creating the Virtual Tour

360° images were imported into 3D Vista. Hotspots were added to connect panoramas. Static icons ensured clarity and minimal distraction. Interactive floor plans allowed navigation via hotspot clicks. A blue radar cone indicated user viewing direction (Figure 5). A minimalist user interface enabled users to view information, switch materials, and navigate easily. Interactive buttons toggled visibility of material variants. The tour was published online via 3D Vista and uploaded to a server using FileZilla. It was embedded into a website using iframe for seamless integration.

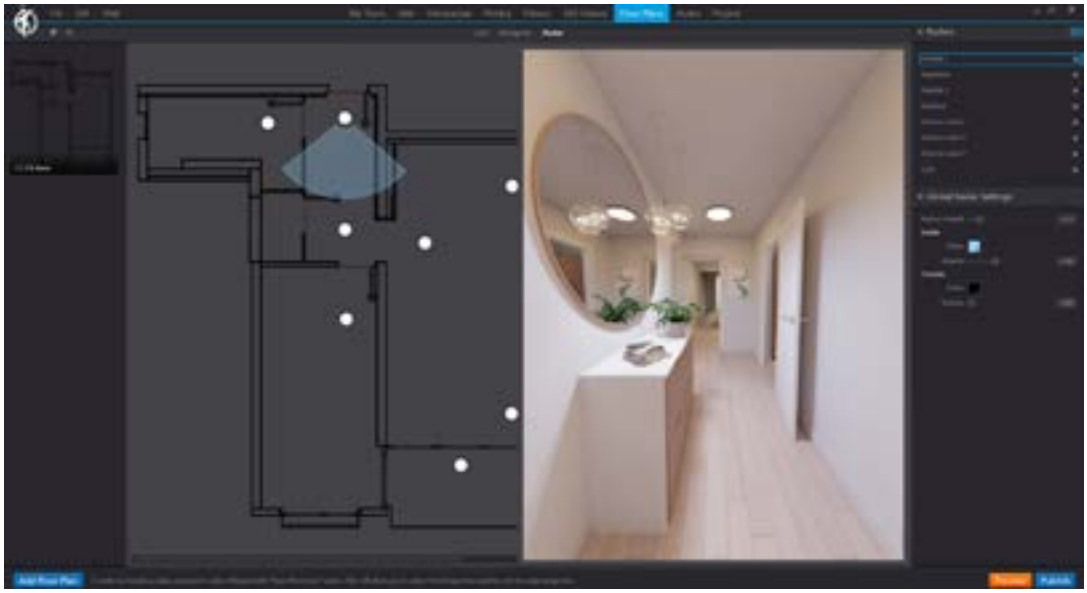

Figure 5: Process of adding a radar to a floor plan

3. RESULTS AND DISCUSSION

The virtual walkthrough created in this project can be accessed online at https://naiponudba.com/3d_ogledi/lagom_c1.2.6/.

Photorealistic rendering and the results of our research rest on three foundational pillars: lighting, material definition, and optics. Among these, lighting and material were the most critical. High-quality lighting—often established through the use of high dynamic range images (HDR)—provided the essential framework upon which material realism could be developed. Properly configured materials then interacted with lighting to create convincing visual outputs. Optics also played an important role by controlling depth of field, focal length, and framing, thereby contributing to the overall realism and narrative clarity of visual compositions.

From the outset of the research to create effective interactive visualizations, established principles of photorealistic visualization were applied to the workflow. This included modelling in real-world scale and using reference-based material and lighting choices. Daylight with medium contrast was selected to simulate natural conditions, while artificial lights were introduced in dimmer areas to ensure uniform illumination. The selected light temperature was a neutral white with a warm tint (approximately 4700K), which contributed to a cohesive and inviting atmosphere.

The result of this design approach was a stylized photorealistic visualization of a newly built residential unit, presented through a fully navigable virtual tour. The final 3D walkthrough enables spatial comprehension by maintaining accurate proportions and dimensions. Visual transitions within the tour follow a logical sequence, which enhances orientation and user experience. The system is further enriched by an intuitive interface that supports user interaction, such as navigation via hotspots, access to detailed information, and the possibility of material customization.

The visualizations are intended for projection on a 3D sphere, where full 360° viewing capability allows for immersive exploration. The interactive functionality and adaptable material options elevate the tour beyond static visualization, offering potential users a highly informative and personalized experience of the space.

In Figures 6-10 final interactive visualizations are presented.

Figure 6: View down the hallway and view in the bathroom

Figure 7: View down the hallway from the other side of the bedroom panorama

Image 8: Panorama in the living room and living room with Arraba Alpine parquet

Image 9: Living room with Timor Heritage Dream parquet and panorama in the kitchen

Picture 10: Panorama in the living room and view on the terrace

Through the presented results of the research work and thus interactive visualizations and interactive viewing and walking, it is possible to accurately view residential buildings remotely and thus experience digital viewing and virtual walking. The solution can be used as advertising material for a residential building, the results of a company's project work or simply as an interactive virtual walk-through experience with a view of furniture, materials, the arrangement of interior elements and architectural solution.

4. CONCLUSIONS

The aim of the presented experimental visualization process work was to establish a workflow for visualizing a new residential building through 360-degree panoramas and integrating them into a virtual tour, with an emphasis on stylized photorealism. Beginning with the floor plan of apartment, we modelled a simplified 3D version of the space, supplemented with online library assets to accelerate production. Lighting was configured using HDR images and additional lights, followed by texturing and the development of the exterior visible from within the apartment. Cameras were positioned to render panoramic views, and material-variant models were rendered separately for personalization. Using 3D Vista, these panoramas were linked with hotspots for interactive navigation. We confirmed our first hypothesis: users could explore the space with interchangeable materials, enabling visual customization. However, the second hypothesis was rejected—despite powerful hardware, the scene's complexity demanded optimization of geometry and textures to ensure stable software performance.

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BLAŽ BAROMIĆ
INTERNATIONAL CONFERENCE ON PRINTING, DESIGN AND GRAPHIC COMMUNICATION

ORIGINAL SCIENTIFIC PAPER

DEVELOPMENT OF A DOMAIN-SPECIFIC LANGUAGE FOR PARAMETRIC MODELING FOR 3D PRINTING

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ABSTRACT

This paper explores the development of a specialized domain-specific language (DSL) for parametric modeling of three-dimensional objects intended for fabrication via 3D printing. The goal is to enable users to easily and flexibly define geometric shapes using high-level commands, without the need for complex CAD tools. The DSL allows for the description of both basic and complex 3D structures through declarative commands that define shapes, transformations, and Boolean operations, with the possibility of parameter-driven control over dimensions and relationships between objects.
The implementation uses a parser generator (ANTLR) and a backend that translates DSL code, enabling rapid generation of STL files ready for 3D printing. The paper describes the language design, syntax, semantics, and the architecture of the system that enables model validation and visualization. Through practical examples, it is shown how complex geometric objects can be defined using a minimal number of code lines. The proposed DSL can be applied in education, rapid prototyping, as well as in automated systems for generating customized 3D parts.

Keywords: domain-specific language (DSL), parametric 3D modeling, additive manufacturing, automated model generation.

1. INTRODUCTION

Domain-Specific Languages (DSLs) are programming languages specifically designed to address problems within a narrowly defined domain [1]. Unlike general-purpose languages such as Python, Java, or C++, DSLs focus on providing concise, intuitive, and domain-relevant syntax. This design approach allows domain experts and developers to communicate more effectively and express complex ideas with minimal code. DSLs are often used in fields such as web development (e.g., CSS), graphic design (e.g., SVG), and build automation (e.g., Makefiles). In the context of 3D modeling and printing, a DSL provides a streamlined alternative to complex CAD software. It enables users to declaratively define 3D objects, apply transformations, and control parameters without requiring deep technical knowledge. This paper introduces the development of a custom DSL for parametric modeling, highlighting its architecture, syntax, and use cases, especially in education and rapid prototyping.
The implementation leverages ANTLR4, a powerful parser generator that facilitates the creation of parsers from formal grammar definitions [2]. By using ANTLR4, we can define the DSL syntax, generate the parser, and integrate it with a backend system that converts the user-written DSL code into 3D models, specifically STL files for 3D printing.
The growing availability of 3D printing technologies in schools, makerspaces, and industry demands more accessible tools for model creation. Traditional CAD tools are often too complex or expensive for casual users and students. Our DSL addresses this gap by offering a lightweight and user-friendly solution. In addition to technical simplicity, the language supports parametric modeling, allowing users to adjust designs programmatically.

This flexibility is essential for iterative design and automated part generation. Importantly, the language commands are written in Croatian to support a more natural cognitive flow for native speakers, helping users think and model in a way that aligns closely with their internal reasoning and linguistic intuition.
This paper seeks to answer the following research questions:

- How can a DSL simplify the process of creating 3D models for printing?
- What are the essential features required for a parametric 3D modeling DSL to be usable in educational contexts?
- How can ANTLR4 be used to develop and maintain a robust syntax parser for such a DSL?
- What are the limitations and opportunities of using a DSL approach over traditional CAD tools?

