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Obuda University
REJTŐ SÁNDOR FACULTY OF LIGHT INDUSTRY AND ENVIRONMENTAL ENGINEERING

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PROMOTING HUMAN POSITIVE FUNCTIONING THROUGH THE INTEGRATION OF POSITIVE PSYCHOLOGY AND AGEING PSYCHOLOGY WITH DESIGN AND ENGINEERING RESEARCH

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Abstract

The promotion of human positive functioning is nowadays a central objective of different areas of research. Positive Psychology has demonstrated, through numerous studies, in synergy with Design, that it can give life to effective projects for health and well-being in the different stages of life. An example, which will be explored in greater depth, concerns the emerging area of research on the relationship between frequenting art venues, particularly museums, and the psychological and social well-being of people of all ages. This result, which is linked to various individual psychological processes under study, is also the fruit of the construction of stimulating and appropriate environments for experiencing knowledge, personal growth, stress reduction, a field of research and intervention of Design and Engineering. A second area of research concerns the phenomenon of population ageing, which is defined by the WHO as a true "global challenge". It requires multidisciplinary research and intervention efforts, in order to promote active, independent and quality ageing for the greatest possible number of people. Even in this field of research, the synergy between Psychology in its various theoretical declinations, Design and Engineering can represent a valid response to this social challenge. Indeed, new areas of research demonstrate interesting connections between healthy lifestyles and cognitive, physical, and social functioning, highlighting the role of resources such as creativity in longevity. Research in Engineering and Design could provide new tools to improve or enhance these transversal skills and abilities.

Keywords: *Positive Psychology; Positive Ageing; psychological well-being; museums attendance; Design; Engineering.*

INTRODUCTION. A changing World; numerous challenges that it faces, the necessity of new approaches to well-being and positive development of people.

The contemporary world is characterized by rapid changes at social, economic, climatic, technological, demographic level. The climate change, for example, will produce (or is producing) substantial changes in agriculture, ways of living (e.g. facing more frequently with events such as floods, hurricanes). Demography, as we can see, is now radically changing the proportion of age cohorts. All these changes bring with them challenges that can expose individuals to difficulties, stress, conflicts, requesting for these reasons new ways of thinking and acting at individual and collective level. The COVID-19 pandemic evidenced the frailty of our societies in the face of extraordinary critical events, requesting effective projects, strategies, actions and competencies for facing them and for preventing them, or their worse outcomes.

For these above mentioned, but not limited to, changes at planetary level, all the disciplines, all the research areas are called to give their contribution for tracing and identifying effective strategies, ways to approach them and, at the same time, to encouraging and promoting the positive development of individuals, groups and societies, helping in finding new solutions, new approaches to these challenges, strengthening the efficacy of individuals and communities.

The integration of different research areas can improve the discovering of new ideas, new answers, new ways of thinking and acting for these challenges, avoiding, were possible, worse outcomes and promoting a positive development for all people, helping to find effective strategies against stress and

other adverse conditions that these challenges can bring with them. Taking into consideration these premises, we discuss, in this article, the possibility of integration between two areas of Psychology, namely Positive Psychology and Ageing Psychology with Design and Engineering research for improving the life quality and the overall well-being of people.
For the joint contribution of Positive Psychology and Design, we discuss some issues about an emerging area of research, the contribution of museums for reducing stress, improving the well-being of people.
Positive Psychology, indeed, together with Positive Design, can help people to reach a better well-being through places of culture: as stated Ryff [1] [2] "the arts, broadly defined, have long nourished human flourishing, including during times of difficulty", and that "the merging of arts, science and practices constitutes a worthy vision of the future". [2].
The second area of research, the population ageing, corresponds to one of the major challenges of the Planet, and requests new approaches in order to reduce the risk of disability, to prolong the autonomy of old people and to assure to them the best choices for participating to the development of the society. Psychology, Design and Engineering are called to work together for reaching these objectives.

Positive Psychology: fostering the well-being of individuals, groups, society

The issue of human well-being has been the subject of reflection and research since 1960s. In particular, with the Social Indicator Movement [3] research has highlighted how it is not only objective parameters such as income, that determine the well-being of individuals, but rather more subjective dimensions such as the perceived quality of life.
It was at the beginning of the 2000s that Positive Psychology was officially born, which, turning back the traditional objective of psychology, emphasizes the promotion of positive experiences, and the study of well-being of individuals, groups, society, instead of maladjustment and suffering [4].
The study of well-being, and the possibility to create models of intervention for improving it, started with two fundamental, individual perspectives, rooted into ancient Greek philosophy, namely the Hedonic well-being and the Eudaimonic well-being.

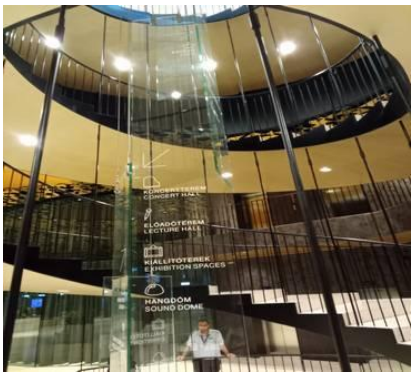
The Well-being in a "hedonic" perspective interprets well-being (and the achievement of happiness) in its affective dimension (presence of positive emotions, reduction of the experience of negative emotions) and life satisfaction [5] (from the Greek philosophy of Aristippus, concept of hedonè). The concept of Hedonic well-being is characterized by a hierarchical structure with well-being at the apex; at the lower level there are four components: Life satisfaction: how close one's life is to the ideals, to the values of the person; Satisfaction for specific areas: how close one's life is to one's ideal in the emotional, work, relational areas; Positive affects: how much positive experiences and emotions are experienced in the last few week; Negative affects: how much negative experiences and emotions are experienced in the last few weeks. In these last decades, studies on hedonic well-being and its relevance for positive functioning confirmed that positive affect, life satisfaction, and happiness predict numerous disease outcomes, including fewer clinical colds [6], lower hospital readmission rates, [7] lower body mass index (BMI) among adolescents, [8], lower risk of stroke [9] and lower risk of incident coronary heart disease and hypertension [10]. Different from the Hedonic perspective of well-being, the Eudaimonic well-being corresponds to the actualization of talents and potentials of individuals, for reaching common good (from the Greek philosophy of Aristotle, Nicomachean Etic; [11], [1], [12]. The well-being, for this perspective, is related to the possibility of growing as person and have projects in life (Little et al., 2007) [13], and is conceptualized as composed by six dimensions: Self-acceptance; Autonomy; Positive relations with others; Purpose in Life; Personal Growth; Environmental Mastery. Other eudaimonic perspectives comprehend the model by Ryan & Deci of Self-Determination, [14] that consider three fundamental human needs: Autonomy; Relatedness; Competence. Extensive research [1] [2] has linked purpose in life, one of the core dimensions of Eudaimonic well-being, to multiple disease outcomes, including reduced incidence of Alzheimer's disease and mild cognitive impairment, [15] reduced risk of stroke,[16] myocardial infarction among those with coronary heart disease [16] and performance-based and subjective cognitive outcomes [17]. Considering the alternative directional influence, poor health or disease has also been associated with compromised Eudaimonic well-being [18]. Eudaimonia is also connected to ego development and maturity in developmental stages of life [19].

The places of culture for improving different kind of well-being and reducing stress. The "case of museums".

An emergent area of research is represented by the studies that try to evaluate the role of places of culture such as the museums for improving the well-being of people at all stages of life. This new area of research is multidisciplinary in nature, collecting several different areas of knowledge such as Psychology, Design, Education. Indeed, recent studies accomplish on the relevance of integration between Psychology and Design for making the visits able to improve the well-being of people [20].
As state Cotter & Pawelski [21], a growing area of research focuses on the connection between arts and humanities engagement, and flourishing. They highlight the Positive Humanities as an emerging field of research and application, connected to the core dimensions of Positive Psychology. Indeed, large-scale studies suggest that greater engagement with the arts is associated with living longer and lower mortality risk,[21], [22] maintains that Eudaimonic well-being can be enhanced through the active engagement in arts.

Positive Design represents a new area of study that intercepts these issues, proposing new ideas, approaches and methodology, integrating Positive Psychology principles within it [23],[24].This approach, firstly elaborated at Delft Institute of Positive Design, is aimed at improving the positive state of mind, the well-being of communities, and stimulating the development of knowledge that supports designers in their attempt to design for human flourishing. Desmet & Pohlmeyer [23] strongly believe that "it is our responsibility as design researchers generate knowledge that enables designers to formulate effective strategies in contributing to the happiness of people". Positive design, for this reason and theoretical premises, can give a strong contribution to the environment of museums, to the usability of interactive tools, to the fascination effect [25] inside the rooms and for the contemplation of the art product, technical products and scientific discoveries. (see figure n. 1 and n. 2).
Numerous studies, with broad samples, suggest that the assiduous involvement in the art is associated at a higher longevity and a lesser risk of mortality [26], less loneliness [27] and to a better perception of health [28]. Research have also evidenced that visual art, its observation, is accompanied by a decrease of stress [29], a decrease of cortisol, the "stress hormone" [30] [32] and an increasing in subjective Hedonic well-being.
Smith [31], speaking about the places of culture, defines a real "museum effect": research suggests that the visitors get involved in reflections on themselves, the future and on broad questions during the visit, that are considered among the most important and long-lasting effects, since they give life to an authentic transformation of the person [32].

Figure n. 1 and Figure n. 2. The "House of Sound" in Budapest. You can stay inside, can listen to music, and enjoy the suggestive design (*photos of the author of the article)*



Several authors have elaborated theoretical models for explaining the possible effects of museum attendance on visitors.

Pelowski et al.,[33] have proposed the Viennese Integrated Model of Art Perception (VIMAP), which considers the perceptual and cognitive responses to museums visit experience and that comprises five possible outcomes:1. Simple and superficial experience; 2. A new and insightful experience, where people experience a certain surprise but do not engage deeply with art; 3. A negative experience in which negative emotions prevail, which determines distancing from art; 4. A harmonious experience thanks to which people experience a range of conditions such as flow, emotion and feeling this experience as pleasant; 5. A transformative experience in which people engage with art, reflect on their pre-existing schemes, modifying them on the basis of new acquisitions.
Shim et al., [34] have proposed the RAISE model, that identifies five mechanisms that contribute to the experience of flourishing in relation to art: 1. Reflection. Changing habits, values through art; 2. Acquisition. Gaining new skills and knowledge; 3. Immersion. Experience of flow; 4. Socialization. Having meaningful conversations during art engagement. 5.Expression of emotions. Express oneself.

The Museum Malmerendi study: an example of integration between Positive Psychology and Positive Design for improving psychological well-being of people. Interactive and immersive tools for psychological personal growth and positive emotions.

This study started for examining the effect of visiting this small prehistoric museum, located in Faenza (Italy), on the Hedonic and Eudaimonic well-being of adult visitors. It integrated two research areas: the Positive Design (that includes, in this case, the construction of new immersive virtual or interactive tools, the creation of a guide that facilitate the visit) and the Positive Psychology, which evaluate the perception of well-being after the visit of the museum. Flow was hypothesized as the connecting experience between the design of artifacts and the well-being outcomes, the experience of positive emotions and the personal perception of growing through the visit to the museum.
The creation of immersive and interactive artifacts/tools and the valuation of flow experience, Hedonic (emotions) and Eudaimonic well-being (personal growth), as outcomes for visiting the museum in a sample of adult people were the main purposes of this research, conducted on 138 adult visitors during the summer 2024.

Figure n. 3.The Malmerendi Museum (Faenza, Italy).

The museum collections and new immersive tools created for the research [35].

Figure n. 4 and Figure n. 5. The prehistoric grouper as fossil and as immersive animated reconstruction.

Figure n. 6. And Figure n. 7. The Mammoth of Oriolo, Faenza (Brizio S. 2025, above cited). The fossil and the dynamic virtual reconstruction of the animal and its habitat.

Main results of the study

The statistical analyses confirm the high level of personal growth for visiting the Malmerendi museum (M= 3.81); the high level of positive emotions experienced (M = 3.82) and the high level of flow experience (M = 4.21). At the same time, these study variables show significant intercorrelations (see figure n.8). The highest level of positive emptions has been reached by the oldest segment of visitors (see figure n.9)

Figure n. 8. Pearson's zero order correlations among study variables: Eudaimonic growth for visiting the museum Malmerendi; Personal Growth as general dimension; Flow experience; Positive emotions; Negative emotions. (**p< 0.05; ** p<0.01; ***p<0.001)*

variables	Eudaimonic growth museum	PWB personal growth Flow	Flow experience	Positive emotions	Negative emotions
Eudaimonic growth museum	-----				
PWB personal growth Flow	0.20*	-------			
Flow experience	0.67***	0.27**	---------		
Positive emotions	0.69***	0.29**	0.61***	----------	
Negative emotions	0.00	0.07	-0.3		------

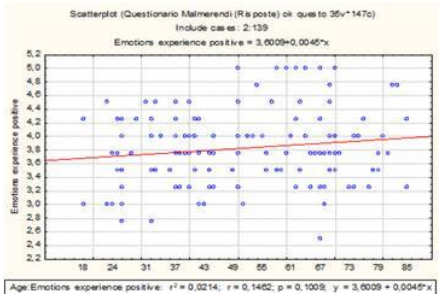


Figure n. 8 Pearson's correlation matrix.
Figure n. 9. Age and positive emotions experienced for the visit at Malmerendi Museum (graphic)

Considerations on results.

Tracing some brief considerations upon the results, we can see how new immersive tools contribute to the flow experience, the personal growth and the positive emotions of visitors of Malmerendi Museum. Positive design confirm itself as a central dimension for cultural places. Integration of psychology (theories and methods, as in this case, from Positive Psychology) and design for creating tools, renewal of rooms, inclusion of immersive tools for improving flow experience and positive dimensions of overall well-being can be a fruitful area of integration [36].

The challenge of the population ageing.

A radical and irreversible change in the population is now occurring, that can be defined as an authentic demographic revolution. This radical change was starting in the developed countries EU, USA, but is now spreading around the world, with relevant consequences for the whole societies as well. The population of the Planet, indeed, is increasing in age, and in life expectancy. As EUROSTAT [37] shows, the best graphic that depicts the age cohorts proportion is similar to a rectangle (decreasing the births, a large proportion of adults, an increasing proportion of old people), and not to the "classic age pyramid", with a large base and a narrow apex. The expected population trend in EU, for example,

identify in the Fourth age, the octogenarians, the age group that will growth more in the next decades, posing several challenges and questions to the entire society.
The issue of positive ageing, and of healthy ageing, constitute indeed nowadays one of the major planet challenges.
As states W.H.O. [38], reaching a healthy ageing and maintaining functional ability constitute two fundamental outcomes for people when they grew older. WHO defines healthy ageing as "the process of developing and maintaining the functional ability that enables well-being in old age. Functional ability is about having the capabilities that enable all people to be and do what they have reason to value" (p. 1). Reaching a healthy ageing means that people possess the following abilities: - meet their basics needs; learn, growth and make decisions; - be mobile; - build and maintain relationships; - contribute to the society.
These core dimensions of healthy and active ageing were established at the end of the previous century by the researcher Rowe & Khan [39], that identified in the so called "successful ageing" the more desirable and favourable outcome for the third and fourth age. For them, successful ageing is the result of systemic interwoven among three systems: physical (having resources from adopting a healthy diet, physical activity, low probability in diseases); cognitive (memory efficiency, problem-solving skills; creative skills); social (active participation to the society, that represents the convergence of the two previous large spectrum of resources in the social dimension). The systemic model of successful ageing represents the first attempt to adopt the systemic paradigm in the study of ageing, which was then adopted by the majority of researcher and that gave life to other complex models of positive ageing (see Kahana et al.[40], the complex model of proactive ageing) and by the WHO [38].
Other theoretical perspectives emphasize the role of competencies and skills for slowing/contrasting the declines and living in autonomy, safeguarding health and bio-psycho-social efficiency and continue to growth. Coming from the Capability Approach of Sen [41], the "Competent ageing" highlights the capabilities as a set of opportunities and freedom available to persons for reaching life styles and /or conditions in accordance with their values. The concept of "Competent Aging " [42] is referred to the improvement of Life Skills (WHO, 1996; [43], [44], that enable old people to choose in competent ways the best options for reaching a positive bio-psycho-social functioning (see figure n.10). For example, the Life Skill Critical Thinking can contribute at increasing digital competencies and positive attitudes toward health, the autonomy and connection with new technology (AI).
Rolandi et al., [45] in a longitudinal study, delineate the characteristic and the dimensions of the "resilience phenotype" in old age (see figure n.9). Bearing in mind that the resilience as outcome in old age is partially rooted in the early experiences and social conditions, other dimensions can be improved, e.g. the level of performance in fluid intelligence, the social contacts, the leisure time, the walking sped, the adherence to Mediterranean diet. This resilience model tells us that it is possible to modify in better ways several dimensions that are implicated in the emergence of the resilience in this stage of life and that the resilience is the result of historical but also biological, psychological and social features posited in the present time.