2. BACKGROUND AND RELATED WORK

Several domain-specific languages are specifically designed for 3D parametric modeling, with varying syntactic approaches, backend engines, and target users. The most notable include: OpenSCAD [3], CadQuery [4], ImplicitCAD [5] and JSCAD (OpenJSCAD) [6]. OpenSCAD is a script-based DSL that uses C-like syntax to define 3D objects. It relies on Boolean operations and transformation stacking and is ideal for engineering prototypes. CadQuery is a Python-based DSL for parametric CAD, built on OpenCascade. It allows readable chaining of commands and full Python logic and is suitable for developers familiar with scripting. ImplicitCAD is a Haskell-based functional language for 3D modeling. It focuses on composability and mathematical expressiveness and offers strong abstraction but has a steep learning curve. JSCAD (OpenJSCAD.org) is a JavaScript-based DSL for browser-based 3D modeling. It uses functions and modules for parametric design and it is accessible for web developers. These DSLs serve as important reference points in our own DSL design process, especially in terms of syntax simplicity, visualization capabilities, and ease of parameterization. Our solution aims to strike a balance between the ease-of-use of OpenSCAD and the expressive power of CadQuery, while targeting educational use with native-language support. ANTLR4 (ANother Tool for Language Recognition) is a well-known tool in compiler construction. It enables the creation of lexers and parsers from a grammar written in EBNF [7]. It supports multiple target languages, including C#, which is used in our implementation.

3. LANGUAGE DESIGN

The language is designed with simplicity and expressiveness in mind. It supports a set of declarative commands to define basic 3D shapes: cube (kocka), sphere (kugla), prism (prizma), cone (stozac), pyramid (piramida) and transformation operations: translate (pomak), rotate (rotiraj), scale (skaliraj), transform (transformiraj). Parameters can be used to dynamically control dimensions and relationships between objects.

3.1. Grammar design

The grammar is defined in a ANTLR4 (.g4) file, consisting of Lexer and Parser rules.
Lexer rules are defined with the tokens (e.g., numbers, keywords, identifiers). Parser rules are defined by the structure and syntax of valid programs.
A sample grammar rule for a cube (kocka) might look like this: kockaStmt : ‘kocka’ argumentList ‘;’ ;
This code defines a command for creating a cube (kocka) with its argument list: width, height, and depth. Figure 1 shows the grammar design of this DSL language.

Figure 1: Grammar design of DSL language

ANTLR4 uses a specific format for defining grammars that describe the structure of a language. The grammar is written in "g4" files as mentioned above and includes lexical and syntactic rules. Lexical rules (also known as tokens) are written in uppercase and are used to recognize basic elements such as numbers, strings, and identifiers. Syntactic rules, written in lowercase, define the structure of expressions, commands, and other constructs, and can use both lexical and other syntactic rules.

ANTLR4 follows a PEG (Parsing Expression Grammar)-inspired approach, and supports LL(*) parsing, which enables it to handle arbitrary lookahead without requiring manual disambiguation. Grammar rules are defined using productions that can include recursion, optional elements (?), repetition (* or +), and alternatives (|). Each rule can include embedded actions—snippets of code in the target language that execute during parsing (in our example C#, or other supported language). ANTLR4 grammars can separate parser rules and lexer rules, allowing fine-grained control over how the input is tokenized and parsed. Figure 2. shows generated tokens for command(s) pomak(kocka(4.4,3.3,2.2), 3.3, 4.3, 2.2);.

Figure 2: DSL command(s) tokens

Token rules in ANTLR4 (also known as lexer rules) define the lowest-level symbols that the parser can recognize in the input stream. These include keywords (if, while, return), symbols (+, (, ,, ;), identifiers, numbers, strings, etc. Token rules are automatically generated or explicitly written in the lexer section of your grammar file. There are two categories of token rules: Explicit token rules and Implicit token rules.

Explicit token rules are defined by the grammar author, like NUMBER : [0-9]+ ('.' [0-9]+)? ; and ID : [a-zA-Z_][a-zA-Z0-9_]* ;. Implicit tokens (such as T__0, T__1, etc.) are automatically generated by ANTLR4 when you use literal symbols directly in parser rules rather than defining explicit named token rules for them.

In our example of grammar we used implicit tokens that allows us to use literal symbols directly in parser rules (e.g., '(', ';'), which helped to speed up prototyping and reduced boilerplate code because we use simple and small grammar. However, they result in auto-generated names like T__13, which can make error messages and debugging less intuitive.

On the other hand if we used explicit tokens, they would require us to define named lexer rules (e.g., LPAREN : '(';), which could improve grammar readability and error reporting. While implicit tokens are convenient for quick drafts, explicit tokens are preferred for maintainable and production-quality grammars.

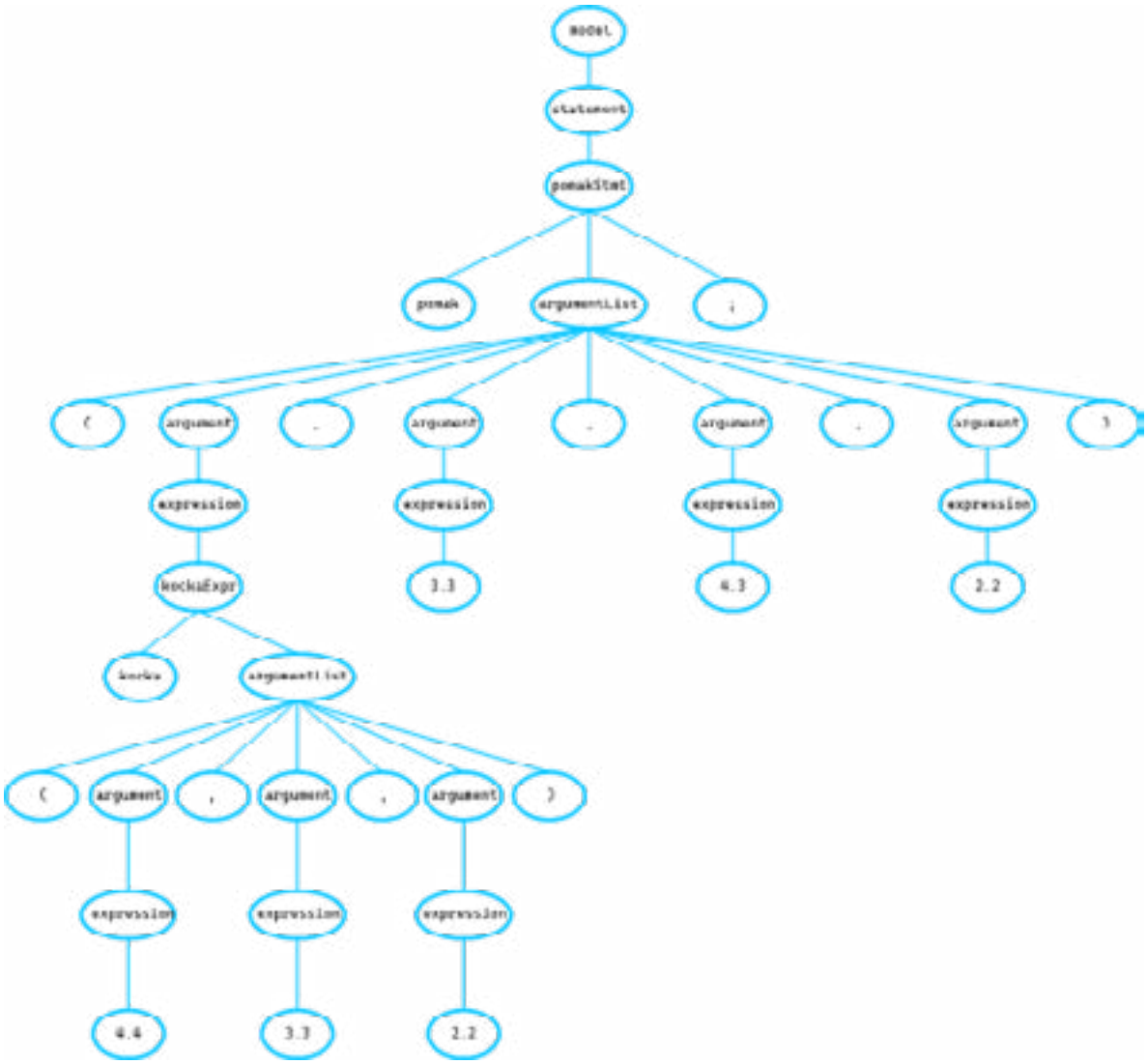

Figure 3: DSL command(s) Abstract Syntax Tree

ANTLR4 automatically generates classes for the parser, lexer, and optionally listeners or visitors, which can then be used to walk the abstract syntax tree (AST) and perform transformations, code generation, or analysis.
For the command(s) pomak(kocka(4.4,3.3,2.2), 3.3, 4.3, 2.2); AST is shown on Figure 3.

3.2. Command examples

```
kocka(4.4, 3.3, 2.2);
stozac(12, 30);
piramida(10, 20, 5);
pomak( kugla(8), 8, 10, -5 );
```

Figure 4: DSL command examples

Figure 4. shows the example DSL code that creates a cube, cone, pyramid and sphere which is positioned by 8 mm on x-axis, 10 mm on y-axis and -5 mm on z-axis from the center of

coordinate system.

3.3. DSL implementation

The DSL implementation process involves several key steps: The grammar definition, parser generation and integration. The grammar definition is written in ANTLR4 format. After that the parser is generated with ANTLR4 tool. ANTLR4 generates C# classes: lexer, parser and visitor. The generated classes are then integrated into a .NET backend. A visitor pattern is used to evaluate commands and construct geometry for writing STL (abbr. Stereolitography) 3D files. The backend interprets parsed commands and generates a 3D model representation.

```
var inputStream = CharStreams.fromString(input);

var lexer = new ModelDSLLexer(inputStream);
var tokens = new CommonTokenStream(lexer);
var parser = new ModelDSLParser(tokens);

var stablo = parser.model();

var visitor = new ModelVisitor();
visitor.Visit(stablo);


visitor.Save("rezultat.stl");
```

Figure 5: C# backend implementation

The backend interprets parsed commands and generates a 3D model representation. This model is then exported as an STL file as it is shown on Figure 5. The STL model then can be directly used in slicing software for 3D printing.
We use C# to manage geometry creation, transformations, and STL file generation. The STL generator is modular, supporting both ASCII and binary formats.
Some of the DSL implemented commands at the time of writing this paper are shown in the Table 1.

Table 1: DSL 3D object creational commands with argument description

Command	Arguments	Argument type	Default arg. value	Mandatory argument	Positional argument	Named argument
kocka	dx	double	10.0			
	dy	double	10.0			
	dz	double	10.0			
kugla	r	double	10.0			
	rseg	int	64			
	vseg	int	32			
prizma	str	int	6			
	r	double	10.0			
	v	double	20.0			
	os	string	“Z”			
	pomx	double	0.0			

	pomy	double	0.0			
	grot	double	0.0			
	rez	int	1			
stozac	rbaze	double	10.0			
	v	double	20.0			
	brstrbaze	int	64			
	— (isCone)	true	(fixed)	—	—	—
piramida	rbaze	double	10.0			
	v	double	20.0			
	brstrbaze	int	4			
	— (isCone)	false	(fixed)	—	—	—

4. CASE STUDIES AND EXAMPLES

In this section, we present practical use cases and code snippets that demonstrate the expressiveness and flexibility of our DSL for 3D modeling in Croatian language.
The language enables users to define simple or complex shapes using intuitive, domain-specific commands. Thanks to native-language syntax, students can more naturally think through geometric structures without a cognitive translation layer.
The DSL program shown on Figure 6 from a grammar perspective are commands as nested function calls where pomak(...) is a transformation applied to a shape. The shape itself is a function like kocka(...) or kugla(...). Each function has a fixed number of parameters and the input is structured and regular, making it ideal for parsing.

```
pomak( kocka(5, 10, 20),   0, 0, 0 );
pomak( kugla(8, 12, 12), -16, 0, 0 );
pomak( kugla(8, 3, 3),   -36, 0, 0 );
```

Figure 6: DSL commands (example of nested functions)

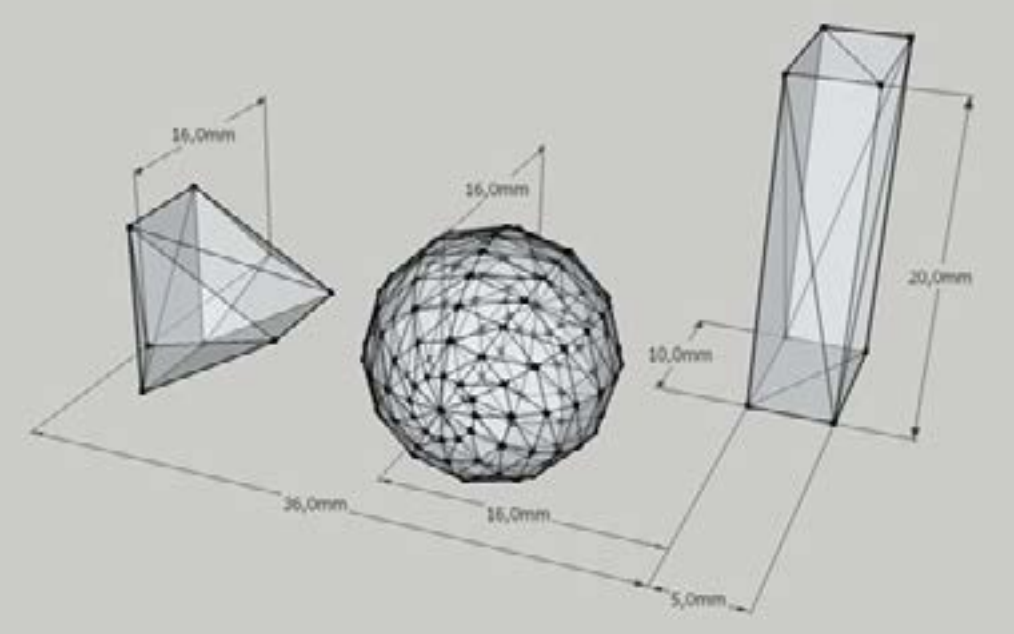

Figure 7: Preview of 3D generated objects with dimensions

Figure 7 shows how "kocka" – cube is generated as STL object with dimensions in milimeter. The "pomak" – translation is precisely defined in milimeter and is like that ready for 3D printing. This DSL supports variables, loops, expressions, and function nesting. Next example shown in Figure 8 are commands within the loop. Here is shown the distinction between statements (like var, +=, functionCall) and expressions (math operations, variable references). The grammar supports operator precedence, block scope, and recursive calls.

```
var i = 3;   # varijabla i
var j = 0;   # varijabla j

ponovi(6) {
  i += 1;
  j += 1;
  pomak(prizma(i, 2, 1 + (i * 1.1)), 6.5 * j, 0, 0 );
}
```

Figure 8: DSL code with variable declarations, loop iteration (ponovi), and parameterized shape transformations

When the code on Figure 8 is parsed and executed the result shows the power of parametric modeling through programming. This DSL code generates six rectangular 3D prisms of increasing size, positioned in a linear sequence along the X-axis. Each prism's width and depth grow proportionally with the loop variable i, while their X-coordinate spacing is controlled by the expression 6.5 * j. The result is a progressive, non-overlapping arrangement of elongated prisms, suggesting a stepped or modular design expanding horizontally.

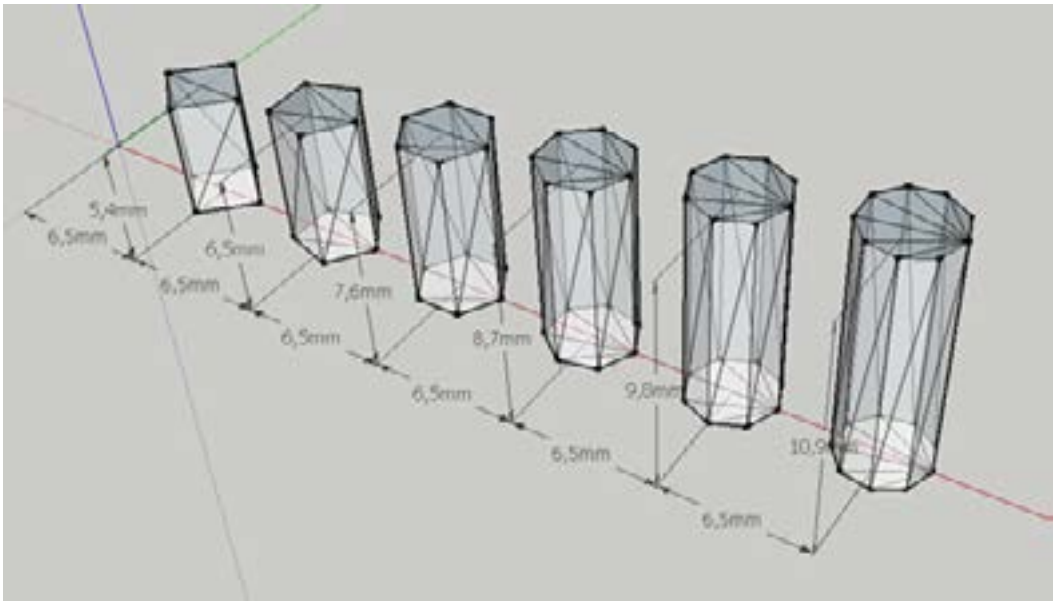

Figure 9: Parametric 3D modeling of prism

Figure 10 shows DSL code that generates a 3D model by extruding the 2D contours defined in the SVG file zupcanik.svg to a height of 5 mm.

```
izvuci("slike/zupcanik.svg", 5);  # visina 5 mm
```

Figure 10: Extruding by Z axis of external 2D vector SVG file defined in milimeter