Figure n. 9. The Resilience phenotype. (Rolandi et al., 2024).

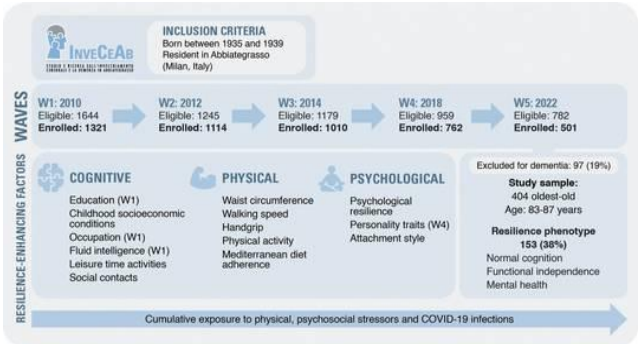


Figure n. 10. The Competent Ageing. (Zambianchi, 2025)

For figure n. 10. *Translation*. The Competent Aging. LSE competent behavior (LSE *comportamento competente*); Autonomy (*autonomia*); creative approach to daily problems *(approccio creativo ai problemi quotidiani*); physical health (*salute fisica*); contrast of cognitive declines (*contrasto ai declini cognitivi*); social ties (*legami sociali*); psychological well-being (*benessere psicologico*). (Zambianchi M. 2025. Life Skills Education in old age. Franco Angeli ed. Milan, Italy)

These models, together, solicit a reflection from not only psychological sciences, but also from areas of research such as Design and Engineering: if several factors can be modified, improved, which could be the role of these mentioned areas of study? How they can work together with Psychology for improving, e.g. creativity (fluid intelligence) in old age? How allow old people to make activities such as walking, bicycling, climbing? How to facilitate the leisure time activities? Psychology and its research theoretical declinations (e.g. cognitive, social, temporal) can be integrated into the knowledge-expertise of designers and engineers for projects, tools featured specifically for the needs of the older?
The AI represents of course an emergent area of research and application suitable for the positive functioning in old age. New robotic technology, such as human-following robots and exoskeletons, can represent examples of Engineering and Design applications for these age cohort. The integration of areas of research such as Psychology with them can add information, contents that facilitate to plan new tools, application that fit their needs and, at the same time, help in creating positive attitudes towards these technologies. Li et al., [46] in a study on human-following robots, which constitutes an example of collaboration of multiple knowledges, from engineering to sociology, highlighted the role of older representations, perceptions, emotions towards this new technology. The research team evaluated, through a qualitative methodology (semi-structured interviews) the needs and requirements of older people regarding the human-following robot. The 17 interviews helped the researcher to better adjusted this technology, as already stated by Roscoe et al., [47] that encourage "bridging Psychology and Engineering to make technology work for people".
The cultural contexts, together with more individual factors, such as personality traits, attitudes, stereotypes, time perspective organization, could influence the openness (or the closeness) to these new opportunities. Knowing them, it is possible to work together in order to dissipate fears and doubts. The design communication can draw important indications from the results that emerged on these factors to better fit the messages toward this target.
In Japan [48] old people are rapidly increasing, with a record of 28 per cent of people aged 65 or older. To encourage older people to stay in or remain in the workforce longer, several tech companies in Japan have developed exoskeletons.
But, they are suitable not only for work, but also for leisure time, as demonstrated in China, where old people use them for climbing the mountain (source: Xinhua, editor: huaxia, 2025,https://english.news.cn/20250210/5e81bae2b5904d77b4bcd1b32f1d4906/c.html).
A question is the following: are our old people (from other Countries not Japan or China) available for adopting these technology resources? Do they possess positive attitudes towards them, or not? Do they perceive them as a gain ("I can continue to climb mountains, despite the advanced age"), or as a loss ("I remember, when I see to them, the physical resources that are lost"...)? Since the perception of them as a gain or, on the contrary, as a loss, can make the difference.
How it is possible, to create positive attitudes towards these new technologies in this ageing cohorts?
Several suggestions can concern: for Designers, to create projects that include an integration with and in line with the most relevant cognitive dimensions (e.g. usability; affordance; principles of good designs, see for example Norman, [49]; social dimensions (e.g. integration with the body image of the person, her/his identity); emotions and well-being (eg. positive emotions, perceived life-quality). For the engineers, the AI seen as a robust resource for smart technologies aimed at improving autonomy, living homes, human following robots.

For closing

The relevance of these areas of study for engineers and designers has been highlighted through an informal conversation with students at Obuda University. Talking with them, during an Open day of the University, about a like-human robot they made (see figure n. 12), asking if they believe it can be suitable

for old people, they answered to me that this constitutes a completely unknown question and issue. But, after my brief explanation, they concluded that the issue of positive aging was very relevant and interesting, “a good idea”.

Figure n. 12. The like-human robot of Obuda University

The introduction of areas of study such as Psychology, in qualities and declinations useful for their professional competencies such as, e.g., Positive Psychology and Ageing Psychology, could help them to enrich those cultural and scientific competencies that can emphasize their creativity devoted to the development and well-being of humans.

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CHALLENGES AND OPPORTUNITIES OF TEXTILE WASTE MANAGEMENT IN SERBIA'S CIRCULAR ECONOMY

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Abstract:

The growing volume of textile waste presents a significant environmental and economic challenge worldwide, and Serbia is no exception. This paper explores the current state of textile waste management in Serbia, examining the current legislative framework, collection systems, recycling capacities, and public awareness levels. Serbia's textile waste sector remains underdeveloped, with most post-consumer textiles ending up in landfills or informal channels. The lack of infrastructure, limited investment in recycling technologies, and weak enforcement of environmental policies further hinder progress. This study identifies key trends likely to shape the future of textile waste management in Serbia, including the adoption of EU-aligned regulations, increased participation of the private sector, and rising consumer consciousness about sustainability. By analysing current barriers and highlighting future opportunities, the paper offers recommendations and directions for building a more efficient and sustainable textile waste management system in Serbia.

Keywords:

textile waste, sustainable development, circular economy, recycling

1. INTRODUCTION

The global textile and apparel industry is one of the largest manufacturing sectors worldwide and a major contributor to trade and employment, but it is also highly resource- and pollution-intensive. Recent reviews show that textiles consume large amounts of water, energy and chemicals across the life cycle, while fast fashion has accelerated production volumes and shortened product lifetimes, leading to rapidly growing material throughput and waste generation [1]. Every year, 92 million tonnes of textile waste is produced globally. In 2024 discarded clothing worldwide reached 120 million metric tons. The global production of textiles has almost tripled, 65% made from fossil energy (plastic fibres from oil). Textile consumption will increase 63% up to 2030. However, recent trends in fast fashion and issues connected to greenwashing are also contributing to increase of textile consumption and generation of textile waste. Most of the textile waste becomes part of municipal solid waste and ends up at landfills - only 1% of used clothes are recycled into new clothes. From extracting raw materials to manufacturing—accounts for 92% of the fashion industry's greenhouse gas emissions

In 2022, 11 million tonnes of textile products were imported to the EU and came mainly from China, Bangladesh and Turkey. Since 2000, the export of used textiles has nearly tripled, from a little over 550,000 tonnes in 2000, to 1.4 million tonnes in 2019. Within the broader transition to a circular economy (CE), the textile and apparel sector is frequently cited as a priority industry because of its significant environmental footprint and complex global supply chains [2].
Environmental pressures occur at all stages of the textile value chain. Fiber production (both natural and synthetic) is associated with land use, pesticide and fertilizer application, fossil resource use, and high greenhouse gas emissions, while wet processing, dyeing and finishing generate large volumes of chemically contaminated wastewater [3]. At the end of life, most post-consumer textiles are still landfilled or incinerated, causing further emissions and the loss of potentially valuable fibres. Systematic reviews of textile reuse and recycling highlight that, although reuse and high-quality recycling can deliver substantial climate and resource benefits, their actual contribution remains limited by low collection rates, quality losses and technological barriers [4].

In response, CE strategies such as durability, reuse, repair, fiber-to-fiber recycling and new circular business models are increasingly promoted for the textile sector. However, evidence from recent literature reviews and empirical studies shows that implementation is uneven and faces multiple challenges. On the technological side, current recycling technologies often struggle with mixed fibers, elastane content, dyes and finishes, and may require high energy or chemical inputs, especially for chemical and advanced recycling routes [5].
On the systemic side, key barriers include fragmented supply chains, insufficient separate collection and sorting infrastructure, unclear economic incentives, and limited market demand for recycled fibers [4]. Studies of circular practices in the textile industry further underline the importance of supportive policy frameworks, extended producer responsibility (EPR), and collaboration among brands, recyclers and public authorities to scale circular solutions [6,7]. Despite growing awareness of circular economy principles, Serbia's waste management system still operates largely under a linear "take-make-dispose" model. According to the national Circular Economy Roadmap, textile materials remain a minor component in formal recycling streams, and the country shows limited capacity for textile-specific recovery operations. Meanwhile, consumer and business attitudes toward textile reuse and recycling are hampered by low environmental awareness and limited incentives for sustainable textile design and disposal.
Given this context, Serbia faces a crucial juncture: the challenges of scaling textile waste management are significant, but so are the opportunities. By integrating circular economy strategies — such as enhanced collection systems, investment in recycling technology, and producer responsibility frameworks. This study identifies key trends likely to shape the future of textile waste management in Serbia, including the adoption of EU-aligned regulations, increased participation of the private sector, and rising consumer consciousness about sustainability. By analysing current barriers and highlighting future opportunities, the paper offers recommendations and directions for building a more efficient and sustainable textile waste management system in Serbia.

2. RESULTS AND DISCUSSION

Dominant waste management method in Serbia is landfilling [8]. Serbia follows global patterns, with approximately 12 kg per capita, much of which is discarded soon after purchase. In average morphological composition of mixed municipal waste in Serbia 2,8% is textile [8]. In 2020 in Serbia 81.405 tons of textile waste generated, 61 tons separated whereas 60 tons recycled. There is no infrastructure for textile waste (separate collection, treatment). According to Waste Management Strategy by the end of 2029 a separate collection of textiles should be established [8].
Based on the research conducted in 120 companies in Vojvodina, micro-enterprises dominate the regional business structure, making up 81 firms (67.5%), with the largest concentration in Southern Bačka (43), followed by Northern Bačka (12), Srem (7), and Southern Banat (6). This pattern reflects a regional economy driven primarily by small entrepreneurial activity, typical of transitional economies. Small enterprises account for 20 firms (16.7%), mostly in Southern Bačka (8), indicating gradual business growth in parts of Bačka. Medium-sized enterprises are limited (11 firms, 9.2%), with Southern Bačka hosting nearly half, highlighting challenges in sustaining mid-scale development. Large enterprises are the least common (8 firms, 6.7%), concentrated in Bačka (5) and Banat (3), underscoring the region's weak industrial base and limited capacity to attract major investment [9]. The main challenge in the adoption of CE practices is financial incentives, particularly for micro and small enterprises, and investment support for medium enterprises. Dominance of micro and small enterprises is a barrier for technological advancement, sustainable practices, and implementation of circular economy practices.
However, largest share of companies operates in the manufacture of other wearing apparel, accounting for 50 firms or 41.7%, followed by smaller groups in finished textile products, workwear and other textile items. The industry is dominated by micro-enterprises, which limits the sector's capacity to scale, invest in new technologies, and adopt sustainable practices. The strong concentration in general apparel suggests market saturation, while specialized segments such as workwear and technical textiles present

opportunities for growth. Overall, the sector remains focused on low value-added production, highlighting the need for modernization, innovation, and diversification into higher-value textile segments [9]. To comply with EU regulation, companies will need to pay for the management of textile waste, proposed by Extended Producer Responsibility schemes [10]. This means producer producers will finance, collection and sorting of post-consumer textiles, recycling system development. and awareness campaigns and eco-design improvements. This will be one of the biggest challenges in long term, and probably impact the micro and small companies, more than medium size.

Sustainable waste management practices in the companies remains very low. Only eight companies (6.7%), mostly large enterprises, send their textile waste to authorized operators, indicating very limited but positive uptake of sustainable waste management practices. Contract manufacturing is used by nine companies (7.5%), mainly micro and small firms, with waste returned to foreign clients. Majority of the companies send their waste to the municipal landfill, more than 50%. Therefore, direct municipal disposal remains the most common method, only 10.8% reuse some textile waste before disposing of it as municipal waste, demonstrating a modest level of circularity [9]. European legal framework will vision for 2030 is that all textile products on the EU market are durable, repairable, and recyclable made primarily from recycled fibres, free of hazardous substances based on Ecodesign for Sustainable Products Regulation [11]. Therefore, challenge for the companies will be, integrating sustainable waste management practices order to meet those criteria. In addition, mandatory digital ID for each product which will means containing sustainability and origin data of the product, become a mandatory for every company export to EU, whereas Serbia exports more than 75% of its textile production.

Use of digital technologies is also at very low level, only 18% of medium and large apparel companies use digital technologies, primarily in design, product development, and material procurement. These tools streamline workflows and significantly reduce material waste, lowering losses from the typical 30–35% to just 8–10%. [9]. This demonstrates the strong potential of digitalization to enhance both operational efficiency and sustainability in the apparel sector. Ecodesign for Sustainable Products Regulation sets buy the EU, among other issued set minimum requirements design for disassembly and repair, thus the increased use of digital technologies over traditional patternmaking and cutting [11].

3. CONCLUSIONS

The transition toward sustainability in the textile industry is no longer optional—it has become an essential requirement for long-term competitiveness and regulatory compliance. To accelerate this shift, financial incentives and targeted investment support are crucial for enabling companies, especially small and medium-sized enterprises, to adopt cleaner technologies, improve resource efficiency, and modernize production processes. Emerging regulatory frameworks—including ESPR, EPR, and DPP will model the market, making circularity a core business model rather than a voluntary practice. In this evolving landscape, textile companies that proactively integrate sustainable design, transparent material flows, and responsible waste management will be best positioned to thrive. In this rapidly transforming regulatory and market environment, textile companies that systematically integrate sustainability principles—from eco-design and material transparency to circular waste management—will be the most resilient and best positioned for long-term growth.

Serbian companies will need to adapt their business to the requirement of EU legal framework in textile industry. Serbian companies are exporting their products to the EU market, 75%. Companies will need to implement best practices and invest in technologies will make their business resilient and best positioned for long-term sustainable growth.

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INFLUENCE OF DRYING TEMPERATURE AND GRAPHITE CONCENTRATION ON THE PERFORMANCE OF GRAPHITE-BASED CONDUCTIVE INK

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Abstract:

This paper examines how drying temperature influences the electrical and mechanical properties of graphite-based conductive ink. Special emphasis was placed on electrical conductivity and abrasion resistance. The ink formulations were prepared using graphite powder with a particle size below 20 μm as the conductive component, while a commercially available water-based printing ink served as the binder. To evaluate the influence of filler loading on the formation of conductive networks, graphite was incorporated at concentrations of 30 wt.% and 40 wt.%. To ensure a uniform coating layer, the inks were applied onto a smooth polymer-coated paper substrate using a glass rod. The printed samples were dried for 15 minutes at four different temperatures (60 °C, 80 °C, 100 °C, and 120 °C). Electrical performance was assessed via surface resistance measurements, while abrasion resistance was used to assess the durability and adhesion of the conductive layers. Based on the measurements, it was found that both drying temperature and graphite concentration significantly influence the performance of the coatings. Improved electrical conductivity was observed at higher graphite content, while drying at moderate temperatures promoted better particle contact and a more stable conductive network. However, excessively high drying temperatures led to reduced mechanical stability, likely due to binder degradation. In our experiment, particular attention was given to maintaining constant homogenization, application with a glass rod and drying time. This paper contributes to a better understanding of the role of processing parameters in graphite-based conductive inks and supports the optimisation of formulations and drying conditions for functional printed materials.