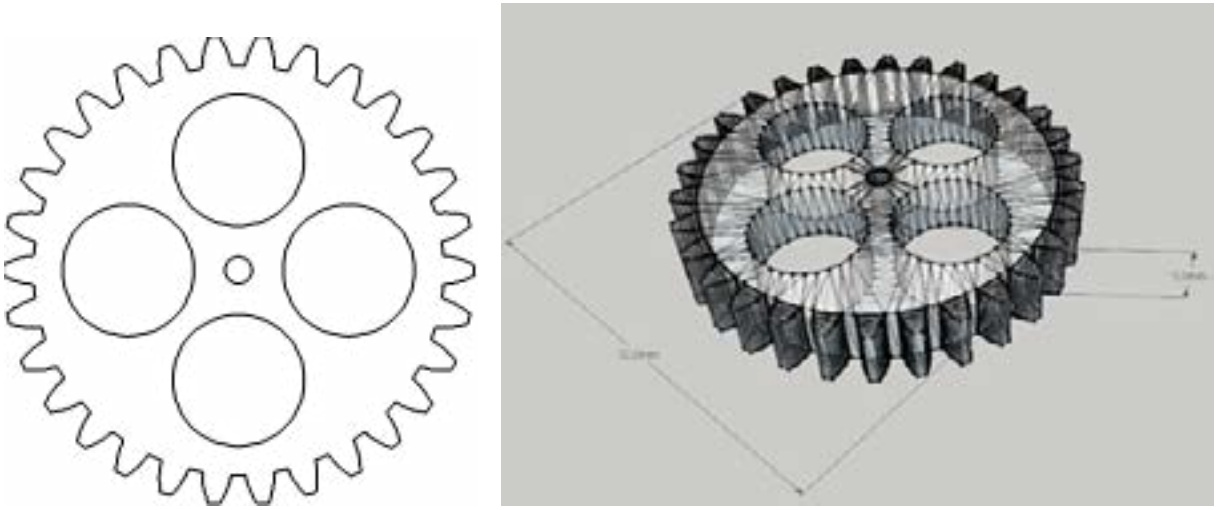

Figure 11: Externaly SVG file loaded by DSL program (left) extruded to 3D object by DSL program (right)

Figure 11 shows the original shape (gear) that retains its precise profile in the X-Y plane while gaining depth along the Z-axis. The result is a flat, solid gear object with uniform thickness, suitable for 3D printing, rendering, or further transformations in the DSL.
The extrusion is typically orthogonal, meaning the original shape is simply “stretched”

along the Z-axis without deformation. This command is useful for creating mechanical components, badges, or decorative elements from vector graphics.

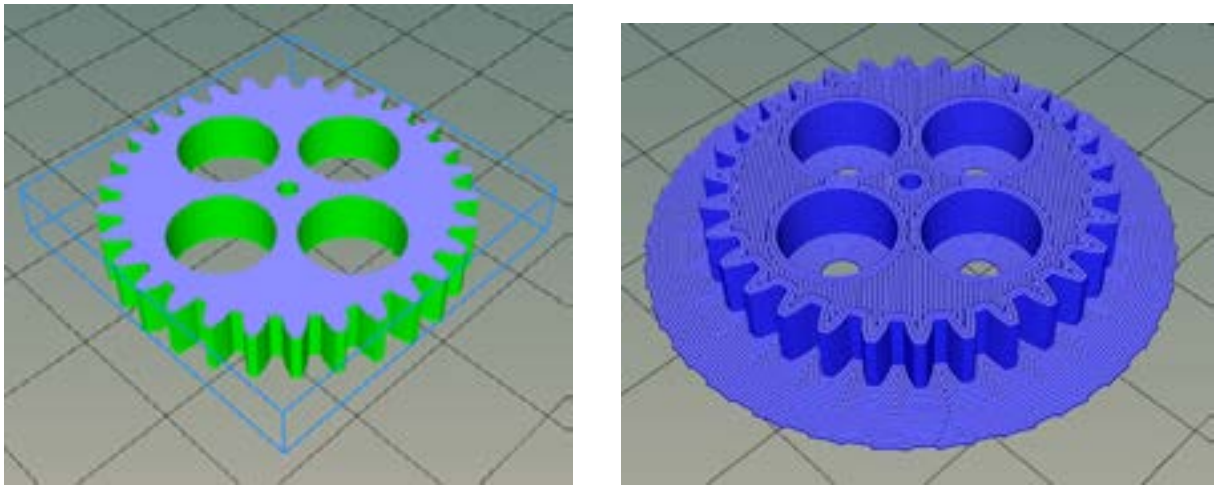

Figure 12: 3D model loaded in Vertex Repetier 1.6.2 (left) and prepared - sliced for 3D printing on Velleman Vertex K8400 3D printer

Figure 12 shows the generated 3D gear model (zupcanik) after being successfully loaded into Vertex Repetier-Host 1.6.2 (shown on left picture) and processed for slicing and prepared for 3D printing on the Velleman Vertex K8400 3D printer (shown on right picture). The slicing results indicate a total printing time of 13 minutes and 35 seconds, with the model divided into 25 layers. The estimated filament consumption is 536 mm, making it a lightweight, quick-to-print component suitable for testing or demonstration purposes. This output confirms the practical applicability of the DSL in producing functional 3D-printable models directly from SVG-based vector shapes.

5. DISCUSSION AND CONCLUSION

The development of a domain-specific language for parametric 3D modeling demonstrates the potential of DSLs in simplifying and democratizing 3D content creation. The combination of declarative syntax and ANTLR-based parsing results in a powerful tool that caters to both beginners and professionals. The language has been tested for creating a simple but powerful examples of a ready to print 3D models with high precision. The syntax is intuitive and significantly lowers the barrier to enter 3D modeling compared to full-fledged CAD software. In educational settings, the DSL serves as a tool for teaching geometry, transformations, and logic programming. This DSL abstracts away the complexities of traditional CAD environments by offering intuitive and readable commands that directly map to modeling actions. This reduces the cognitive load for users, especially beginners, and accelerates the design process by minimizing the need to navigate complex interfaces or understand intricate modeling workflows.

An important contribution of this work is the use of Croatian language commands within the DSL. By aligning the syntax with the natural language of the target user group, the barrier to entry is lowered, especially for students and non-programmers.

This approach improves mental mapping between spoken reasoning and written code, fosters confidence in using technical tools, and supports inclusive education by valuing native linguistic expression in computational contexts. The DSL is particularly suited for education, prototyping, and automation, and serves as a foundation for further research in DSL-driven design automation.

Current version of DSL is limited to predefined primitives. It also lacks advanced mesh operations (e.g., smoothing, boolean unions etc.). We developed a C# tool with GUI for writing, parsing and generating STL files without 3D renderer. Currently we are using third party tools to render STL files like 3D Builder, Google Sketchup and Blender 3D. We plan to address these limitations in future versions of DSL. For future work it is planned to include extrusions along arbitrary paths, parameterized pattern generations, enhanced syntax with conditional and looping constructs. It is planned to test DSL with students and other user groups.

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BALANCING COMPLEXITY AND PERCEPTION: A DATA-DRIVEN OPTIMIZATION FRAMEWORK FOR GAME DESIGN

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ABSTRACT

This paper explores the relationship between the technical complexity of video games and users' subjective perception of quality, aiming to determine the optimal combination of features that maximizes satisfaction under resource constraints. The main contribution lies in the development of a simulated multi-criteria optimization model implemented in Python. It uses aggregated user evaluation metrics as a proxy for perceptual value, while resource allocation is constrained by variables such as price, content density, and game duration, derived from a large-scale open dataset of Steam games. The model integrates discrete attribute vectorization, utility function scaling, and numerical optimization using simplex-based projection over a high-dimensional feature space. Additionally, the analysis includes the dimensionality reduction of categorical game descriptors to identify latent patterns in user preferences. The simulation results show that the marginal benefit of additional technical features decrease over time and that the optimal configuration of game features deviates from intuitive design expectations. These findings highlight the potential of data-driven modeling in identifying design strategies that are both perceptually effective and resource-efficient, especially relevant for independent developers and low-budget production environments. The proposed approach opens new directions for balancing design ambitions with technical feasibility in user-centered game development.

Keywords: game design, user perception, optimization model, technical complexity, Python, Steam dataset.

1. INTRODUCTION

Video games have evolved in recent decades from a niche entertainment industry to one of the dominant forms of media and digital expression, with significant market influence and increasingly sophisticated users. In such an environment, game design is no longer just a matter of creative expression but also a product of structured production processes, balancing various constraints including technical resources and user expectations. This raises an important question: which combination of technical and content features contributes most to the user's perception of game quality while remaining within production constraints?

Traditional approaches to game design often rely on the designer's experience, subjective judgment and generally accepted design principles. However, the increasing availability of user data and ratings provides an opportunity to develop more objective, data-driven approaches to design optimization. This paper is situated in this context and proposes a multi-criteria optimization framework that models the relationship between technical complexity and subjective quality perception using real data from the Steam platform.

The aim of the research is to develop a simulation model that considers various technical and content features of games along with constraints such as price, game duration and production resources, and uses aggregated user ratings to determine the optimal configuration of features that maximizes user satisfaction. The goal is to provide a concrete tool and methodological approach that can be particularly useful for independent develop-

ment teams and low-budget productions, where every design decision needs to be carefully optimized.
The paper presents the theoretical background, the methodological approach, the simulation results and a discussion on the potential impact of this framework on modern game development.

2. THEORETICAL BACKGROUND

The optimization of video game design based on user perception is gaining prominence in academic literature, largely due to the expanding availability of behavioral data and user-generated ratings. Research in this area encompasses a range of approaches, from psychological models of user experience and metrics for evaluating game quality to the use of data analysis techniques to identify preference patterns and predict user satisfaction. Traditional heuristic methods and designers' intuition are gradually being complemented by data-driven models that integrate machine learning, interpretable prediction algorithms, and multi-criteria decision techniques. Recent studies emphasize tools and frameworks that support strategic design decisions, especially given the constraints and limited production resources that characterize independent game development.
Ben Or, Kolomenkin, and Shabat developed a deep learning-based model (DL-DDA) for real-time dynamic difficulty adjustment. Their system continuously modifies difficulty levels based on user behavior and game objectives, aiming to enhance user satisfaction while maintaining a balanced gameplay experience [1]. The authors highlight that it is possible to accurately model the threshold between boredom and frustration through algorithmic regulation of difficulty in real time.
Similarly, Kristensen et al. applied factorization machines to personalize the prediction of players' preferred difficulty levels based on their prior behavior and in-game context [2]. Their model demonstrated high prediction accuracy (MAE < 0.2 across most datasets) and notably improved the user experience, particularly in games without a fixed progression structure.
In recent research, modeling user experience through real-time optimization has gained increasing attention, particularly in the context of mobile and resource-constrained systems. One example is an optimization framework that balances latency and visual quality in a metaverse environment, accounting for its impact on both user perception and gameplay profitability [3]. Using a multi-objective optimization approach with low computational complexity, the authors demonstrate that trade-offs between technical limitations and user experience can be effectively managed.
Barthet, Khalifa, Liapis, and Yannakakis introduced the concept of generative personas, AI agents trained to simulate user behavior and emotional responses. These agents, developed through real gameplay data, allow for early-stage testing of content design and balance, and have been shown to effectively predict critical frustration and drop-off points [4].
From a practical standpoint, Andersen and Lund demonstrated how user satisfaction can be optimized in real time using physical "playware" platforms equipped with interactive sensors. Their findings suggest that adaptive systems significantly enhance engagement and reduce user abandonment during gameplay [5]. The approach has proven effective in both educational and recreational settings, indicating strong potential for broader application.
To interpret complex models such as XGBoost in a user-centered design context, SHAP (SHapley Additive exPlanations) is increasingly adopted as a tool for local interpretability. According to Mourgan, SHAP values quantify the marginal contribution of each feature to the model's output while preserving consistency and intelligibility, particularly in nonlinear models where other interpretation methods fall short [6].

In multiplayer game environments, machine learning algorithms are used to dynamically balance difficulty, detect dominant or struggling players, and tailor experiences based on individual user profiles [7]. These adaptive systems significantly improve retention rates and minimize disruptive behavior, such as premature exits or toxic interactions.
CelerData describes systems that employ user interaction data as input for design optimization loops. By continuously monitoring behavioral signals, these systems identify underperforming content, such as levels with high bounce rates, and recommend targeted design interventions [8]. This data-driven feedback loop allows for agile, experimental design iterations based on minimal viable data.
Whimsy Games further emphasize the potential of machine learning to detect engagement drops in real time and automatically adjust core gameplay variables such as pacing, difficulty, and reward frequency to maintain player motivation and immersion [9].
From a technical design perspective, balancing visual fidelity, content richness, and performance efficiency is essential. Polydin Studio highlights that performance optimization is not only necessary for technical functionality but also for maintaining user retention, as overloaded interfaces and design clutter can adversely impact the gaming experience [10].
The foundational framework for these approaches was primarily provided by Seif El-Nasr, Drachen, and Canossa in [11]. Their work outlines a systematic methodology for collecting, processing, and interpreting player behavior data and demonstrates how quantitative metrics can be combined with qualitative user experience indicators to guide design decisions. Particularly valuable is their emphasis on embedding behavioral analytics directly into iterative design cycles. The literature provides a well-defined theoretical and methodological basis for developing a predictive framework that utilizes real user data, interpretable machine learning models, and feature optimization under technical constraints. This approach enables informed design decisions, particularly relevant for environments with limited development resources.

3. METHODOLOGY

This paper introduces a hybrid multi-objective optimization model that combines supervised machine learning and numerical optimization techniques. Its purpose is to identify the optimal configuration of video game features that maximize perceptual utility under constraints imposed by design complexity. The model is implemented in Python and leverages structured and semi-structured data sourced from a large-scale public dataset of Steam games.
In contrast to conventional heuristic or intuition-driven design strategies, the proposed framework incorporates data-driven prediction of user satisfaction, interpretable utility construction through explainable AI methods, and constrained optimization conducted within a high-dimensional convex decision space.

3.1. Predictive modeling of perceptual value

Prior to model training, an exploratory data analysis was conducted to examine the distributions and correlations of selected features. Prior to model training, an exploratory data analysis was conducted to examine the distributions and correlations of selected features. Pearson correlation was used solely as a preliminary tool for orientational evaluation of linear relationships between individual features and the target variable (pct_pos_total). It served visual inspection via correlation matrices and for the initial removal of features that showed no linear association. The correlation analysis was strictly descriptive, while the core modelling approach relied on non-linear methods (XGBoost).
User-perceived value is modeled as the target variable y, calculated as the empirical probability of positive ratings relative to the total number of ratings:

$$y = \frac{r^+}{r^+ + r^-} \quad (1)$$

where r^+ and r^- denote the number of positive and negative user ratings, respectively. Given the non-linearity and sparsity of the input feature space, the prediction model employs the eXtreme Gradient Boosting (XGBoost) regressor, incorporating regularization and tree depth constraints to mitigate overfitting.
Let $x \in \mathbb{R}n$ denote the feature vector of a game instance, where xi represents the normalized value of feature i. The predictive mapping $f : \mathbb{R}n \rightarrow [0,1]$ is learned from the training dataset, defined as:

$$\mathcal{D} = \left\{\left(\boldsymbol{x}^{(k)}, y^{(k)}\right)\right\}_{k=1}^{N} \quad (2)$$

using an ensemble of decision trees Tj, such that:

$$f(\boldsymbol{x}) = \sum_{j=1}^{M} T_j(\boldsymbol{x}) \quad (3)$$

Each tree Tj is trained to minimize a regularized objective function consisting of a convex

$$\mathcal{L}(y, \hat{y}) + \Omega(T_j) \quad (4)$$

where $\mathcal{L}(y, \hat{y})$ denotes the loss function between true and predicted values (i.e., squared error or logistic loss), and the regularization term is defined as:

$$\Omega(T_j) = \gamma \cdot |T_j| + \frac{1}{2}\lambda \sum_{w \in T_j} w^2 \quad (5)$$

where |Tj| represents the number of leaf nodes in tree Tj, and w denotes the weights associated with the leaf outputs.

3.2. Dataset and preprocessing

A sample of 1,000 entries (999 valid rows) was extracted from the cleaned Steam dataset. Ten variables were selected for analysis, grouped into three categories: target variables (pct_pos_total, num_reviews_total), complexity constraints (dlc_count, achievements, supported_languages, average_playtime_forever), and descriptive input features (genres, categories, tags, release_date). All selected entries contained complete data, with consistent data types across columns. As no missing values were detected, no imputation was required.
Numerical features were normalized using Min–Max scaling, as described in Section 3.5. Categorical features (genres, categories, tags) were transformed using one-hot encoding. Additionally, an optional outlier check was performed using the interquartile range (IQR) method:

- Lower Bound = Q1 − 1.5 × IQR
- Upper Bound = Q3 + 1.5 × IQR
- IQR = Q3 − Q1

The fully preprocessed dataset was saved under the name steam_game_analysis_sample_1000_normalized.csv and used in subsequent modeling and evaluation procedures.
To support further interpretability, the following variables were included in the analysis:

- pct_pos_total – the proportion of positive user reviews out of the total reviews; used as the target variable in predictive modelling.
- num_reviews_total – total number of user reviews, indicating general exposure

and popularity.

- dlc_count – number of downloadable content (DLC) items available for the game, reflecting its post-launch expansion.
- achievements – total number of in-game achievements offered to players.
- supported_languages_count – number of languages officially supported by the game interface.
- average_playtime_forever – average cumulative playtime per user, expressed in hours.
- genres, categories, tags – categorical descriptors of gameplay style and functionality, encoded using One-Hot Encoding.
- release_date – year of official release, converted to numerical format to enable chronological analysis.

All numeric variables were normalized, and categorical attributes were preprocessed as binary indicators where applicable.

3.3. Derivation of utility function using SHAP values

To enable interpretable optimization over the feature space, the output of the prediction model is decomposed into additive feature contributions using SHAP (SHapley Additive exPlanations), a unified framework grounded in cooperative game theory. SHAP assigns to each feature xi a value ϕi ∈ ℝ, represents its average marginal contribution to the model's output across all possible feature coalitions.
The resulting utility function U(x) is expressed as a linear combination of the normalized features, weighted by their corresponding SHAP values:

$$U(\mathbf{x}) = \sum_{i=1}^{n} \phi_i \cdot x_i \quad (6)$$

where:

- ϕi denotes the SHAP value of feature xi,
- xi is the normalized feature value,
- and n is the number of features.