Keywords: conductive ink, graphite, abrasion resistance, ink drying

1. INTRODUCTION

The development of conductive inks for printing and applications in functional printed materials is becoming increasingly important, especially in the context of flexible electronics, RFID antennas, sensors, and interactive surfaces. Key formulation parameters of such inks include the choice of conductive fillers (e.g., graphite, graphene, carbon nanotubes), the ratio of filler to binder and processing conditions. Drying rate and drying temperature are particularly significant parameters. High temperature can cause binder degradation and a deterioration in the mechanical resistance of the coating. At the same time, too low temperature can result in weak cohesion of graphite particles and high electrical resistance [1, 4, 6]. Previous studies have shown that increasing the concentration of graphite fillers allows the formation of a better conductive network and reduces surface resistance [1, 5, 9]. A review on carbon-based conductive inks indicates that filler concentrations in metal or carbon-based inks can range approximately from 30% to 80% of the dry filler mass [1].

The drying process has a dual role. Elevated temperatures can improve contact between graphite particles and reduce resistance, but they may also cause shrinkage, stress, microcracks, or binder degradation, leading to reduced abrasion resistance [2, 3, 4]. Marchianò et al. analysed the drying process of water-based graphite conductive inks, showing that inadequate drying can lead to surface

cracks and defects in printed electrodes [2]. For water-based graphite ink formulations, optimising suspension, viscosity, drying, and filler–binder interactions is particularly important [2, 8]. Marchianò et al. reported that drying at 100 °C after ink application on a flexible substrate provided good electrochemical performance [2], while Leng et al. demonstrated that high conductivity can be achieved even at moderate drying temperatures (around 80 °C), avoiding issues with substrates and binders [3]. S.S. Azim et al. investigated how the graphite content in epoxy binder affects the resistance and adhesion of the coating [4]. Similar results were obtained for hybrid graphite-carbon systems [9].
The goal of our team is to develop simple graphite-based conductive inks that are accessible and biocompatible, and this paper aims to investigate how graphite concentrations (30% and 40%) and drying temperatures (60 °C, 80 °C, 100 °C, and 120 °C) contribute to the understanding and optimisation of graphite-based conductive inks. The results can help define optimal drying and formulation conditions for achieving the best electrical conductivity and mechanical resistance [1–4, 6–9].

2. MATERIALS AND METHODS

2.1. Materials

For the preparation of conductive printing layers, water-based printing ink was employed as the binder matrix. Graphite powder (Sigma-Aldrich, particle size < 20 μm) was incorporated into the ink formulation at concentrations of 30 wt% and 40 wt%, respectively. The ink mixtures were homogenized by mechanical stirring until a smooth and uniform paste was obtained, ensuring optimal dispersion of graphite particles within the aqueous medium. The prepared inks were applied onto the paper substrates using a glass rod coating technique. It provided a controlled and uniform film thickness across the entire sample surface. After coating, samples were dried in a laboratory oven at four different temperatures: 60 °C, 80 °C, 100 °C, and 120 °C (each for 15 minutes). The temperature conditions were selected to examine the influence of drying temperature on the structural stability and surface homogeneity of the printed layers. The paper used for printing was a coated paper (UPM Finesse White Gloss, 300 g/m²). The higher-grammage paper provided better mechanical stability during coating and reduced deformation and wrinkling compared to thinner substrates. This paper provides a reliable surface for uniform ink deposition and allows accurate evaluation of the coating's morphological and optical properties under controlled conditions.

2.2. Electric resistance testing

The electrical conductivity of the printed coatings was evaluated using a simple conductivity test circuit based on the Technic Conductivity Test Apparatus design (Technic Inc., USA). The circuit consisted of a 4.5 V DC power source, a light-emitting diode (LED), an ammeter and the printed conductive trace connected in series. When the circuit was closed, the current flow through the printed path was measured using the ammeter, and the brightness of the LED served as a qualitative indicator of conductivity. This setup allowed for a quick comparative assessment of the electrical performance of coatings with different graphite contents and drying conditions. The tests were conducted at ambient laboratory temperature, and each measurement was repeated three times to ensure repeatability. The voltage drop across the LED was measured separately to determine the actual voltage applied to the printed line. Based on the measured current (I) and the calculated voltage on the line (V_{line}), the electrical resistance of the printed trace was obtained from Ohm's law($R_{\text{line}} = V_{\text{line}}/I$). The sheet resistance (R_s) was then calculated using the geometrical relationship:

$$R_s = R_{\text{line}} \cdot \frac{W}{L}$$

where $W = 3\ \text{mm}$ is the width and $L = 28\ \text{mm}$ is the length of the printed conductive line. This normalisation allows for direct comparison of samples with different geometries and provides a reliable measure of the intrinsic electrical performance of the printed coatings.

2.3. Mechanical testing

The rub resistance of the graphite-based conductive prints was evaluated using a Hanatek Rub and Abrasion Tester (tribometer). This test method is employed to determine the durability of a dried coating when subjected to frictional contact, either against another surface or material. The test aims to assess the tendency of the conductive layer to wear off or transfer due to mechanical abrasion. The goal of this test was to determine whether the graphite coatings remained electrically conductive after the rubbing test.

Microscopic analysis was performed using an Olympus BX51 optical microscope (Olympus, Japan) equipped with a DP72 digital camera (12.8 megapixels, 4140 × 3096 pixels). The system enables high-resolution image capture under magnification up to 1500×, providing low-noise, high-sensitivity imaging suitable for detailed observation of micro structured coatings. Images were acquired at 40× magnification for printed samples containing 30 wt.% and 40 wt.% graphite, dried at 60 °C, 80 °C, 100 °C, and 120 °C. All images were processed and analysed using the Fiji distribution of ImageJ (NIH, USA), which allows for reproducible and quantitative evaluation of surface morphology and texture.

3. RESULTS

The electrical performance of the printed coatings was evaluated by measuring the current flow through the conductive lines in a simple circuit. The results, expressed as sheet resistance (Ω/m^2) (Table 1), show a clear dependence on both the graphite concentration and the drying temperature.

Table 1: Sheet resistance (R_s) of printed conductive coatings containing 30 wt.% and 40 wt.% graphite at different drying temperatures

Drying Temperature (°C)	30 wt.% Graphite (R_s [Ω/m^2])	40 wt.% Graphite (R_s [Ω/m^2])
60	127.5 ± 2.1	37.8 ± 0.7
80	327.8 ± 32.3	25.7 ± 0.5
100	85.9 ± 2.1	20.3 ± 0.2
120	141.2 ± 13.2	23.5 ± 0.7

For the 30 wt.% graphite formulation, the sheet resistance values ranged from approximately 85.9 Ω/m^2 to 327.8 Ω/m^2, with the lowest resistance obtained at 100 °C. At this temperature, the coating exhibited the highest current and, consequently, the best electrical conductivity. Samples dried at lower (60 °C, 80 °C) or higher (120 °C) temperatures showed higher resistance, indicating incomplete particle connection at low temperature and potential microstructural stress or binder contraction at excessive heating.

In the 40 wt.% graphite coatings, ranging between 20.3 Ω/m^2 and 37.8 Ω/m^2, confirming that the higher graphite content significantly enhances electrical conductivity by promoting particle-particle contact and network formation. Like the 30 wt.% samples, the minimum resistance was again observed at 100 °C, which corresponds to the temperature where microstructural analysis also revealed the most uniform and compact surface texture.

Based on the measurements, our results demonstrate that both the graphite loading and drying temperature strongly influence the electrical response of the coatings. The optimal combination of low sheet resistance and structural homogeneity was achieved for coatings dried at 100 °C. That sample exhibited approximately four to six times lower resistance than the 30 wt.% samples under the same conditions.

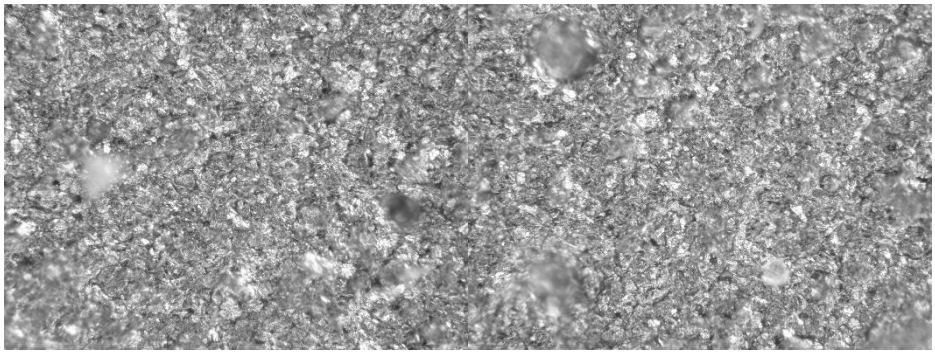
Table 2: Sheet resistance (R_s) of printed conductive coatings after abrasion testing

Drying Temp (°C)	30 wt% – Sample 1	30 wt% – Sample 2	40 wt% – Sample 1	40 wt% – Sample 2
60	85.62 ± 0.65	99.99 ± 2.95	50.84 ± 1.28	25.60 ± 0.53
80	187.27 ± 2.55	89.26 ± 4.59	30.05 ± 1.24	29.56 ± 1.95
100	103.84 ± 1.39	471.34 ± 24.12	23.36 ± 0.15	23.57 ± 0.35
120	78.15 ± 2.63	145.09 ± 4.13	45.42 ± 0.97	47.42 ± 1.54

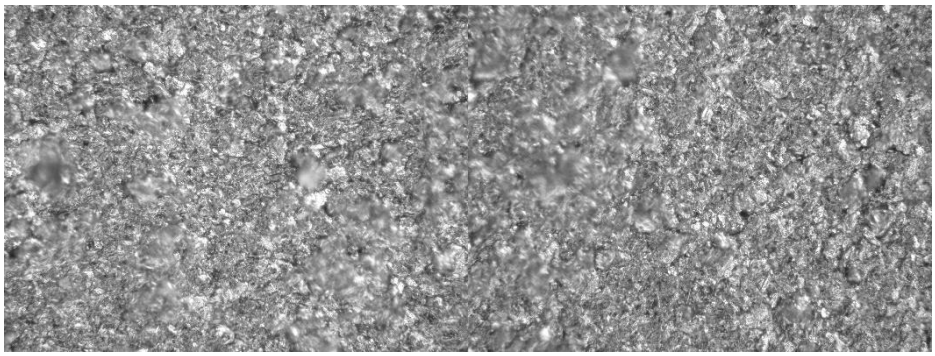
The measurements (Table 2) revealed notable differences in the electrical stability of the coatings depending on graphite content and drying temperature. Samples containing 40 wt% graphite exhibited consistently lower sheet resistance values after rubbing compared to the 30 wt% coatings. That confirms that a higher concentration of conductive particles improves both electrical conductivity and mechanical durability. For both formulations, the lowest sheet resistance was obtained at 100 °C, indicating that this drying temperature promotes optimal interparticle contact and a stable conductive network. In contrast, coatings dried at lower (60 °C, 80 °C) or higher (120 °C) temperatures showed higher resistance and greater variability between samples. It suggests less uniform film formation or partial disruption of the conductive pathways. Coatings with 40 wt% graphite dried at 100 °C showed the best balance between conductivity and abrasion resistance.

The captured micrographs were first converted to 8-bit grayscale and enhanced using the CLAHE (Contrast Limited Adaptive Histogram Equalisation) algorithm to improve local contrast and emphasize particle boundaries. Segmentation was performed using Otsu's thresholding, followed by particle analysis to determine the number of detected graphite domains. Also, it determines their total and average projected area and the percentage of surface coverage. The same grayscale images were used for Gray Level Co-occurrence Matrix (GLCM) texture analysis using a custom macro script in Fiji. Texture parameters (contrast, energy, homogeneity, and correlation) were calculated at a pixel offset distance of 5 px in four angular orientations (0°, 45°, 90°, 135°) and averaged to describe the uniformity and organisation of the surface.

The visual inspection of the microscopic images presented in Figures 1 (a–d) and 2 (a–d) revealed noticeable differences in the surface morphology of the printed conductive coatings depending on the drying temperature and graphite content.

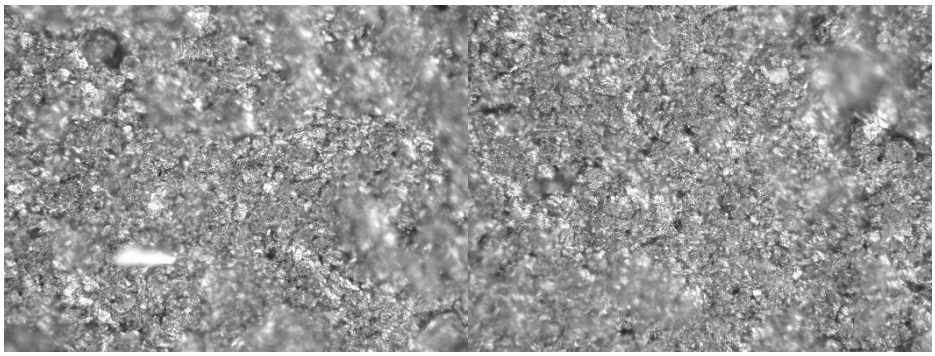


a) b)

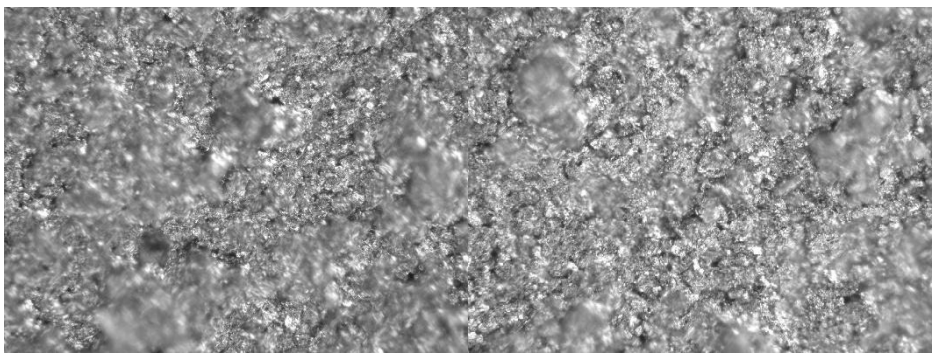


c) d)

Figure 1: 30 wt.% graphite a) 60°C, b) 80°C, c) 100°C, d) 120°C



a) b)



c) d)

Figure 2: 40 wt.% graphite a) 60°C, b) 80°C, c) 100°C, d) 120°C

The microstructural and textural analyses showed a clear influence of both drying temperature and graphite content on the morphology of the printed conductive coatings.

Table 3: Surface morphology and texture parameters of 30 wt.% and 40 wt.% graphite coatings dried at various temperatures

Sample	Count	Area/%	Contrast	Homogeneity	Correlation
30 wt%/60°C	2676	51.534	34.739	0.333	0.804
30 wt%/80°C	2074	60.965	32.637	0.344	0.800
30 wt%/100°C	1836	60.017	31.748	0.342	0.809
30 wt%/120°C	1752	62.164	30.301	0.349	0.808
40 wt%/60°C	1264	59.731	21.072	0.419	0.864
40 wt%/80°C	1883	58.546	26.558	0.381	0.828
40 wt%/100°C	1078	61.586	17.996	0.433	0.872
40 wt%/120°C	2388	56.395	29.228	0.388	0.834

For the formulation containing 30 wt.% graphite, the number of graphite particles decreased with increasing temperature (from 2676 at 60 °C to 1752 at 120 °C), while their average projected area and total surface coverage increased. This shows the gradual coalescence of smaller graphite domains into larger agglomerates. The result is a continuous conductive network. The mean grayscale intensity also increased, suggesting a reduction in surface porosity and improved optical uniformity. The optimal morphology was achieved between 80 °C and 100 °C. At that temperature, coverage exceeded 60 %, and the surface exhibited a balanced texture characterised by moderate contrast and high homogeneity.
For the 40 wt.% graphite formulation, the overall coverage remained high (56–62 %) but showed stronger fluctuations with temperature. The particle count and average size varied irregularly, reflecting local aggregation and partial fragmentation of the graphite phase. GLCM analysis confirmed the observation that the lowest contrast (17.99) and highest homogeneity (0.433) occurred near 100 °C, indicating the most uniform surface at this temperature. At both lower (60 °C) and higher (120 °C) drying temperatures, contrast increased and homogeneity decreased. It implies a rougher and more heterogeneous structure due to incomplete drying or matrix contraction at elevated temperatures.
When comparing the two formulations, increasing graphite content from 30% to 40% led to improved particle connectivity and higher baseline homogeneity at lower temperatures. It reflects enhanced percolation within the conductive network. The higher filler concentration also reduced the structural stability of the coating upon heating, which caused greater textural variation and local irregularities at extreme temperatures.
For both formulations, the most favourable microstructural properties were observed at around 100 °C, suggesting an optimal particle distribution and the formation of a dense, uniform conductive film.
The abrasion test performed on the coating containing 40 wt.% graphite dried at 80 °C revealed a decrease in the number of detected graphite domains and a simultaneous increase in their average size.