This formulation transforms a non-linear ensemble model into a linearized utility function that preserves local interpretability while enabling convex optimization. The SHAP values ϕi are extracted post hoc from the trained XGBoost model and serve as empirically derived weights reflecting the relative impact of each feature on the predicted user-perceived value.

3.4. Constrained optimization in a high-dimensional feature space

To support the main objective of the research, an optimization mechanism was developed based on a SHAP-weighted utility function, where each feature is assigned, a value representing its contribution to user perception and a corresponding cost coefficient. The goal is to identify a configuration of features that maximizes the overall perceptual value within a predefined complexity budget, thereby enabling the selection of feasible design solutions under limited development resources.
The optimization problem is defined as the task of maximizing the SHAP-derived utility function over a bounded, high-dimensional feature space, subject to a global constraint on design complexity. Each feature is assigned a scalar cost coefficient ci ∈ ℝ+, reflecting its relative contribution to overall development effort, such as implementation cost, content richness, or integration complexity.

Let x = (x_1, x_2,...,x_n) ∈ ℝn denote the normalized feature vector, and let ϕi ∈ ℝ represent the utility weight of feature i, derived from SHAP analysis. The optimization problem is formally defined as:

$$\text{maximize} \quad U(\boldsymbol{x}) = \sum_{i=1}^{n} \phi_i \cdot x_i \tag{7}$$

$$\text{subject to} \quad \sum_{i=1}^{n} c_i \cdot x_i \leq B \tag{8}$$

$$0 \leq x_i \leq x_i^{max}, \forall_i \in \{1, \dots, n\}$$

In this formulation:

- B ∈ ℝ+ is the upper bound on total complexity or effort,
- ximax is the empirically defined maximum for each feature,
- and ci serves as a linear penalty coefficient related to design overhead.

The feasible region defined by the above constraints is convex and bounded, which guarantees the existence of a global optimum as a consequence of the convex objective function and linear constraint set. Optimization is performed using a projection-based simplex method, implemented via the scipy.optimize.linprog routine, with dual feasibility tracking and anti-cycling rules applied to ensure numerical stability.
This optimization framework identifies near-optimal design configurations that maximize predicted perceptual utility while remaining within realistic development constraints.
Although price was initially considered as a potential proxy for development cost or feature richness, preliminary analysis indicated a weak and inconsistent relationship with perceptual utility. As such, it was excluded from the final optimization formulation, though retained in exploratory visualizations and correlation analysis.

3.5. Feature encoding and normalization

The original dataset contains both continuous and categorical variables that require preprocessing to support numerical optimization. Categorical features such as genres, tags, and supported_languages are transformed using one-hot encoding, resulting in a high-dimensional sparse binary matrix:

$$X \in \{0,1\}^{N \times d} \tag{9}$$

where N is the number of game instances and d is the total number of unique categorical values across all encoded features.
Continuous and ordinal variables, including average_playtime_forever, achievements, supported_languages_count, are normalized using min-max scaling to ensure comparability within the utility function:

$$x'_i = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \tag{10}$$

This transformation maps each feature xi to the interval [0,1], preserving relative magnitudes while eliminating differences in scale. For features with outliers or long-tailed distributions, winsorization was applied prior to normalization to reduce potential distortions.
Feature vectors were verified for dimensional consistency across the training and optimization phases to ensure that no structural changes occurred between SHAP value extraction and utility evaluation.
The corresponding optimization problem can be formally expressed as:

$$\mathbf{x}^* = \arg\max_{x} \left\{ \sum_{i=1}^{n} \phi_i \cdot x_i \;\middle|\; \sum_{i=1}^{n} c_i \cdot x_i \leq B, 0 \leq x_i \leq x_i^{max} \right\} \quad (11)$$

where x* denotes the optimal feature configuration that maximizes predicted perceptual utility within the feasible design space defined by the specified constraints.

3.6. Technical implementation

The entire pipeline was implemented in Python. A modular architecture was employed to separate the prediction, explanation, and optimization phases. The following libraries and frameworks were used:
xgboost (version 1.7.6) for training and tuning the predictive model
shap (version 0.41.0) for post hoc model explanation and utility weight extraction
scipy.optimize (SciPy version 1.11.3) for linear programming and numerical optimization
pandas (version 1.5.3), numpy (version 1.24.2), and scikit-learn (version 1.2.2) for preprocessing, feature engineering, and data processing
matplotlib (version 3.7.1) and seaborn (version 0.12.2) for visualizations, diagnostics, and exploratory data analysis
All computations were performed using Python 3.12 in a reproducible environment with fixed random seeds and controlled data splits. The code was executed on a standard personal computer, and all dependencies were managed via pip using a requirements.txt file to ensure full reproducibility.
Version control was maintained throughout the development process. All results presented in this paper can be reproduced using the documented pipeline and fixed initialization parameters.

4. RESULTS

This chapter presents the results of data analysis and predictive modeling related to the perceptual value of games. The focus is placed on the distribution of key features, model interpretation, and the optimization of design decisions.

4.1. Exploratory data analysis

For the descriptive data analysis, the distribution of the key features used in the modeling was examined, including pct_pos_total, num_reviews_total, dlc_count, achievements, supported_languages_count, and average_playtime_forever. The following figures illustrate the distributions of the core features included in the analysis.

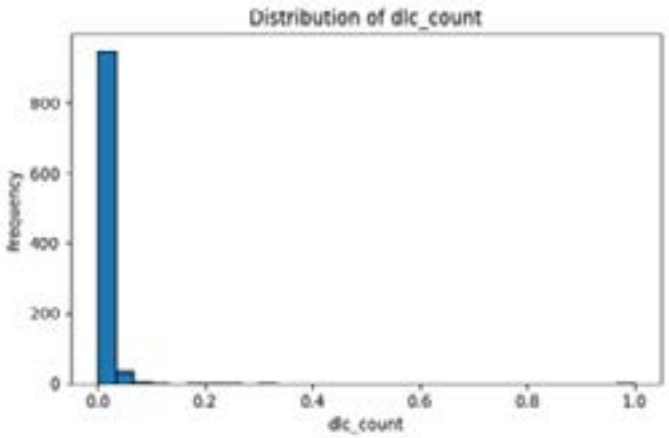

Figure 1: Distribution of dlc_count

As shown in Figure 1, the distribution of the variable dlc_count, which exhibits a pronounced right skew. Most games offer a very limited amount of additional content (DLCs), while a smaller number of titles include a significantly higher number of expansions. This distribution suggests that the majority of games do not rely on DLCs as a central design element, whereas a select group of titles use them extensively, likely as a strategy to extend the game's lifecycle and increase revenue.

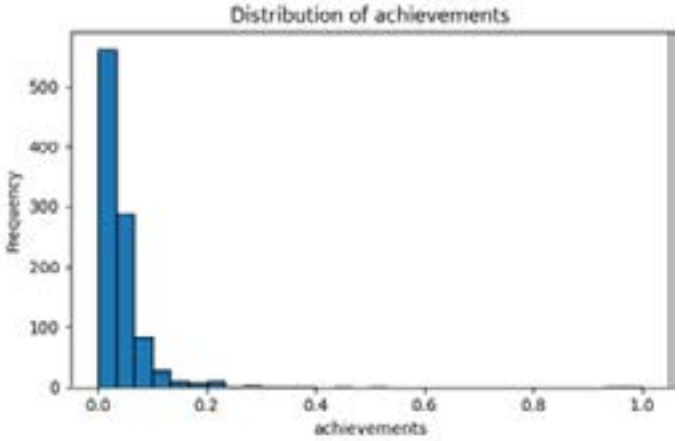

Figure 2: Distribution of achievements

Figure 2 shows that the distribution of the achievements variable also exhibits a pronounced right-skewed pattern. Most games offer a relatively small number of achievements, while a smaller subset features extensive reward systems with a high count. This distribution reflects divergent design strategies: some development teams incorporate achievements only minimally, whereas others employ them as a key mechanism for enhancing player engagement and retention.

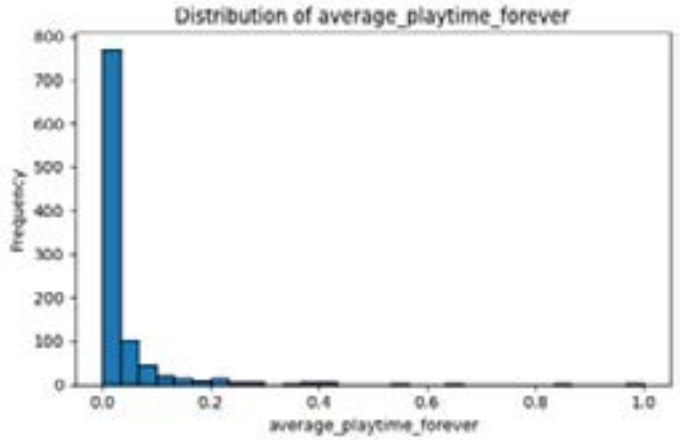

Figure 3: Distribution of average_playtime_forever

According to Figure 3, the distribution of the variable average_playtime_forever, which also exhibits a pronounced right skew. Most users spend a limited amount of time in the game, while a smaller number of players accumulate significantly longer playtimes. This pattern suggests the presence of a small group of highly engaged users, whereas the majority of interactions remain time-constrained, possibly due to differences in game genres, mechanics, or target player demographics.

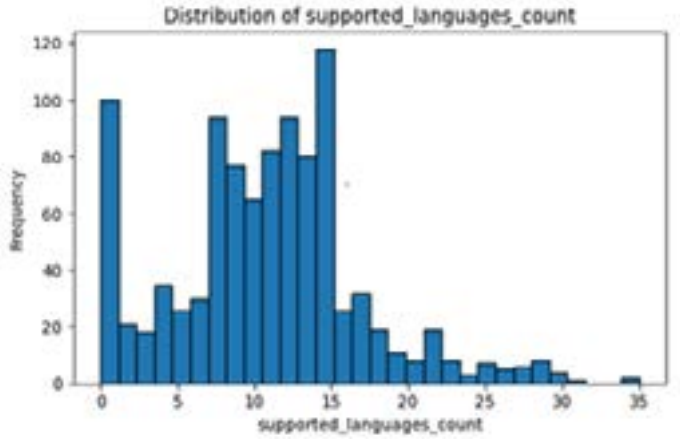

Figure 4: Distribution of supported_languages_count

As shown in Figure 4 the distribution of the variable supported_languages_count, which spans a very wide range from 0 to over 35 languages. Most games support a relatively small number of languages, typically between one and five, while a smaller subset of titles stands out with exceptionally high levels of localization. This distribution reflects substantial variation in localization strategies: some publishers deliberately expand their market reach through multilingual support, while others focus solely on the most essential or dominant languages.

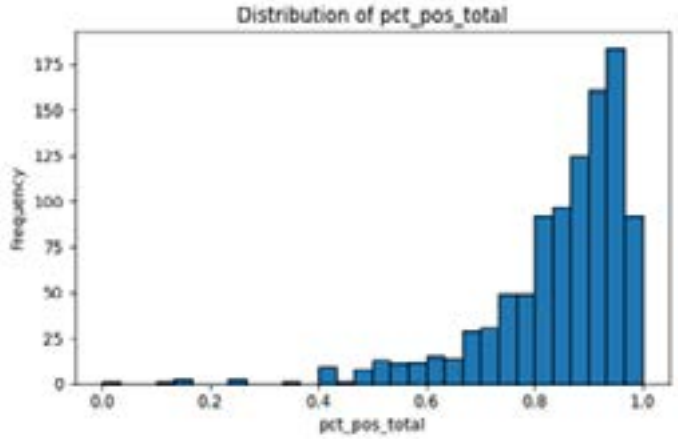

Figure 5: Distribution of pct_pos_total

Figure 5 shows the distribution of the target variable pct_pos_total, which displays a pronounced concentration of values at the upper end of the spectrum. Most games have a proportion of positive user ratings between 0.8 and 1.0, indicating a generally high level of user satisfaction. Lower scores are much less common, suggesting that negatively rated games are the exception rather than the norm. This distribution further supports the use of this variable as a reliable indicator of perceived game quality.

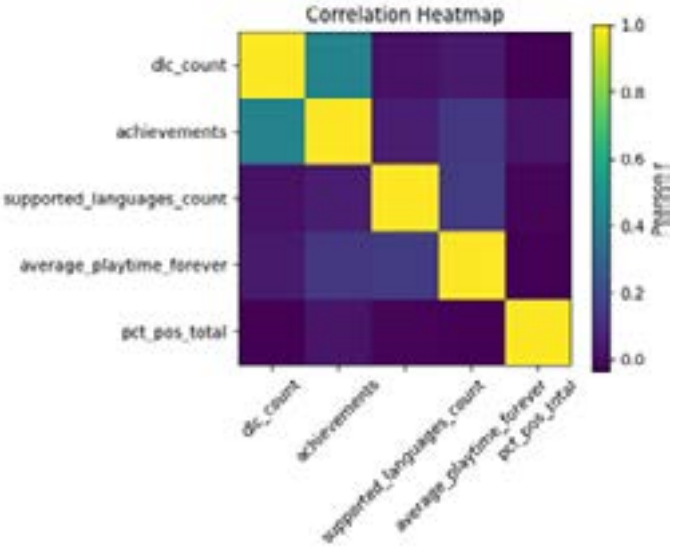

Figure 6: Correlation Heatmap

As illustrated in Figure 6 the correlation matrix based on Pearson coefficients for all numerical variables included in the analysis. Most features exhibit very weak linear relationships with the target variable pct_pos_total, with correlation values rarely exceeding an absolute value of 0.2. These findings indicate the limited predictive capacity of linear models in this context and further justify the application of non-linear approaches in the subsequent modeling stages.

4.2. Performance Evaluation of the Predictive Model

A machine learning model based on XGBoost regression was trained to predict the perceptual value of games, expressed as the proportion of positive user ratings (pct_pos_total). The model was trained on 80% of the dataset and evaluated on the remaining 20%, with all numerical features normalized prior to training.
On the test set, the model achieved a root mean square error (RMSE) of 0.0712 and a coefficient of determination (R^2) of 0.6833. These results indicate a moderately high capacity of the model to explain the variability of the target variable, particularly in light of the non-linear and high-dimensional relationships among the input features. The observed level of predictive accuracy supports the relevance of the selected features and the appropriateness of a non-linear modeling approach for capturing subjective quality perception.

4.3. Interpretability and Optimal Feature Configuration

To better understand the underlying factors behind the model's predictions and to enable rational optimization of game features, the results were interpreted using SHAP values. This method allows each individual prediction to be decomposed into the additive contributions of individual attributes, providing insight into the relative influence of each feature on the predicted perceptual value of a game.
The analysis revealed that the number of positive and negative user ratings dominates as the most influential variable in the model. Among technical features, those related to additional content, particularly achievements and dlc_count, exhibited the highest mean absolute SHAP values, indicating a consistent and significant contribution to perceived quality (Figure 7).

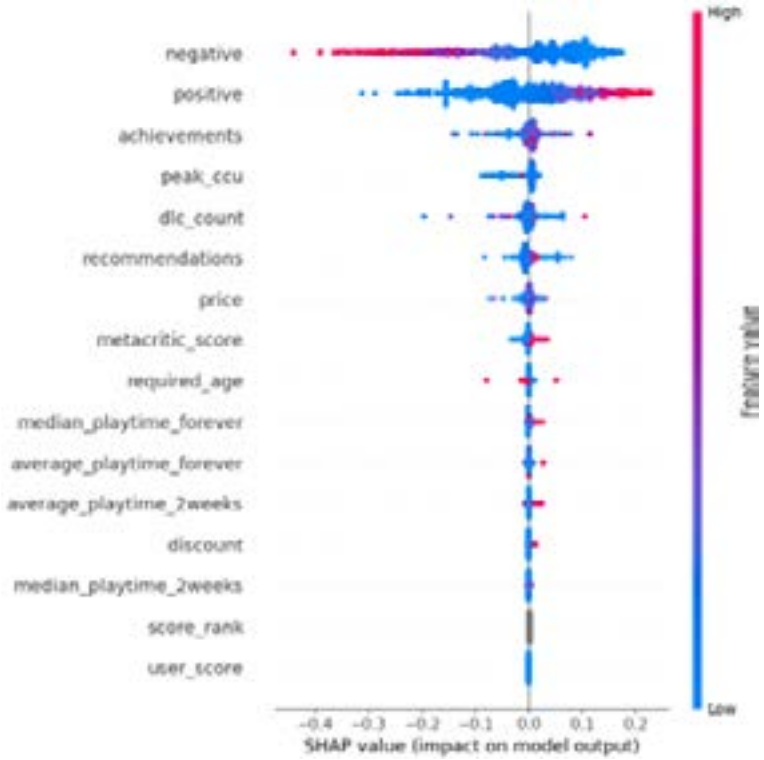

Figure 7: SHAP summary plot

Figure 7 shows the SHAP values for all features used in the model, ranked by their average influence on the prediction of the perception score. Variables related to user ratings (neg-

ative and positive) have the greatest impact, while among the technical features, achievements and dlc_count contribute the most. This visualization enhances model transparency and confirms the relevance of the features later used in the optimization process.
Based on these insights, an optimization problem was formulated with the objective of maximizing overall perceptual value under a predefined resource constraint. A complexity budget of B = 5.0 was imposed, and the optimal configuration was derived by solving a linear optimization problem using the normalized feature values and their corresponding SHAP weights.
The resulting solution allocates the entire available budget to achievements and dlc_count ($x = 1.0$), while all other features are set to $x = 0.0$. This outcome clearly suggests that prioritizing the development of additional content such as achievement systems and downloadable expansions, yields the greatest perceived value under limited development resources.