Table 4: Surface morphology and texture parameters of 40 wt.% graphite coatings dried at 80 °C before and after the abrasion test

	Count	Area/%	Contrast	Homogeneity	Correlation
Before abrasion	1883	58.546	26.558	0.381	0.828
After abrasion	1326	59.995	18.444	0.436	0.874

Smaller, weakly adhered particles were removed by rubbing, leaving behind larger and more compact agglomerates firmly embedded in the polymer binder.

The total surface coverage slightly increased, and the mean brightness became higher, indicating a smoother and more uniform surface.
GLCM texture parameters confirmed these findings: contrast decreased from 26.6 to 18.4, while homogeneity and correlation increased, suggesting improved structural uniformity and surface compactness after abrasion.
From the abrasion test, it was observed that the conductive layer retained good structural integrity and that the remaining graphite phase exhibited enhanced uniformity and adhesion to the substrate.
The combined morphological, textural, and electrical analyses clearly demonstrate the strong influence of both graphite content and drying temperature on the performance of the printed conductive coatings. Microscopic observations (Figures 1 and 2) showed that increasing the drying temperature led to gradual particle coalescence and improved surface uniformity up to 100 °C, while higher temperatures (≥120 °C) caused localised cracking and binder shrinkage. These visual trends were supported by texture analysis parameters, where coatings dried at 100 °C exhibited the highest homogeneity and correlation values, indicating the formation of a compact and well-connected microstructure.
Electrical measurements further confirmed these observations. For both graphite concentrations, the sheet resistance decreased with temperature, reaching its minimum at 100 °C, consistent with optimal particle packing and reduced interparticle gaps. Coatings containing 40 wt% graphite showed up to a sixfold improvement in conductivity compared to those with 30 wt%, emphasizing the role of conductive filler concentration in establishing continuous pathways for electron transport.
After the abrasion test, 40 wt% coatings retained low sheet resistance values and exhibited only minor variation between repeated measurements, suggesting excellent mechanical integrity and electrical stability of the conductive network. In contrast, 30 wt% coatings were more sensitive to mechanical stress, showing higher variability and partial loss of conductivity.

Based on the measurements, it was found that the combination of 40 wt% graphite and a drying temperature of 100 °C gives coatings with the most favourable structural, morphological, and electrical properties. This formulation provides a reliable balance between high conductivity, coating uniformity, and abrasion resistance.
Although the rub resistance of the printed samples was visually assessed on a five-point scale, this evaluation was not the main focus of the study. Our primary goal was to determine whether the samples retained electrical conductivity after rubbing. Samples dried at 100 °C showed the lowest resistance and the highest conductivity, suggesting optimal particle connectivity and a homogeneous coating structure.

4. CONCLUSION

Both graphite concentration and drying temperature were found to affect the electrical, morphological, and mechanical performance of printed conductive coatings. An increase in graphite content from 30 wt.% to 40 wt.% led to improved electrical conductivity. At the same time, higher filler loading contributed to improved surface uniformity and greater resistance to mechanical abrasion.
Drying temperature proved to be an equally important processing parameter. Among the investigated conditions, drying at 100 °C consistently provided the most favourable balance between electrical conductivity and structural stability. At this temperature, the coatings exhibited a compact microstructure, high surface homogeneity, and the lowest sheet resistance values for both graphite concentrations. Drying at lower temperatures led to incomplete particle contact, while excessive heating caused localised structural defects and reduced mechanical integrity, likely associated with binder shrinkage and degradation.
The abrasion tests showed that coatings containing 40 wt.% graphite maintained stable electrical performance even after mechanical stress, indicating strong adhesion to the substrate and a robust conductive network. In contrast, coatings with 30 wt.% graphite showed greater variability in resistance values, highlighting their increased sensitivity to mechanical loading.

Overall, the combination of 40 wt.% graphite and a drying temperature of 100 °C proved to be an optimal formulation within the scope of this study. From a practical perspective, these findings are particularly relevant for printing on paper-based substrates.
This system combines high conductivity, good surface uniformity and abrasion resistance, which makes it suitable for potential application in flexible and wearable electronic devices. Future work will aim to improve environmental compatibility, electrical efficiency and long-term stability.

5. ACKNOWLEDGMENTS

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COMPARATIVE ANALYSIS OF COLOR REPRODUCTION IN DIGITAL AND FLEXOGRAPHIC PRINTING OF PACKAGING MATERIAL

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Abstract

The study sought to answer the question of how a given digital printing technology reproduces colours on a typically frequently used packaging material (20µ thick transparent polypropylene) as a printing substrate, and how the colour reproduction characteristics of digital and flexographic (flexo) printing compare. The study revealed the impact of prepress (printing plate production technology) on colour reproduction in flexographic printing. The research focused on 10 flexographic printing samples produced using different printing plate production processes and/or different printing machines. Similarly, a sample was produced using a digital printing process on an HP Indigo 20000 printing machine. The print sample used for the CMYK colour space tests was a GMG Flexo chart.
By measuring, comparing, and evaluating the colour profiles of the 11 print samples, it was found that both digital and flexographic printing technologies can cover approximately half of the Lab colour spectrum. Both the technology and type of printing plate production and the screen structure used on the printing plate have a clear impact on the colour gamut reproduction capability of flexographic printing.

Keywords: *Packaging material printing, flexography, digital printing, scene reproduction.*

1. PRINTING PROCESSES IN PACKAGING PRODUCTION

All major printing processes are employed in the production of packaging materials [1]. The principal processes include flexography, offset lithography, screen printing, and digital printing [1, 2]. For many years, flexography has been one of the most significant and frequently applied printing technologies within the packaging industry [3]. When compared to other printing methods, flexography offers several considerable advantages [4]. Consequently, it has become one of the most widely used printing processes in packaging production across North America, Latin America, and Europe (HP Inc., 2016). According to Henry [5], the flexible packaging segment represents a broad market in which flexography dominates, accounting for approximately 75% of total market share, while digital printing holds only about 1%. Bates et al. [6] identified both flexographic and digital printing as the most dynamically developing printing technologies. Typically, digital printing is applied for products with lower print volumes; as print quantities increase, flexographic printing assumes a more dominant role. According to Hohmann [7], the United States is the market leader in extended-gamut flexographic printing, although the number of practical implementations remains relatively low.

2. COLOUR MANAGEMENT IN THE PRINTING INDUSTRY

Colour is the perceptual appearance of a stimulus resulting from the visual response of the human eye to light [8]. Measurable physical properties trigger physiological and psychological processes of human colour perception, resulting in the subjective impression that an object appears to possess a certain

colour. The stimulus is referred to as the colour stimulus, while the human perceptual response—mediated through visual and cognitive processes—is termed the colour perception [9]. The range of light visible to the normal human eye extends approximately from 400 nm to 700 nm [10,11] or roughly 380–780 nm [12]. There are two fundamental methods of producing colours from primary hues: additive and subtractive colour mixing. Primary colours are defined as those that cannot be generated by mixing other colours, yet all other colours can be derived from them [13]. Subtractive colour mixing occurs in printing when inks containing the primary pigments—cyan, magenta, and yellow (CMY)—are combined in varying proportions.

Theoretically, a perfect combination of cyan, magenta, and yellow should yield black; however, in practice, the inks differ from ideal pigments, producing a less than perfect black [2]. For this reason, a separate black ("K" for "Key") ink is introduced in the printing process. According to Dharavath and Kokil [14], colour can be regarded as a quantitatively analysable and measurable science. Nevertheless, for the human eye, colour perception remains a subjective phenomenon, which presents challenges in the printing industry. The visual evaluation of colour is subjective and influenced by numerous factors simultaneously [15]). One of the principal objectives of the printing industry is to produce accurate and consistent colours for customers [16], even when packaging materials are printed at different locations, using different printing processes, or on diverse substrates. Colour management serves as a means of regulating colour throughout these processes. As graphics are reproduced across various devices and substrates [17], process calibration and ICC profiling ensure reliable and verifiable colour data conversion between colour spaces [18]. Without colour management, an identical input colour value (RGB or CMYK) may appear differently across devices or substrates. To enable precise colour transformations between devices, eight industry leaders established the International Color Consortium (ICC) in 1993. The ICC Profile Format Specification defines the open ICC profile format, enabling colour conversion between devices and colour spaces via a device-independent reference colour space [19]. In flexographic printing, colour appearance is always device dependent. This means that every printing process produces slightly different visual results, even when using identical inks. When a specific process colour composition (CMYK) is defined, the outcome will still vary between printing machines [11]. The printing and reproduction processes must therefore be evaluated and profiled, so that calibrated proofs can accurately simulate the expected print appearance [15]. Each configuration and printing setup must be measured individually. It is recommended to follow relevant ISO standards, such as ISO 12647-7:2016, during measurement and calibration [15]. Process colour assessment is conducted through colour gamut fingerprinting, the implementation of which may vary.

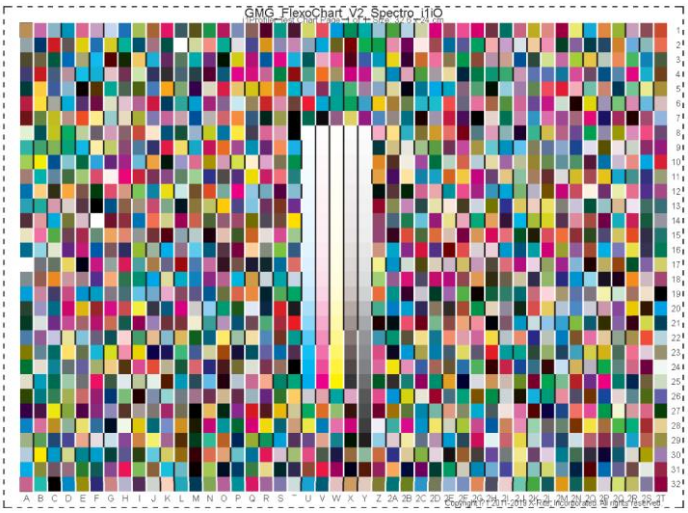

Figure 1: illustrates an example of a test chart suitable for evaluating the colour gamut of a printing process.

3. AIM OF THE RESEARCH

Colour gamut reproduction remains a continually relevant topic within the field of printing technology. The primary objective of every printing process is to reproduce the widest possible colour gamut, although this gamut will always represent only a portion of the spectrum perceptible to the human eye. During the course of our research, representatives of the flexographic printing industry acknowledged the potential of digital printing as a complementary or even competing technology in the future development of print production. Digital printing may gradually become a competitor to flexography as the technology continues to evolve and improve in terms of print quality and colour accuracy.
The research was therefore designed to address the following key questions:

- What is the colour gamut reproduction capability of digital printing?
- How does the colour reproduction performance of digital printing compare with that of flexographic printing?
- What is the impact of prepress processes, specifically the plate-making technology, on the colour gamut reproduction in flexographic printing?

4. IMPLEMENTATION OF THE PRINTING TESTS

Our research began with the mapping of digital printing capabilities. The printing tests were conducted using an HP Indigo 20000 digital press. This press has a web width of 762 mm and a printing speed of 101 ft/min (30.78 m/min) in four-colour mode, 82 ft/min (25 m/min) in five-colour mode, and 137 ft/min (41 m/min) in EPM mode (Hewlett Packard, 2013).
Utilizing the full potential of this printing system, a test form was designed to cover the entire web width. The test included multiple photographic elements, flexographic test patterns, and a measurement chart consisting of 1,472 colour patches, from which an ICC profile could be generated. The substrate used for the test was a 20 µm transparent polypropylene film. Upon completion of the printing test, the ICC profile was measured using the GMG colour management system and an i1iO automatic scanning spectrophotometer. These tools provided precise colour measurement and profiling to evaluate the gamut reproduction capabilities of the HP Indigo 20000. To extend the scope of the study, additional colour profiles were required. For this purpose, a set of flexographic colour gamut tests conducted over the past two to two and a half years was selected. The samples represented multiple printing companies, covering both solvent-based and UV-curable ink systems, and included several plate-making technologies. Thus, a broad cross-section of the flexographic industry was incorporated. In total, ten flexographic ICC profiles were selected for inclusion in this stage of the research.

Table 1: Color profiles and their manufacturing parameters involved in the study (Source: author)

Nr.	Printed substrate	Type of the printing plate	Platemaking technology	Type of the ink
1.	PP TR	MacDermid Lux® ITP™ 60	Bellissima DMS	UV
2.	PP TR	MacDermid Lux® ITP™ 60	Bellissima DMS	UV
3.	PP TR	Kodak Flexcel FNXH	Kodak NX A	UV
4.	PP TR	DuPont™ Cyrel® ESXR	Digital Flat Pixel A	UV
5.	PP TR	DuPont™ Cyrel® DPN	Classic Digital	solvent
6.	PP TR	MacDermid Lux® ITP™ 60	Bellissima DMS	solvent
7.	PP TR	Kodak Flexcel FNXH	Kodak NX A	solvent
8.	PP TR	DuPont™ Cyrel® ESXR	Digital Flat Pixel A	solvent
9.	PP TR	MacDermid Lux® ITP™ 60	Bellissima DMS	solvent
10.	PP TR	Kodak Flexcel FNXH	Kodak NX A	solvent

All profiles were measured using the same GMG software and i1iO measurement device, ensuring consistency and comparability. As a result, a total of eleven ICC profiles (one digital and ten flexographic) were available for analysis. The comparison was carried out using the Gamutvision software, which allows visual and numerical comparison of ICC profiles. The software can display two colour gamut's in three-dimensional space and quantify the gamut volume, thereby expressing the extent of the reproducible colour range. The outcomes of these comparative analyses are presented in the following section.

5. PRESENTATION OF THE EXPERIMENTAL RESULTS

The first stage of the analysis examined the colour gamut reproducible by the HP Indigo 20000 digital press using the Gamut vision software. The reference colour space for comparison was the D50 Lab colour space. The visual representation of the result is shown in *Figure 2*.

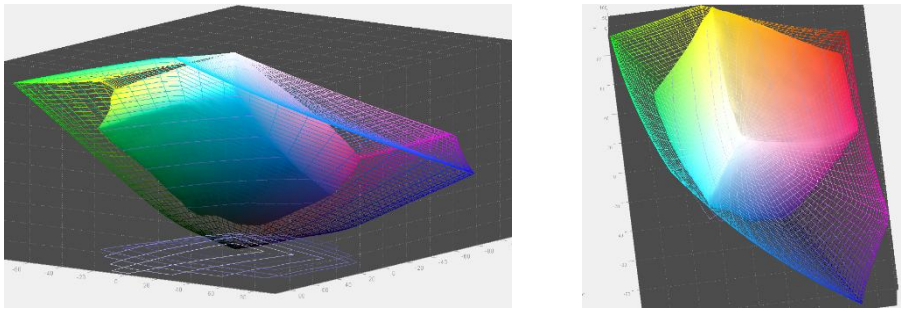

Figure 2: Comparison of the HP Indigo 20000 and D50 Lab colour spaces (Source: author)

The analysis revealed that the gamut volume of the D50 Lab colour space was 840,064, while that of the HP Indigo 20000 was 460,722. As illustrated in the figure and confirmed by the numerical data, the digital print sample was capable of reproducing approximately half of the D50 Lab colour gamut. The next comparison was made between the HP Indigo 20000 and the first flexographic print sample. This flexo print used UV-curable inks, a MacDermid Lux® ITP™ 60 plate, and Bellissima DMS screening technology, printed on a transparent polypropylene substrate. The visual comparison can be shown in *Figure 3*.

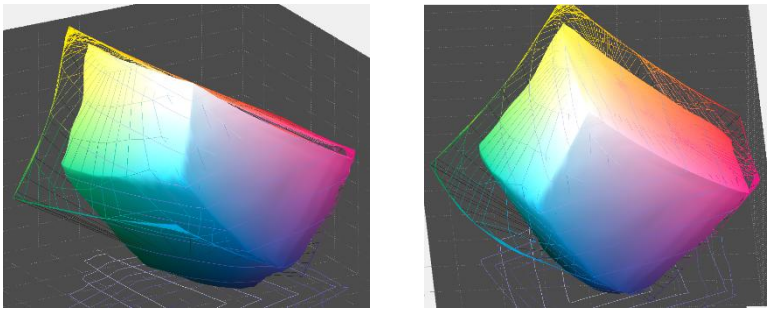

Figure 3: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 1 (Source: author)

In this case, the gamut values were as follows: the HP Indigo 20000 remained at 460,722, while the flexographic sample yielded a gamut volume of 348,449. It can therefore be concluded that digital print exhibits a wider colour gamut. The colour gamut reproduction relative to the D50 Lab space was 41.47%, and relative to the HP Indigo 20000, 75.63%. The second flexographic sample was produced using the same plate material and substrate as the first but printed in a different printing plant.