5. CONCLUSION

This paper presents a data-driven framework for optimizing video game design by integrating technical complexity with user-perceived quality. The model combines machine learning, interpretable SHAP values, and numerical optimization to determine the feature configuration that maximizes perceptual value under constrained development resources. The analysis results show that while most games receive high positive user ratings, only certain technical features consistently contribute to this perception. Although many features are intercorrelated, SHAP-based interpretability analysis clearly identified achievements and additional downloadable content (dlc_count) as the features with the highest average impact on user satisfaction. Under a fixed complexity budget ($B = 5.0$), the optimal configuration allocates all available development resources to these two features, disregarding all others.
This data-driven approach demonstrates that although technical features may co-vary, it is the depth of post-release content that most effectively boosts user satisfaction per unit of effort. Independent development teams, particularly those with limited resources, should prioritize reward systems and additional content over extensive localization or prolonged gameplay features.
The proposed framework shows that objective and rational design decisions can be made based on real user data and highlights the potential for broader application of similar models in the video game industry.
All scripts and processed data used in this study are available upon request from the corresponding author.

6. CODE AVAILABILITY

The Python scripts used for data preprocessing, modelling, and optimization are available at https://github.com/TGraba/SteamDesignOpt

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STUDENT PHOTO COMPETITION AND EXHIBITION: HUMAN CHARACTER

8 May – 8 July 2025

EXHIBITION VENUE:

Entrance hall of the University of Zagreb Faculty of Graphic Arts, Getaldićeva 2, Zagreb

CURATORS & JURY:

Ivana Pavlović, PhD; Assist. Prof. Mario Periša; Assoc. Prof. Miroslav Mikota

EXHIBITION LAYOUT:

Ivana Pavlović, PhD

TECHNICAL PREPARATION TEAM:

Francesca Danese; Antonela Kljajić; Filip Marjanović; Iva Šarčević, PhD

EXHIBITORS:

Laura Baronić, Domenica Beronić, Marin Čanković, Ema Crneković, David Fabić, Marija Jelkić, Teodora Lukavski, Marta Maglić, Filip Marjanović, Sara Iva Merlić, Melani Mihalić, Lorena Miletić, Tena Naglić, Laura Orešić, Tea Pokas, Sunčica Pušnik, Gabrijela Radić, Lara Rich, Iva Roca, Karla Rogić, Gordana Sambol, Ivana Sladović, Nikolina Sršen, Doris Stanimirović, Lara Suknaić, Vanesa Vasilj, Veronika Žužinjak

EXHIBITION DESCRIPTION:

In a time when the concept of identity is being reconsidered through the lenses of social media, the crisis of closeness, and the redefinition of the boundaries between public and private, students from various faculties present their own visions of the human figure. This exhibition is the outcome of a competition that attracted over 70 authors from Croatia and the region.

Through ten carefully designed exhibition frames, the show explores emotion, presence, authenticity, and the expression of body and face — and also what lies behind them: fragments of identity, intimacy, resistance, and belonging. Each photograph carries a personal story, and together they form a powerful collective portrait of a generation — vulnerable, loud, quiet, introspective, tender, and defiant.

A total of 73 students submitted 269 photographs for the “Human Figure” competition, held as part of the Blaž Baromić conference. The exhibition features 27 authors with 35 photographs. Represented are students from the University of Zagreb (Faculty of Graphic Arts), University North, University of Split, University of Rijeka, and University of Mostar.

THE AWARDED WORKS BY STUDENTS ARE:

Individual category:

Laura Orešić – 1st place

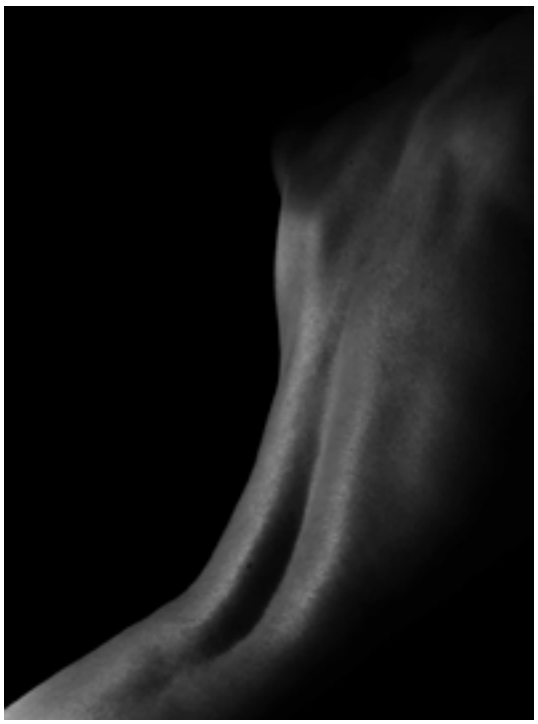
Teodora Lukavski – 3rd place

Iva Roca – 2nd place

Ema Crneković – Honorable Mention

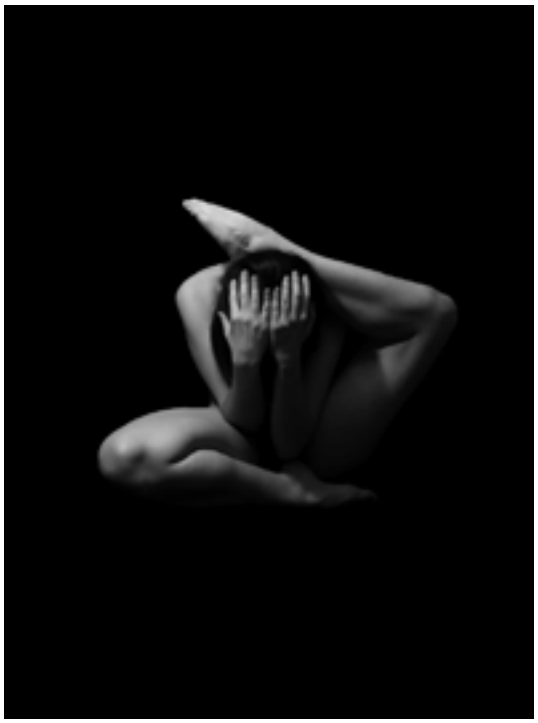
Lara Rich – Honorable Mention

Series category:



Marija Jelkić – 1st place

Melani Mihalić – 2nd place



Laura Baronić – 3rd place

Doris Stanimirović – Honorable Mention

Veronika Žužinjak – Honorable Mention

EXHIBITION: CONCEPTUAL SOLUTIONS FOR AN EDUCATIONAL BOARD GAME

This exhibition showcases student works on the design of visual identities for board games with an ecological theme, including trademarks, logos, game cards, and augmented reality elements. The projects were created within the Graphic Media Design 1 course.

EXHIBITORS:

Mara Đurica - ZEKOEKO
Ani Einwalter - ZOOZ
Elena Harastil – BLOSSOM BEARS
Korina Holjevac – PRIMI SE MOTIKE

EXHIBITION: CONCEPTUAL SOLUTIONS FOR TRADEMARK DESIGNS

The exhibition presents ten student works showcasing the process of developing logo design concepts for a fictional client, based on a given brief and two concepts that the visual identity should communicate. The concepts are analytically developed across different categories and approaches intending to achieve professionalism, innovation, and communicative solutions that are technologically feasible and applicable across various media. Categories include logo design solutions (typography), initials, symbols, or a combination of these. Approaches focus on the selection of motifs and the level of stylization through the choice of structural elements (lines, shapes), types of contrast (color, size, positive/negative), and composition of elements (symmetry, asymmetry, harmony, unity). The visual presentation is complemented by textual explanations to aid the understanding of the concepts based on the category of solution execution and the aesthetic approach to design. This exhibition presents the practice of solving project tasks from public competitions, which students are trained for within the course.

EXHIBITORS:

Laura Baronić - Gallery DIVERSONA
Tea Fazinić - 3D Modelling Studio PERXPEKTIVA
Danica Jurič - Marketing Agency RADIA
Nina Kalin - Radio station OAZA STREAM
Veronika Lojan - Dental 3D Modeling SMILE MODEL
Dora Podbevšek - Medical 3D Object Visualization ORTOFORM3D
Iva Presečki - Photo studio FOTOSTORIA
Tereza Puhalović - Amateur Theatre Group DRUGA
Anastazija Savčukov - Library MUDRA SOVA
Dorotea Turkalj - International Conference on Sustainable Development SAPECON

EXHIBITION: DESIGN OF SELECTED GRAPHIC PRODUCTS

Design of Selected Graphic Products is an immersive course where students engage with the entire design process – from initial concept to finished product. Through practical projects including packaging redesigns, 3D mockups, and comprehensive branding development, participants acquire essential skills in packaging design, typography, and product creation from scratch. Students learn to harmonize aesthetic appeal with practical functionality while responding to real-world design challenges. Coursework emphasizes creative problem-solving, with projects evaluated on four key criteria: innovation, usability, functionality, and presentation quality – effectively preparing students for professional design practice.

EXHIBITORS:

Laura Baronić, Rea Franković, Katarina Hrabar, Andrea Ivanković, Nina Kalin, Borna Knežević, Mateja Marijić, Matej Mlakić, Ante Parunov, Iva Presečki, Lana Prigorac, Paula Rambrot, Anastazija Savčukov, Dario Zagorac

This conference is supported by:

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