Interestingly, the printing presses and anilox rollers were identical, while the ink manufacturer differed. The results are illustrated in *Figure 4*.

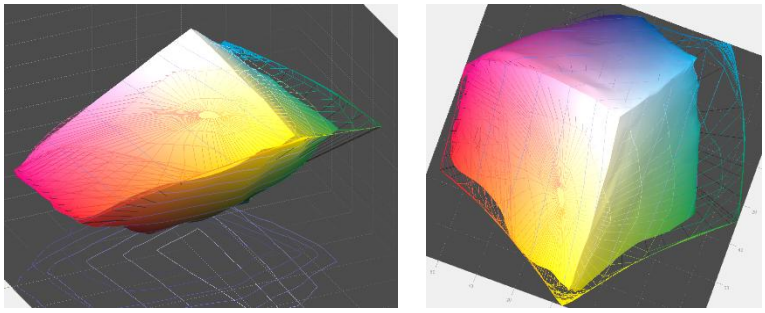

Figure 4: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 2 (Source: author)

The second flexographic sample shows better colour gamut reproduction than the first. Although the digital print still displays a broader gamut, this flexo sample approaches it more closely. In the yellowish, reddish, and purplish tones, the match is very good — in some areas, the flexo print even outperforms the digital sample. However, the bluish and greenish hues are more accurately rendered by digital print. The gamut value of this flexo sample is 407,321, compared to Indigo's 460,722. Thus, the colour gamut reproduction relative to D50 Lab was 48.48%, and relative to HP Indigo 20000, 88.40%. The third sample was again a UV-curable flexographic print on transparent polypropylene film. The printing plate was made using Kodak Flexcel NXH technology, which employs flat-top dots via a semi-digital plate-making process.The visual comparison is shown in *Figure 5*.

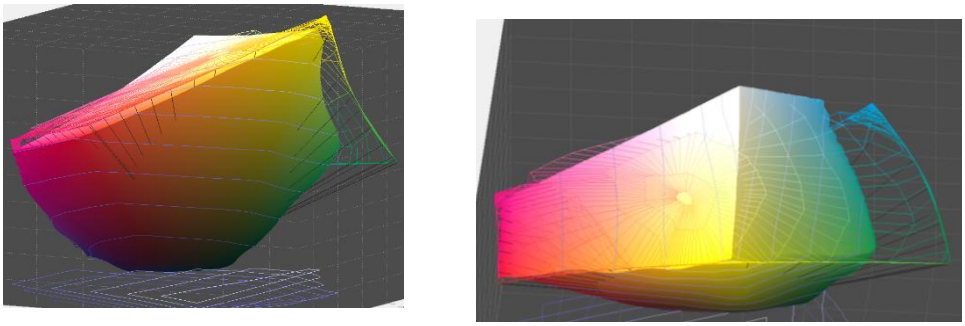

Figure 5: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 3 (Source: author)

From the visualization, in certain regions of the colour space the flexographic sample performs better, particularly in the magenta, yellow, and red ranges, where its performance is comparable or even superior. Conversely, digital print continues to outperform in the cyan and green tonal areas. The gamut value of this third flexo sample is 388,433, corresponding to 46.23% of the D50 Lab gamut and 84.30% of the HP Indigo 20000 gamut. The fourth sample represents the last UV-based flexographic print in the study. It was produced in the same printing plant as the second and third samples, allowing for conclusions regarding the influence of plate-making technology on the reproducible colour gamut under identical press conditions. The sample was printed using a digitally processed plate with flat-top dots and surface microstructure. The results are shown in *Figure 6*.

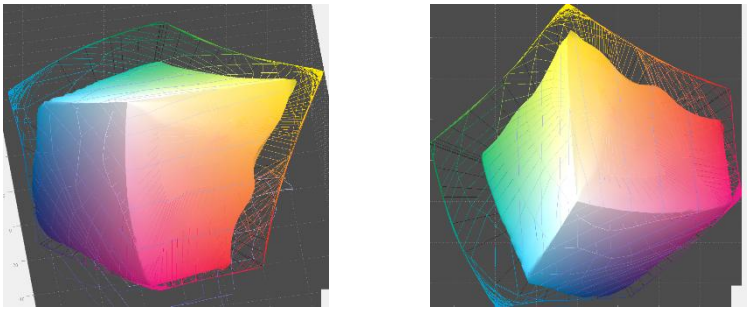

Figure 6: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 4 (Source: author)

The measured gamut volume was 340,696, indicating a considerably narrower colour gamut compared with the digital print. The closest match between the two gamuts was found in the magenta, bluish, and purplish tones, whereas the cyan, green, and yellow regions showed more substantial differences. The reproduction relative to D50 Lab was 40.55%, and relative to HP Indigo 20000, 73.94%. The fifth sample was the first solvent-based flexographic print. A relatively older-generation digital plate was used, without flat-top dot technology, resulting in rounded dot geometry. The substrate was again transparent polypropylene, consistent with previous samples. The results are presented in *Figure 7*.

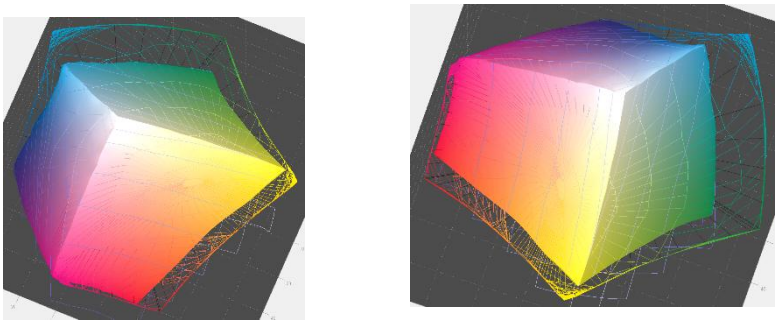

Figure 7: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 5 (Source: author)

This sample demonstrates that digital printing outperformed flexography across nearly all colour regions. The greatest deficiencies in the flexo colour gamut were observed in the blue and green areas, while even the yellow and red regions were not reproduced as effectively as in digital printing. The gamut value was 341,701, equivalent to 40.67% of the D50 Lab gamut and 74.16% of the HP Indigo 20000 gamut. The sixth sample employed Bellissima DMS screening technology on a MacDermid Lux® ITP™ 60 plate. The ink type was solvent-based, and the print was produced on transparent polypropylene. This sample was particularly interesting as it was printed on a modern, high-specification wide-web flexographic press equipped with 420 lpi anilox rollers. The results are illustrated in *Figure 8*. This sample exhibited a significantly larger colour gamut than the two previous solvent-based prints. The colour spaces are slightly shifted relative to one another, with the flexographic print performing better in the yellow–orange–red–blue regions. However, as observed in previous cases, bright green and light cyan–green tones were reproduced more effectively by the digital print.

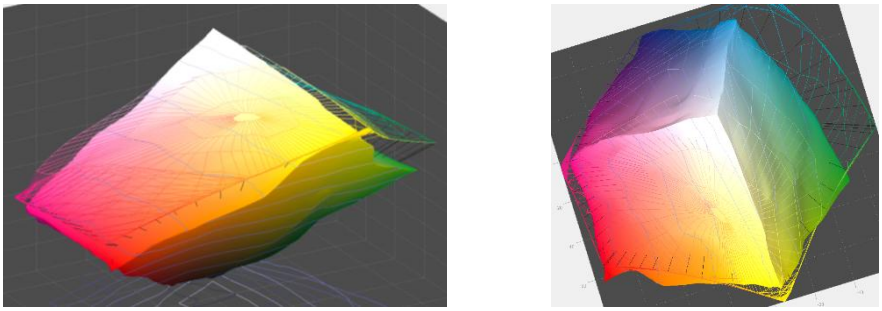

Figure 8: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 6 (Source: author)

The gamut volume for this sample was 397,610, corresponding to 47.33% of the D50 Lab gamut and 86.30% of the HP Indigo 20000 gamut. The seventh sample was produced using the Kodak Flexcel NX standard technology with solvent-based inks on transparent polypropylene. The visualisation is shown in *Figure 9*.

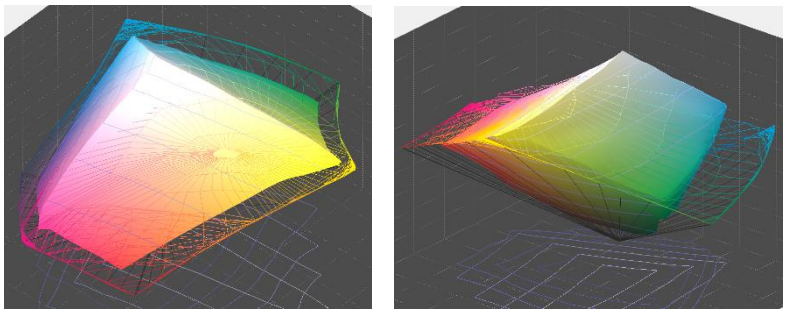

Figure 9: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 7(Source: author)

This sample represents one of the narrowest colour gamuts among all flexographic prints. Across nearly all hues, the flexo colour space is smaller than that of the digital print, with relatively uniform distribution of the uncovered regions and no pronounced outliers.

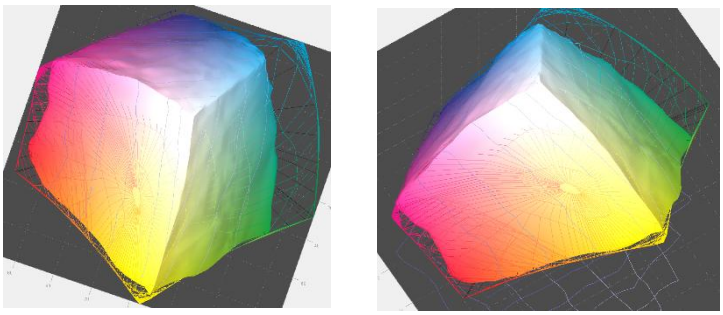

Figure 10: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 8 (Source: author)

The gamut volume was 297,472, representing 35.41% of D50 Lab and 64.56% of HP Indigo 20000. The eighth sample was produced under identical printing conditions as the seventh, with the only difference being the plate material. In this case, a Dupont ESX-R plate was used, featuring a stochastic (FM) screen developed by a Slovak plate manufacturer. This screening method eliminates screen angles and moiré effects, and forms dot structures that differ substantially from conventional AM or FM screens. The results are illustrated in *Figure 10*.

With the exception of the bright green and light blue-green regions, the flexographic sample closely approximated the digital print's colour gamut. In several cross-sections, the two gamuts ran almost parallel. The gamut value was 398,108, corresponding to 47.39% of D50 Lab and 86.40% of HP Indigo 20000. The ninth sample was also produced in the same printing plant as the seventh and eighth samples. This allows for a comparative assessment of how different plate-making technologies affect colour gamut reproduction within the same printing environment. This sample used Bellissima DMS screening on a MacDermid plate, with all other parameters held constant. The visualisation is shown in *Figure 11*.

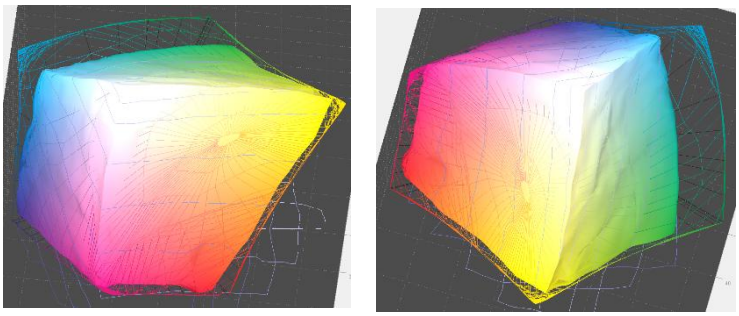

Figure 11: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 9 (Source: author)

Similarly to the eighth sample, this print exhibited a relatively wide colour gamut, performing well compared to the previous results. Although the digital print again exceeded the flexographic sample at nearly all gamut peaks, the overall performance of this plate configuration was strong. The measured gamut volume was 386,358, corresponding to 45.99% of D50 Lab and 83.85% of HP Indigo 20000. The tenth and final flexographic sample originated from a different printing plant than the previous ones. Only Kodak tests were available from this facility. The plate was produced using Kodak Flexcel NX technology with a standard Kodak NX plate.

Among all the samples, this one exhibited the closest match to the digital print's colour gamut. As in previous cases, bright green, light blue, and blue-green hues could not be fully matched by flexography; however, in all other regions, the results were notably consistent. In the light magenta region, the digital print performed slightly better, whereas in the yellow–red–green sector, the flexo print achieved stronger results. The visual comparison is shown in *Figure 12*.

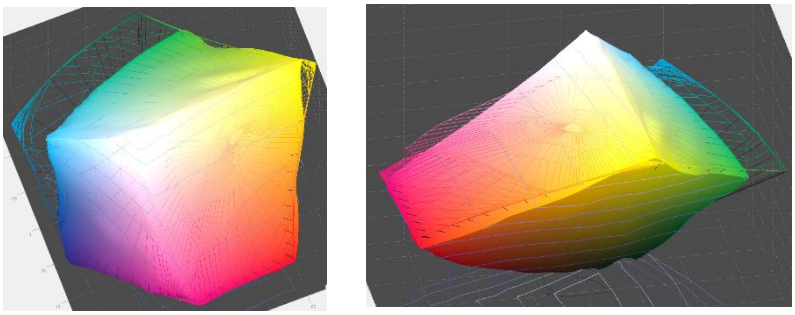

Figure 12: Comparison of the color spaces of the HP Indigo 20000 and Flexo Sample No. 10 (Source: author)

The measured gamut volume for this sample was 419,919, the highest value among all flexographic samples. This represents 49.98% of the D50 Lab gamut and 91.14% of the HP Indigo 20000 gamut.

6. EVALUATION OF THE EXPERIMENTAL RESULTS

The study included 11 samples, from which ICC profiles were measured using the appropriate technology and subsequently compared. The results obtained are summarized in the table below.

Table 2: Manufacturing parameters and test results of the color profiles involved in the study (Source: author)

Nr.	Substrate	Printing plate	Inks	Printhouse	GV	% to Lab	% to D
1.	PP TR	Digitális	digital	PH 1	460722	54,84 %	100%
2.	PP TR	Bellissima	UV	PH 2	348449	41,47 %	75,63 %
3.	PP TR	Bellissima	UV	PH 3	407321	48,48 %	88,40 %
4.	PP TR	Kodak	UV	PH 3	388433	46,23 %	84,30 %
5.	PP TR	Digital Flat	UV	PH 3	340696	40,55 %	73,94 %
6.	PP TR	Classic Digital	digital	PH 4	341701	40,67 %	74,16 %
7.	PP TR	Bellissima	digital	PH 5	397610	47,33 %	86,30 %
8.	PP TR	Kodak	digital	PH 6	297472	35,41 %	64,56 %
9.	PP TR	Digital Flat	digital	PH 6	398108	47,39 %	86,40 %
10.	PP TR	Bellissima	digital	PH 6	386358	45,99 %	83,85 %
11.	PP TR	Kodak	digital	PH 7	419919	49,98 %	91,14 %

Based on these results, the following conclusions can be drawn:

- Digital and flexographic printing technologies can cover approximately half of the Lab colo**u**r spectrum. Among them, digital printing outperformed the best-performing flexo sample by 4.86%.
- The technology and type of printing plate affect the color space reproduction in flexographic printing. Evidence of this can be seen in samples 3, 4, and 5, as well as in samples 8, 9, and 10. These samples were produced at the same printing houses, printed on the same presses, using identical anilox rollers, ink settings, substrates, operators, etc. Nevertheless, significant differences in gamut ranges are visible in both cases. At Printing House No. 2, which used UV ink, the gamut fluctuation interval was 340,696–407,321, showing a difference of 66,625. In the case of Printing House No. 6, this value was even higher: the interval was 297,472–398,108, resulting in a difference of 100,636, which should be considered significant, as compared to the higher value, the other plate's color space performance reached only 74.72%.
- The screen structure applied on the printing plate also influences the color space reproduction in flexographic printing.
- The influence of multiple factors on flexographic printing is evident. This is demonstrated by samples 2 and 3. The samples were produced by two different printing houses, but the press type and manufacturer, the printing plate, and the substrate were identical. Two different ink suppliers provided the inks to the two printing houses. This difference caused a gamut range discrepancy of 58,872. The first printing house achieved only 85.54% of the performance of the second in this area.
- For future research, it would be an interesting question to investigate methods that could expand the reproducible colo**u**r spectrum in flexographic printing.

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ASSESSING INFOGRAPHICS AS A TOOL OF VISUAL COMMUNICATION IN TEACHING AND LEARNING

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Abstract:
In recent years, infographics have gained popularity in online teaching and learning as a means of visually presenting information. While widely used as a communication tool, little is known about how infographics influence students' interpretation and understanding of concepts compared to text-only materials. The literature highlights challenges such as poor application of design principles, ineffective use of layout and colour, and inclusion of irrelevant visuals, which may affect learning outcomes. This paper investigates the influence of infographics on students' interpretation and understanding of art and design concepts in comparison to text-only information. The study was conducted at the Department of Design and Studio Art at the Central University of Technology (CUT), Free State, South Africa, during the 2018/2019 academic years. Quantitative data were collected from two experimental groups: one group received text-only instructional material (N = 23), while the other received infographic-based material (N = 20). The findings reveal no significant difference in mean percentage scores between the two groups. Both groups performed similarly in the assessment, with average scores showing no meaningful distinction, suggesting that the use of infographics did not significantly enhance students' understanding compared to text-only content.

Keywords: *Infographics, visual communication, text, teaching and learning, visual representations.*

1. INTRODUCTION

Throughout the history, communication has been an integral part of human interaction taking place in various forms such as verbal conversation, visual representation, or even through physical movement. The visual representations by early humans were through cave paintings and later developed mapping techniques (Lankow, Ritchie, & Crooks, 2012). In recent years, there has been a significant interest favouring the use of text and attractive infographics, to communicate information. There are many definitions for infographics. One of these definitions is "…visual displays in which graphics (illustrations, symbols, maps, diagrams, etc.) together with verbal language communicate information that would not be possible otherwise" (Meirelles, 2013). Another description of infographics is that "they can be used to represent data and ideas visually, in pictures, engaging more parts of the brain to look at a problem from more than one angle" (Krauss, 2012). In simple terms, infographics are visual representations of information and often used interchangeably with the term "data visualization" (Dur 2014; Reeve & Morris, 2017).
The interpretation and understanding of infographic representations require a broad range of skills. Infographic representations contain images, which could be difficult to interpret and to attach the correct meaning if the appropriate skills are lacking (Sherin, 2013). Some of the most important skills required for the correct interpretation and understanding of infographic representations are critical thinking, critical reading, understanding of statistics, understanding of mathematical concepts, and general visual perceptual skills (Hobbs, 2017). Although there is a growing interest in the use of infographics in conveying information, it seems as if in most cases infographics are misused by focusing on visual presentation rather than presenting information appropriate for the audience and content, (Albers, 2015).

In teaching environment, educators increasingly rely on the use of infographic representations of to convey ideas and concepts to students. However, with the rapid increase in the use of such representations in the classroom, many students fail to achieve their expected learning outcomes (Lundy and Stephens, 2015). This is mostly because of their underdeveloped visual literacy skills which hinder their ability to fully grasp the information presented in infographics. This paper seeks to address this gap in the literature by investigating the impact of infographics on comprehension of abstract art and design concepts among students in the Department of Design and Studio Art. By exploring the benefits and limitations of using infographics as a pedagogical tool, this research aims to provide valuable insights for educators, curriculum developers, and instructional designers seeking to optimize visual learning experiences in creative disciplines.

Research questions

This investigation will be guided by the following research questions:

How do students perceive and engage infographics as a visual aid in art and design education?

What are the perceived benefits and limitations of infographics in facilitating the comprehension of art and design concepts among students?

Aim

This research aims to assess the impact of infographics on the comprehension of abstract art and design concepts among students in the Department of Design and Studio Art.

Objectives

To achieve this, aim the following objectives were devised:

- Assess students' perceptions and engagement with infographics in art and design education.
- Identify the perceived benefits and limitations of infographics in facilitating comprehension of art and design concepts.
- Investigate the influence of infographics on students' comprehension of abstract art and design concepts.

2. LITERATURE REVIEW

2.1 Introduction

The use of visual aids in education has long been recognized as an effective method to enhance students' learning experiences and improve their comprehension of complex concepts (Traboco, Pandian, Nikiphorou Gupta 2022; Dur, 2014). Within the field of visual communication, infographics have gained prominence as powerful tools for presenting information in a visually engaging and concise manner. A study conducted by Yildirim in 2016 discovered that participants showed a preference for receiving information in visual formats such as infographics rather than plain textual content. This literature review aims to explore how infographics influence students' interpretation and understanding of art and design concepts, with a focus on their advantages over traditional text-based materials. It begins with an overview of the historical background of infographics within the broader context of information visualization. The authors strongly believe that this understanding would shed light on trends, innovations, and shifts in the field, offering insights into the development of effective visualization practices. Additionally, the literature review discusses the application, benefits, and challenges of using infographics in educational settings.

Visual communication involves how we interpret and understand certain things using pictures and images in our minds (Lester, 2012). It includes many ways of showing and sharing information, like what we think about and what we see with our eyes. In our everyday lives, we remember things that are important to us, often because they are creative, cultural, or emotional—like old things from history that people still care about (Baldwin and Roberts, 2006). These old things, like pictures and artworks, are kept and remembered by many people in Western culture. They help teach future generations about the past. Infographics, which are visual representation of information communication, have become widely

used in various fields like journalism, marketing, and data analysis. They make it easier to understand complex data and statistics (Kennedy et al., 2014). In essence, an infographic is a way of using pictures and symbols to share information. Infographics do not have to be complicated or include a lot of data. They can be as simple as a picture of a person digging with a shovel to indicate construction work ahead, or as complex as a detailed analysis of the global economy (Lankow, Ritchie, & Crooks, 2012).
Despite their widespread use in various areas, their effectiveness as a teaching tool for art and design concepts remains uncertain. This raises the question of whether infographics can be equally effective in the context of art and design education. One important factor to note from the literature is that when providing students with infographics is that they need to be evidence-based or made carefully with credible sources (Traboco, Pandian, Nikiphorou Gupta 2022). This will ensure that the information provided is correct and not misleading to students. Understanding these important aspects about infographics can help educators show students in teaching students how to evaluate the reliability of information presented in infographics.

2.2 The Roots of Infographics: A Look back in History

Infographics, visual representations of information, have a long history dating back to ancient times and of which the first known examples were from the late Stone Age, around 30,000 BC (Smiciklas, 2012). Early civilizations used symbols and hieroglyphs to convey ideas, with notable examples including Egyptian hieroglyphs and Mesoamerican imagery (Mol, 2011). In the 18th century, Scottish engineer William Playfair introduced graphs and charts in his book, pioneering the interpretation of numerical data (Smiciklas, 2012). In the 20th century, newspapers and magazines began incorporating infographics to engage readers. This trend continued with the rise of the internet, as infographics offered a more visually appealing alternative to text-heavy reports. Notably, Florence Nightingale used infographics to illustrate health issues among soldiers during the Crimean War.
Technological advancements have made infographic production more accessible, transitioning from manual processes to computer-based design. Infographics are valued for their ability to simplify complex information, making it easier for viewers to understand and engage with the material (Chicca & Chunta, 2020). They are widely used in mainstream media and online platforms to communicate ideas effectively. In the modern context, infographics serve as visualizations of data or ideas, aiming to convey information quickly and clearly. They are used to tell stories, explore issues, and disseminate research findings in a visually engaging manner. With the availability of software tools and online resources, creating infographics has become more accessible than ever before. Today, infographics are ubiquitous, found everywhere from restaurant menus to social media platforms. They offer a visually appealing way to present information, drawing viewers in and encouraging engagement. By following accurate patterns and utilizing reliable data sources, infographics can effectively communicate complex ideas and statistics to a wide audience.

2.3 Early Studies on Visual Communication and Learning

This idea of using pictures and visuals to aid learning has been studied for a long time, especially in educational psychology. Back in the middle of the 20th century, researchers like Paivio (1963) proposed the dual coding theory (DCT) suggesting that humans possess separate cognitive systems for processing verbal (linguistic) and nonverbal (visual) information. Paivio’s research arose from his extensive research on word pairs and mental imagery. Paivio's experiments revealed that concrete nouns, such as "dog" or "tree," tend to evoke clearer mental images compared to abstract nouns or adjectives. They found that when information is shown both as pictures and words, it can improve how well we remember and understand it. This highlights the importance of using pictures and visuals in things we use for learning, especially in subjects like art and design. This conceptualization provides a foundation for understanding how individuals encode, process, and retrieve information in both verbal and nonverbal formats, highlighting the richness and complexity of human cognition.

In the 1970s, Baddeley introduced the working memory (WM) model as a reaction, to the drawbacks of the prevailing idea of short-term memory (Baddeley, 2010, Baddeley and Hitch, 1974). Originally proposed in Atkinson and Shiffrins (1968) multi store model short term memory (STM) was viewed as a system designed to store and process information. Nonetheless Baddeley and Hitchs findings implied an operational system. The Working Memory Model, proposed by Baddeley and Hitch in 1974, describes short-term memory as a system with multiple components. The working memory model suggests a dynamic system involving several components. The phonological loop is responsible for the temporary storage of verbal information, involving both the auditory and speech perception areas of the brain. This loop enables the repetition of details assisting in their memory retention. In contrast the visuospatial sketchpad deals with spatial data enabling people to manipulate and navigate visual content. The main part of our brain that brings everything together in our memory system is the processor. This part works to coordinate the loop and visuospatial sketchpad while also connecting with long term memory to help us remember and recall information.

Moreover, the theory introduces the idea of "chunks" which are pieces of information that can be grouped together to improve memory performance. For instance, instead of trying to memorize a series of numbers individually people can organize them into meaningful sequences like phone numbers or dates. Furthermore, the episodic buffer was later incorporated into the theory to explain how information from sources is combined into episodes for long term memory storage. This buffer enables the consolidation of information from memory systems into unified episodes or experiences enhancing the encoding and retrieval of memories. Baddeleys model of working memory offers a framework for understanding how information is temporarily stored, manipulated and integrated in the brain. It provides insights into processes such as learning, problem solving and decision making.

Cognitive Load Theory (CLT), originated by Sweller, focuses on managing cognitive processing load to optimize learning. It identifies three types of cognitive load: intrinsic, extraneous, and germane. Examples and integration of information reduce extraneous load, enhancing learning by conserving cognitive resources for relevant processing. Bartlett's experiments on schema formation also influenced CLT, emphasizing the role of schemata in expanding long-term memory. Swellers Cognitive Load Theory (CLT) aims to manage processing load, for improved learning outcomes. CLT categorizes load into three types: intrinsic, extraneous and germane. By providing examples and integrating information extraneous load is minimized, allowing learners to allocate resources efficiently for processing relevant information. Bartletts research on schema development has also played a role in shaping CLT by highlighting the importance of schemata, in enhancing long term memory retention. Schemata are mental frameworks that help individuals organize and interpret information based on prior knowledge and experiences. Bartlett's studies, particularly his work "Remembering: A Study in Experimental and Social Psychology" (1932), demonstrated how people use these cognitive structures to make sense of new information by integrating it with what they already know.

Bartlett's findings suggest that learning is not a passive absorption of data but an active process where new information is integrated into existing mental structures. This idea is central to Cognitive Load Theory (CLT), developed by John Sweller in the late 1980s, which focuses on the mental effort required to process new information. In the 1990s, Sweller expanded CLT to guide instructional designers on minimizing cognitive overload by reducing split attention and redundancy, which can burden working memory. By effectively managing extraneous and germane cognitive loads, designers can optimize cognitive resources for meaningful processing, leading to improved learning outcomes. This approach has significantly influenced multimedia learning theory by highlighting the importance of managing cognitive load to facilitate successful learning.

This brief overview regarding early studies on visual communication and learning is meant to provide valuable insights for educators who want to incorporate infographics in teaching art and design concepts. Infographics, which combine various visual information such as images, diagrams, graphs and text (Yildrim 2016), have been shown to enhance learning by leveraging visual elements to make complex information more accessible and engaging (Alyahya, 2019; Chicca & Chunta, 2020). By understanding theories such as DCT which suggests that combining verbal and visual information can improve

memory, as well as CLT, which focuses on reducing the mental effort required to process information, educators can create infographics that not only capture students' attention but also help them better understand and remember key principles of art and design. These perceptions can help educators in designing materials that not only capture students' attention but also facilitate a deeper understanding and better retention of art and design principles, ultimately enriching the learning experience.

2.4 Emergence of Infographics in Education

In the late 20th and early 21st centuries, researchers began investigating the use of infographics as educational tools. In a seminal study by Mayer and Anderson (1991), it was demonstrated that multimedia presentations, which incorporated visuals like diagrams and illustrations alongside text, led to better understanding and recall of complex information compared to text-only presentations. This study highlighted the potential benefits of incorporating visuals in educational materials. Following these foundational theories and studies, the use of infographics in education began to flourish. Infographics combine text, images, and design elements to convey information succinctly and engagingly. They are particularly useful in summarizing complex data, illustrating processes, and highlighting key points, making them a valuable tool in educational settings.

The rise of digital technology further propelled the adoption of infographics in education. Tools like Adobe Illustrator, Canva, and Piktochart made it easier for educators to create high-quality visual content. Additionally, the proliferation of online learning platforms and digital classrooms provided new venues for deploying infographics to enhance learning experiences. Today, infographics are widely used across various educational levels and disciplines. They support differentiated instruction, catering to visual learners and helping to simplify complex subjects. Educational research continues to explore the most effective ways to integrate infographics and other visual aids into curricula, ensuring that teaching methods evolve to meet the needs of 21st-century learners. The emergence of infographics in education appears to be rooted in a deep understanding of cognitive psychology and supported by technological advancements. Seminal research by scholars like Mayer and Anderson (1991), has demonstrated the effectiveness of multimedia learning, paving the way for the widespread adoption of infographics as a powerful educational tool.

2.5 Design Principles for Educational Infographics

As mentioned in the introduction of this section, the integration and use of infographics into educational settings has gained considerable attention due to their ability to visually communicate complex information effectively (Traboco, Pandian, Nikiphorou Gupta 2022; Dur, 2014). It is also acknowledged that the role of infographics in education is continuously changing due to the emergence of new methods and strategies (Bhat & Alyahya, 2023; Alyahya, 2019; Dur, 2014). Therefore, understanding the key design principles that underpin successful educational infographics is essential for educators and instructional designers aiming to optimize the learning experience for students.

2.6 Accessibility and Inclusivity

Designing infographics with accessibility and inclusivity in mind is paramount to ensuring equitable access to educational content, (Beene, Koelling & Thompson, 2020; Anete Ezera, 2023). Incorporating features such as alternative text descriptions, high contrast visuals, and compatibility with assistive technologies broadens the reach of infographics and accommodates diverse learning needs (Dunn, 2019). By prioritizing accessibility, educators can foster an inclusive learning environment that caters to the needs of all students (Burgstahler & Doe, 2004).

2.7 Visual Hierarchy

One fundamental principle of infographic design is establishing a clear visual hierarchy (Lankow, Ritchie, & Crooks, 2012). By strategically organizing elements such as text, images, and graphical

representations, designers can guide the viewer's attention and convey the intended message with clarity (Arslan & Toy, 2015). In educational contexts, this principle becomes particularly crucial as it aids in prioritizing information and facilitating comprehension, thus enhancing learning outcomes (McCloud, 1994).

2.8 Simplicity and Clarity

Educational infographics should prioritize simplicity and clarity in their design to ensure accessibility for diverse audiences (Cairo, 2012). By employing concise language, minimalistic graphics, and intuitive layouts, designers can mitigate cognitive overload and foster engagement with the content (Cairo, 2016). Moreover, simplification of complex concepts through visual representation facilitates knowledge retention and promotes active learning (Tufte, 2001). To sum it up, adherence to key design principles enhances the effectiveness of educational infographics by promoting clarity, engagement, and accessibility. When design decisions are aligned to teaching goals and include communication techniques, educators can leverage infographics to create valuable learning opportunities, for students.

3. METHOD

3.1 Research design

This study employed a pre-test/post-test experimental design, as recommended by Wimmer and Dominick (2006), to assess the influence of infographics on students' interpretation and understanding of art and design concepts. Before the experiment, participants undertook a pre-test to determine their basic knowledge of art and design concepts, specifically focusing on principles of design. This pre-test was administered using a questionnaire, to ascertain the participants' existing knowledge.

After completing the pre-test, participants were randomly assigned to experimental groups, where they were exposed to instructional materials either in text-only format or exclusively through infographics. The content of these materials in both groups was identical and related to art and design concepts, with the only difference being the mode of presentation. covered various topics related to art and design education, aligning with the curriculum of the Department of Design and Studio Art at the Central University of Technology, Free State. Following the instructional intervention, all participants underwent a post-test assessment aimed at evaluating their comprehension and interpretation of the presented concepts. This post-test comprised a multiple-choice questionnaire that encompassed participants' biographical information and assessed their understanding of key terms such as graphic design, visual literacy, and infographics. Additionally, participants were asked to interpret infographic and text visual representations, providing insight into their learning outcomes.

By employing this experimental design, which included pre-test and post-test assessments, this study aimed to systematically measure the impact of infographics on students' learning outcomes in the context of art and design education. Therefore, this approach facilitated the examination of relationships among variables and provided valuable insights into the effectiveness of different instructional formats in promoting student understanding and interpretation of art and design concepts.

3.2 Setting and participants

The study samples consisted of senior students enrolled in the Department of Design and Studio Art at the Central University of Technology, Free State. Design and Studio Art students were deemed appropriate participants for this study due to their specialized knowledge in visual communication and design principles. Given their background in this field, they possess a substantial base in understanding and interpreting visual information, making them well-suited for assessing the efficacy of infographics in conveying complex concepts. Additionally, their familiarity with art and design concepts aligns closely with the content of the study, ensuring relevance and applicability of the instructional materials provided. Furthermore, Design and Studio Art students are likely to encounter infographics frequently in their academic and professional activities, highlighting the importance of investigating the impact of

this instructional format within their educational context. Therefore, their participation in the study provides valuable insights into the potential benefits and challenges associated with the use of infographics in art and design education.
The sampling method selected for this study is convenience sampling, which involves selecting participants based on their ease of accessibility and availability. Convenience sampling was chosen due to practical considerations, as it allowed for the recruitment of participants from the Department of Design and Studio Art at the Central University of Technology, Free State (CUT), Bloemfontein, South Africa, during the specified academic year/s. Given the constraints of time and resources, convenience sampling provided a feasible approach for obtaining a sufficient number of participants within the target population. While convenience sampling may introduce some degree of bias, particularly in terms of generalizability, its use in this study was deemed appropriate for the specific research context and objectives. Additionally, efforts were made to ensure that participants were representative of the broader population of Design and Studio Art students at CUT, enhancing the validity of the study findings within this particular educational setting.

3.3 Data collection methods Measures

Data were collected using a controlled experimental design involving two distinct groups: a text-only group and an infographics-only group. Each group was exposed to educational material presenting art and design concepts in either text or infographic format. The data collection methods included pre-tests, exposure to educational materials, and post-tests to evaluate comprehension and interpretation. To assess students' interpretation and understanding of art and design concepts, multiple measures were employed. These included pre-tests to establish baseline knowledge, post-tests to gauge comprehension following exposure to educational materials, and surveys or questionnaires to gather qualitative feedback on the effectiveness of the presentation format.

3.4 Materials and procedure

Educational materials were carefully developed to ensure consistency in content between the text-only and infographics-only formats. The text-based materials consisted of written descriptions, explanations, and examples of art and design concepts. In contrast, the infographics included visual representations, diagrams, and concise text to convey the same information. The procedure involved administering pre-tests to both groups to establish initial knowledge levels. Subsequently, participants were exposed to the respective educational materials—either text-only or infographics-only. Finally, post-tests were administered to assess changes in comprehension and interpretation resulting from exposure to the materials.

3.5 Data analysis

Quantitative analysis was performed on the collected data to assess the impact of infographics on students' comprehension of abstract art and design concepts. Descriptive statistics were calculated to summarize the participants' performance on the pre-test and post-test assessments. Additionally, inferential statistics, such as t-tests or ANOVA, were utilized to determine any significant differences between the text-only and infographics-only groups.

5. RESULTS

Figures, i.e. illustrations and pictures, should be set into the body of the text at the appropriate point, close to where they are referenced in the text and not grouped together at the end of the paper. Place the pictures between paragraphs and centre them between the margins. The figure layout should be in line with the text. Figures should be made in high quality suitable for reproduction and print. The notations on figures must be clearly readable. They must be numbered using Arabic numbers. Figure captions should be written below each figure.
The results of the pre-test and post-test for the Infographic Group and Text Group are given below.

4.1 The pre-test results

There were 20 participants in the IG Group and 23 participants in the Text Group. An independent samples t-test was run to determine if there were differences in the mean percentages scored for the pre-test between participants in the IG Group and participants in the Text Group. There were no extreme outliers in the data, as assessed by inspection of a boxplot. Pre-test percentages for each level of the independent variable were normally distributed, as assessed by Normal Q-Q Plots, and there was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = 0.818$). There was no statistically significant difference in the percentage scored for the pre-test between participants in the IG Group ($M = 38.33$, $SD = 18.81$) and participants in the Text Group ($M = 29.71$, $SD = 18.09$), $t(41) = 1.531$, $p = 0.134$.

The study conducted independent samples t-tests to compare the pre-test and post-test scores between the Infographic Group (IG) and the Text Group. Prior to the intervention, there was no statistically significant difference in pre-test scores between the IG Group ($M = 38.33$, $SD = 18.81$) and the Text Group ($M = 29.71$, $SD = 18.09$), $t(41) = 1.531$, $p = 0.134$. Similarly, after exposure to the respective interventions, the post-test scores did not reveal a significant difference between the IG Group ($M = 42.08$, $SD = 15.87$) and the Text Group ($M = 41.67$, $SD = 13.99$), $t(41) = 0.092$, $p = 0.928$. These findings suggest that both infographics and text-based materials yielded comparable outcomes in terms of comprehension and retention of art and design concepts.

Table 1: Statistics of comprehension scores for IG and Text group

Group_RECODED		N	Mean	Std. Deviation	Std. Error Mean
Pre-test_Practicality_Percentage	IG Group	20	38.3330	18.80861	4.20573
	Text Group	23	29.7104	18.08776	3.77156

4.2 Post-test results

Independent Samples Test: There were 20 participants in the IG Group and 23 participants in the Text Group. An independent samples t-test was run to determine if there were differences in the mean percentages scored for the test between participants in the IG Group and participants in the Text Group. There were no extreme outliers in the data, as assessed by inspection of a boxplot. Test percentages for each level of the independent variable were normally distributed, as assessed by Normal Q-Q Plots, and variances were homogeneous, as assessed by Levene's test for equality of variances ($p = 0.949$), thus meeting the assumptions of equal variances.

Mean scores: The mean percentage score achieved by participants in the IG GROUP was ($M = 42.08$, $SD = 15.87$) and participants in the Text Group ($M = 41.67$, $SD = 13.99$), $t(41) = 0.092$, $p = 0.928$.

There was no statistically significant difference in the percentage scored for the test between participants in the IG Group and Text Group.

Table 2: Statistics of post-test scores for IG and Text group

RECODE_GROUP		N	Mean	Std. Deviation	Std. Error Mean
Total_Percentage	IG_GROUP	20	42.0833	15.87483	3.54972
	TEXT_GROUP	23	41.6667	13.98953	2.91702

6. FINDINGS AND DISCUSSION

The study's results reveal that infographics had a minimal impact on the comprehension of art and design concepts among students in the Department of Design and Studio Art. While participants could identify these concepts, they struggled to interpret and understand the visual representations in the infographics. This raises the question: do infographics and text-based visual representations provide the same level of understanding? The findings suggest that both infographics and traditional text-based materials were equally effective in helping students grasp art and design concepts. Despite the visual appeal and narrative efficiency of infographics, they did not offer a significant advantage over text-based formats in this context. It is possible that factors such as individual learning styles, prior knowledge, and the complexity of the subject matter influenced these results.

Furthermore, the study indicates that participants possessed knowledge of design principles but encountered difficulties interpreting the infographic visual representations. This suggests a deficiency in critical thinking skills and, more notably, visual literacy skills. Participants, however, expressed a preference for learning through infographic visual representations. They believed that, with improvements, infographics could be a more effective learning tool. The study highlights the need to refine the design of infographics and to conduct additional tests before using them in comprehension assessments. It also notes that the sample size and the specific design of the instructional materials may have contributed to the lack of significant differences observed. Further research is needed to explore the nuanced effects of infographics on different learner populations and in various instructional contexts.

7. CONCLUSIONS AND RECOMMENDATIONS

The findings of this study suggest that both infographics and text-based materials are viable means of presenting art and design concepts to students. While infographics are often praised for their visual appeal and potential to enhance information processing, this study did not find empirical evidence supporting their superiority over traditional text-based formats in terms of comprehension and retention. The study's results indicate that although participants could identify art and design concepts, they struggled with interpreting the visual representations in the infographics. This suggests that infographics may not inherently improve understanding without considering the audience's visual literacy and critical thinking skills. The equal effectiveness of both instructional formats highlights the importance of considering several factors when choosing educational materials. Educators and instructional designers should evaluate pedagogical objectives, audience characteristics, and content complexity. For example, individual learning styles and prior knowledge play significant roles in how students interact with and benefit from different formats.

The study also emphasizes the necessity of refining infographic designs to enhance their interpretability and educational value. Participants expressed a belief that infographics could be a better learning tool if their design were improved, suggesting a need for ongoing testing and iteration.

The study's limitations, such as sample size and the specific design of instructional materials, also call for further research. Future studies should explore the effects of infographics on diverse learner populations and in various instructional contexts to provide a more comprehensive understanding of their educational impact. By adopting a careful and thoughtful approach to instructional design, educators can optimize learning experiences and empower students to develop robust competencies in art and design. Ongoing research and evaluation will be essential to effectively leverage visual and textual modalities in educational interventions, ensuring they meet the evolving needs of students.

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ON THE SUSTAINABILITY OF DIGITAL MEDIA

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Abstract:

In the need to keep up with rapid innovations individuals and enterprises are urged to connect to the largest global computer network comprised of billions of interconnected devices, servers, and the underlying infrastructure. Most people are aware of the fact that the digital world has a significant environmental impact. This awareness drive the efforts of companies and organisations to make a good impression in this aspect as well. The World Wide Web Consortium recently introduced Web Sustainability Guidelines to make web products and services more sustainable. Efficiency indices were created and standardised to quantify data centre's total power effectiveness. It has a high marketing value wether the infrastructure runs on clean energy. Stakeholders of the internet seem to be willing to take efforts towards the usual goals of environmental awareness. The the concept of sustainability is multifaceted and so is digital media's sphere of influence. The UN sustainable development goals may provide a comprehensive framework for evaluation, the supportin institutions generally look positively on the impact of digitization and digital media regarding society and economy. Although sustainability has a wider scope than just the environment, putting prosperity and people before the planet would be a backward step. This study aims to highlight crucial aspects and trends that may direct ICT developments, including digital media, towards a more sustainable future.

Keywords: *sustainability, digital media, word wide web, energy efficiency*

1. INTRODUCTION

In the 1999 movie The Matrix humans live a passive life lying in their pods with their minds interfaced to a virtual reality world. A quater of century later we may interpret this as a sinister allegory for new generations to come. In the movie the ecosystem of artificially intelligent machines lives on the energy harvested from human bodies. Today in modern societies people do not have to have their bodies exploited as batteries, yet they contribute with a considerable amount of resources to the digital infrastructure which becomes fundamental for entertainment, work and everyday life. The development of the digital framework is quantitative and qualitative simultainously, more and more people access the improving services of the digital platforms.

Indeed, technological progress has the greatest impact on our lives. Within this, technological development over the past decade or two has been understood almost exclusively in terms of the expansion of the capacity of information and communication tools and networks and the deepening of their integration. This dramatic change has had a fundamental impact on our economic structure, social relationships and cultural relations. The ICT development is one-sided, seemingly unstoppable, and planetary, global networks shape our view on our personal future. We have become passive and reluctant recipients of technology, rarely questioning its expansion, with critical interpretations hardly ever appearing in public discourse. One exception is the perspective of sustainability, which is a fashionable ideological trend of our time.

Sustainability is often interpreted as the balanced mixture of the three primaries: environment, society and economy. The concept also involves meeting the needs of the present without compromising the future. The impact of the ICT development on society and economy is impressive but difficult to characterize in terms of quality due to its fast sweeping nature. For example we have very little control over social media companies, or people using their products. The impact on environment has direct and indirect, positive and negative components. A direct negative factor is the increasing energy

consumption and carbon footprint of the evolving infrastructure. An indirect positive impact are efforts and investments toward digital innovation that accelerate environmental and social sustainability.
The latter is included in the Action Plan of the UN Coalition for Digital Environmental Sustainability (CODES) [1]. It supports the 9th UN Sustainable Development Goal (SDG): Industry, Innovation and Infrastructure. The SDG framework has 17 goals detailed in 169 targets providing a roadmap for governments, businesses, and individuals to foster sustainable development [2]. Novel technologies can support certain sustainability goals, but they can also threaten others. Similarly, digital media can contribute to achieving a number of SDGs. Hunger and malnutrition can be reduced (SDG 2) by making agricultural practices more data-driven and efficient, to increase crop yields and reduce the use of energy. Direct patient care, health informatics contribute to good health and well-being (SDG 3). Improved connectivity promotes quality education and skilled workforce (SDG 4) also the closing of the gender gap (SDG 5) by digital access to jobs and education from home while reducing inequalities (SDG 10) by extending access to technologies and knowledge to disadvantaged groups of society [3]. While the big picture looks promising it is worth to look what is hiding in the details.

2. DISCUSSION

In the following section I would like to highlight a few diverse topics that are closely related to the sustainability of digital media. Processing units of the underlying infrastructure translate complex tasks into a sequence of fundamental binary operations which makes energy efficient computing a key factor. Modern tasks, e.g., big data, cloud computing, often require IT equipment to be concentrated in so-called data centers, where data is not only stored but also processed. These facilities have special energy requirements worth addressing because their number and significance are growing. The World Wide Web is fundamental to our digital activities, its development is diverse and offers a wealth of opportunities, thus it is important to know that guidelines were worked out for those who want to make it sustainable as well. And last but not least: artificial intelligence, which will definitely have a substantial impact and is already affecting all three dimensions of sustainability.

Computation costs energy

Advances in semiconductor fabrication brought forward dramatic increases in transistor density per chip. It resulted in exponentially enhancing processing power as well as energy efficiency. The former is often characterised by Moore's law: the number of transistors on a microchip doubles in every 18 to 24 months. Efficiency is addressed by Koomey's law which observes that the number of computations per joule (J) doubles also in about roughly 18 months [4]. Both laws slowed down in the past decade [5] as transistor sizes approaching a few nanometers thus physical limits, material constraints and other factors challenge development. From a sustainability perspective, it is desirable for operations to consume as little energy as possible, but is there an ideal value and how far are we from it at present?
It would be an overstatement to say that modern computing architecture technically consist only of NAND gates, but these logical gates (a combination of an AND gate and a NOT gate) are theoretically important for understanding the minimum energy requirement of computation. Any Boolean function can be implemented by using a combination of NAND gates allowing for the construction of any complex digital processing unit using type of logical gate only. Table 1 shows shows the outputs for the possible input combinations the 2-input NAND gate.

Table 1: Truth table of a NAND gate

Input		Output
A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0

Since the NAND gate has only one output, one of its inputs has effectively been erased in the process, whose information has been lost forever. The change in entropy that is associated with the lost of one bit of information is $ln(2)$, which, thermodynamically, corresponds to an energy increase of $k_B T\, ln(2)$, where k_B is Boltzman's constant and T is the temperature. Thus the operation of NAND gates will in theory and practice dissipate heat as a sign of physical irreversibility.
The above principle was named after Rolf Landauer, who proposed it first in 1961 as the minimum energy needed to erase one bit of information. The Landauer limit can be demonstrated under laboratory conditions, but modern transistors in a computing environment where performance matters consume energy several orders of magnitude higher than that. The Landauer limit sets the ceiling to how efficient classical computers may become, which may be approached as technology continues to advance, but it will not happen in the near future. [6]

Data centers

There are more than 12,000 data centers worldwide, about 10% of them are hyperscale data centers (often >1,000m2 and 5,000+ servers) with extreme scalability capabilities, often owned and operated by a single provider. In these facilities the vast amounts of GPU and CPU servers, storage systems, cooling, networking and UPS (to survive power outages or fluctuations) devices generate a power demand that is quite a challenge.
Deloitte forecasts that global data center electricity usage could nearly double from 536 terawatt-hours (TWh) - about 2% of global electricity - in 2025 to approximately 1,065 TWh by 2030 (3.7%). AI data centers' annual power consumption is roughly one-seventh of the predicted consumption of all data centers globally [7].
The concept of Power Usage Effectiveness (PUE) was introduced in 2007 in response to the demand for a consistent method to compare the energy performance of data center facilities. It compares the total energy used by the entire data center (IT equipment and support systems like cooling, UPS and lighting) to the energy used strictly by the computing equipment using a simple formula:

PUE = Total Facility Energy / IT Equipment Energy

The ideal PUE value is 1.0, in this 100% power is utilized by the IT equipment [8]. A facility that uses evaporative water for cooling will have a further impact on the environment by using water resources. Evaporative cooling consumes less energy, but significantly more water. The trade-off between water and energy use is addressed by introducing Water Usage Effectiveness (WUE) as a data center key performance indicator [9]. WUE is measured in cubic meters of water per megawatt hour of energy (m^3/MWh).
While DCs consume enormous amounts of power it is rewarding to invest into innovative cooling and renewable energy to reduce cost and environmental impact. Many big tech and cloud providers are investing in carbon-free energy sources demonstrating their commitment to sustainability and benefiting on the marketing side as well.
Nevertheless, two important observations must be added to the above. First, the global average PUE has been stagnating at around 1.5 for the past five years. In addition, note that PUE is a dimensionless quantity, a ratio of two energy values that does not indicate the specific quantity involved.

Efficiency of the World Wide Web

The Web infrastructure is the underlying framework of hardware, software, network systems or simply servers plus internet. There are a number of environmental consiserations regarding the architecture and operation of the indidvidual components of the framework.
Since big tech companies own and manage the lions' share of this infrastructure, it may seem, that there is little room for maneuver for web developers. But web power consumption is divided between the front-end (user device) and the back-end (servers and internet), and optimization on the front-end can reduce client-side energy consumption significantly. Also, a lot depends on how the web application uses back-end resources. Therefore the World Wide Web Consortium (W3C) colleted best practices to design and implement digital products, services and content to meet sustainability requirements.

The Web Sustainability Guidelines

The W3C adopted the PPP (Planet, People, Prosperity) principles of sustainability that includes protecting environmental ecosystems, individuals, communities, and society, and ensuring a good quality of life without crossing the boundaries of our planet.
The initiative is very similar to their previous achievement, the Web Content Accessibility Guidelines which explain how to make web content more accessible to people with disabilities. The implementation of the sustainability guidelines can have several benefits regarding economy, performance, security, privacy, environment, social equitiy, etc. Economic and performance benefits are direct motivation to carry out development in compliance with the guidelines.
The guidelines are organized into four groups: user experience design, web development, hosting, infrastructure and ecosystems, business strategy and product management [10]. The qoal of user experience design is to create efficient, relevant, functional and pleasant experiences for users. The Web Development section mainly addresses client and server-side software development. The goal is to obtain a code that runs faster, more efficiently and uses the least hardware resources. Guidelines about infrastructure and ecosystems help content, code, and data to be stored and processed in a sustainable way. A well-designed system will be resource efficient, save energy and reduce operational and investment costs. Business strategy and product management can be as important as technical considerations. High level strategic decisions can align company actions with the sustainability goals, if they are made by well-informed, aware and committed people.
The W3C recommends a "progress-over-perfection" approach when utilizing the Web Sustainability Guidelines. Indeed, the specification is long and comprehensive, but specialists can easily find and focus on their fields where they can introduce sustainability concepts step by step. The rest is just a question of commitment and persistence - provided that the energy saved here is significant compared to the demand of the underlying infrastructure.

The AI challenge

Most of us do not want a much bigger house or car than what we already have. But is there a limit to how intelligent one would like to be - especially when we consider the benefits that come with it? The rapid evolution of AI can be measured in months rather than years. Generative AI (Gen AI) produces media such as text, images, audio, video and animation by learning patterns from large datasets to create novel content. Gen AI investments demand so much electricity that global net additional power for AI data centers increased 25% the previous year [11]. While generally the electricity demand is growing at a relatively stable rate due to industrialization, electric transportation, the energy for AI is rising much more steeply. Its widespread application could unleash such a demand for electricity in the world that within years it could challenge electricity grids, which are already struggling due to the fluctuations of green energy.
At this stage of its development, it is transforming and restructuring the social and economic environment so swiftly and in such a complex way that it would be too early to perform an in-depth analysis [12]. There are plenty of well-founded optimistic and pessimistic ideas about this. However, its

direct impact on the environment - the crucial factor of sustainability - is clearly negative due to its extraordinary energy requirements. The question is whether the knowledge and services created by AI can sufficiently reduce its overall environmental impact.

3. SUMMARY

The aim of this study was to draw attention to the side effects and downsides of the developments contributing to digital media, as well as to energy efficiency considerations that are often overlooked in a technological context. The minimum energy cost of computation can be theoretically defined by the Landauer principle. The Landauer limit represents a very small amount of energy, however modern computers consume several orders of magnitude more energy for single logical operation. The Web Sustainability Guidelines establish a framework to reduce the emissions of digital media by optimizing code, data, infrastructure and services. Followers of the Guidelines contribute to the creation of a faster, more efficient, user-centered and sustainable Web. Data centers concentrate energy guzzler hardware in facilities, which has a higher potential to become energy efficient than the IT equipment inside. Then AI infrastructure will far surpass the present scenario of environmental impact within a very short time. It is still spreading its wings, while the ambitious vision of tech companies, the intensive publicity and novel investment opportunities result in a driving force that foreshadows an enormously growing footprint.

In terms of sustainability, the environmental impact of digital media is perhaps the most significant, but its influence on the economy and society should not be underestimated either. Unfortunately, society's reaction time for innovative, game-changer technologies can be measured in years, remember the time it took to make laws that allow regulation of the use of cell phones in schools. It is reasonable to assume that with such an unprecedented growth rate of development, investment, and energy demand the interaction of the various trends can lead to unpredictable extremes even in a relatively short term.

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INVESTIGATING BRAND COLOR ACCURACY OF DYE SUBLIMATED TEXTILES

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Abstract:
Textiles do not currently encompass a large part of the print industry; however, they are one of the fastest growing segments. With emerging production alternatives growing in popularity including dye sublimation, direct-to-garment printing, and direct-to-film, the need to ensure color accuracy becomes even more important and arguably more difficult due to the switch from spot colors with screen printing to CMYK on these newer technologies. This paper builds on a previous study which examined color brand accuracy and durability of two brand colors using the three most common production processes on a variety of textiles. Results revealed that performance varied based on material, process, and ink color. This study seeks to focus on a single process, dye sublimation, and analyze color accuracy on three different textile samples, consisting of polyester and polyester blends, and expand to include a broader spectrum of brand colors based on the athletic branding for eighteen universities in the United States. Our primary research goal is to determine if there are parts of the color spectrum that are more difficult to print consistently using dye sublimation on the three different textiles. The findings will add to existing research by providing recommendations for brands and printers who print textiles with dye sublimation.

Keywords: *Color accuracy, dye sublimation, textile printing*

1. INTRODUCTION

The global dye sublimation printing market size was estimated to be at 14.9 billion USD in 2024 and is projected to grow to 28.0 billion USD by 2030, at an increase of 11.3% from 2025 to 2030 [1]. The textile market has experienced substantial growth due to the increasing demand for customized apparel and promotional merchandise [1]. Dye sublimation printing accounted for the largest share of the market based on product type, print technique, and application in 2024 [1]. Dye sublimation is quickly becoming a popular printing method for garment printing due to its flexibility in design and its cost effectiveness, particularly for shorter print runs [2]. However, color accuracy is challenging when printing textiles on dye sublimation due to the many variables that can affect the results.
This study is based on previous research by Walker and Bridges [3] which tested two brand colors, orange and purple, and used three different printing processes: dye sublimation, direct-to-garment (DTG) printing, and screen printing. Testing was conducted with the following three types of textiles: 100% cotton, 50/50% cotton/polyester blend, and 100% polyester. Consistency and durability tests were run in order to determine color accuracy. Findings were mixed revealing that performance varied based on material, process, and ink color. Screen printing produced the most accurate and consistent color when compared against the brand specifications. On all three fabrics, the Delta E was 2.5 or below, with the cotton shirt being the most accurate color with a Delta E of 1.35. Purple colored ink produced less accurate color reproduction than the orange, although screen printing was still the most accurate process even when printing purple. Delta E measurements for that group ranged from 5.27 to 7.52 for the purple colored ink. Cotton fabric was the least accurate color reproduction with the purple ink on the blend material reproducing the purple brand color most closely. Both the dye sublimation and the DTG

processes produced much less accurate color compared to the screen printing process. Delta E values ranged from fourteen to twenty-eight which would not be acceptable in a commercial setting. Between these two processes, dye sublimation produced the most accurate colors on polyester fabrics with Delta E readings of fourteen for both brand colors. DTG performed better on orange across all three textiles compared with purple.

This study seeks to focus on a single process, dye sublimation, and analyze color accuracy on three different textile samples, consisting of polyester and polyester blends. The researchers have expanded the color target to include a broader spectrum of brand colors based on the athletic branding for eighteen universities in the United States. Our primary research goal is to determine if there are parts of the color spectrum that are more difficult to print consistently using dye sublimation across these three different textiles. This study also seeks to explore how effectively dye sublimation reproduces accurate color when using manufacturer provided color profile settings. The findings will add to existing research by providing recommendations for brands and printers who print textiles with dye sublimation. It will be particularly beneficial for small-scale print production facilities that may not have the capability to create custom color profiles for each textile type. The researchers are also post-secondary educators who teach the dye sublimation process and the findings will help in instructing students regarding color management when printing textiles using alternate production processes.

2. EXPERIMENTAL

Dye sublimation, also referred to as heat transfer printing, is an indirect printing method that uses sublimation inks that are transferred onto a special paper, heated, and then pressed onto the substrate under controlled pressure [4]. During the sublimation process, the ink is heated and changes from a solid to a gas [5]. When using this process to print onto textiles specifically, the ink becomes part of the fabric fibers rather than laying on top of the surface, allowing for greater print durability [6]. Due to this fact, dye sublimation has been used in the textile printing industry for many years [4], and is considered a viable alternative printing method to traditional screen printing. Some notable advantages of dye sublimation printing are substrate versatility, durability of the print, the ability to print a wide range of colors, and the process is relatively easy to use [6]. However, experts agree that one of the main challenges in dye sublimation printing is color accuracy and management, particularly when producing branded athletic apparel and matching colors to dyed fabrics [7].

This study began with 64 brand colors to represent each athletic team in the ACC (Atlantic Coast Conference division). Duplicate colors were removed which resulted in 40 colors on the test target. Each school provided brand color values as: Pantone, CMYK, RGB, and hex values. LAB values were pulled from Esko Color Pilot software, which has the Pantone digital library installed. From there the test target was built in Adobe Illustrator. Each value was repeated three times on the target, Figure 1.

Figure 1: Example of printed targets on the Epson SC-F570 printer used to produce them.

The textiles used for the study were 100% polyester, 60%/40% polyester/cotton blend, and 50%/50% polyester/cotton blend. All textile samples were the same brand and ordered from the same vendor. Textiles were treated with Dyepress Poly T Pro sublimation coating according to the manufacturer's recommendations which required the coating to be sprayed on followed by the application of a water border around the poly coating. The materials were then cured in a clothing dryer for 30 minutes on high heat and cooled before being pressed in the heat press to print.
The printer used for printing the test targets was an Epson Sure Color F570 series with Epson brand dye sublimation inks loaded with 24" roll dye sublimation paper, Figure 1. The dye sublimation press used to print the textile samples was a George Knight Swing Away flatbed heat press with a 16 x 20 inch platen. Settings used for output from Adobe Illustrator were "Don't Color Manage" and the print was set to "Custom" with Epson SC-F500 series selected as the printer. Color handling was set to "Let Illustrator determine colors." The printer profile selected was "Epson SC F-500 General Purpose/Rigid" with rendering set to "Relative Colormetric." Printing was completed according to poly coating recommendations at temperature 385 fahrenheit with heavy pressure for 10 seconds followed by a sublimation time of 70 seconds with heavy pressure, Figure 2.

Figure 2: Photograph of the three different textiles with the finished printed targets.

The device used for measuring the color targets was the i1Basic Pro 3 Plus spectrophotometer set to D50/2°. This particular unit has a wider aperture of 8 millimeters, which is more accurate when measuring textiles. Calibration was done prior to each measurement using the manufacturer provided white patch. A white poster board backing was placed under each sample to ensure no external colors interfered with the color measurements. Measurements were completed manually under natural UV light and conditions were set to M1 (D50). All three areas printed on the target of the brand color were averaged to produce final LAB values for each brand color. Averaging all three patches was done to evaluate whether or not the color varied across multiple locations on the fabric. Delta E 2000 values were then calculated against the LAB reference color used to build the target in Illustrator. Recording was completed using Microsoft Excel.

3. RESULTS

Previous findings would suggest that textiles with more polyester result in more accurate color with dye sublimation printing. Results in this study showed that 100% polyester performed the best in all color families compared to any other fabric. However, the 60/40 polyester/cotton blend performed worse than

the 50/50 polyester/cotton textile for all the color families except for yellow/gold, Figure 3. In addition, no color family met acceptable Delta E values of <5, but yellow/gold performed the best of all the color families across all three textiles tested.

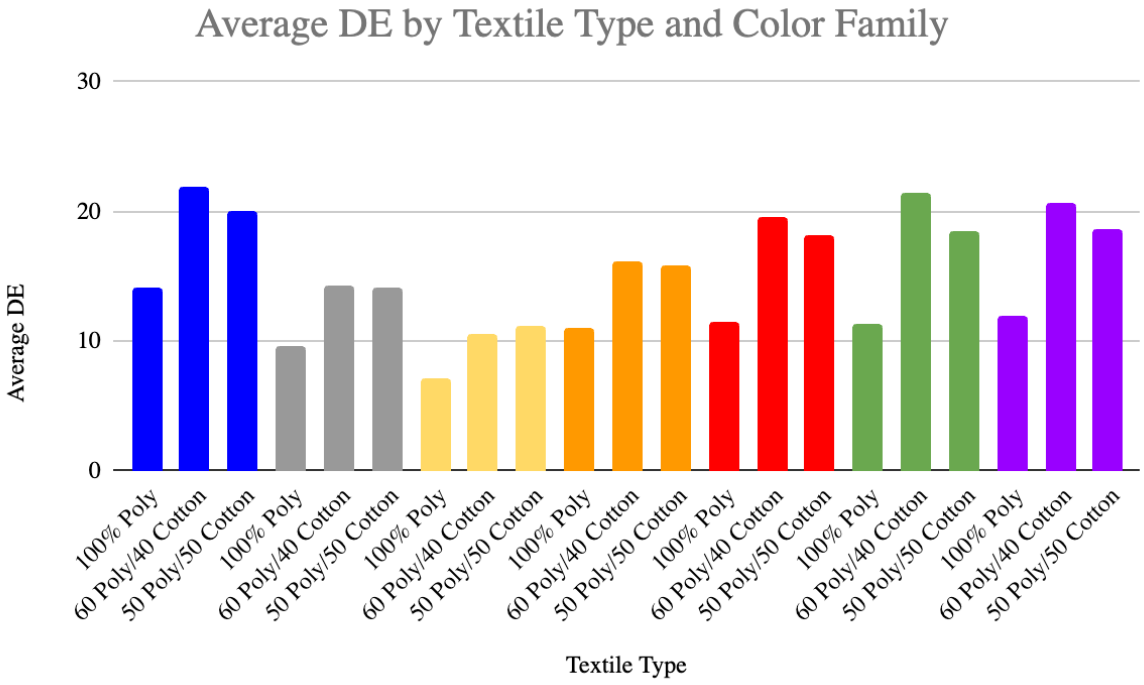

Figure 3: Averaged results for brand color families across all three fabric types showing that 100% polyester performed best across all the fabric choices and that the yellow/gold, black/grey, and orange color families performed better than cooler colors such as blues, purples, and greens.

As with previous studies, the results were not cleanly delineated. When looking at the colors individually, two of the blue brand colors, “Carolina Blue” and “Light Blue” printed on 100% polyester, produced the most accurate color reproduction of any individual color on any of the textile types, DE=4.36 and DE=4.98 respectively. All three patches of each of these two colors produced readings that were very similar. No other blue color read as less than a DE=14 with eight out of ten of the worst readings registering from the blue family, Figure 4.

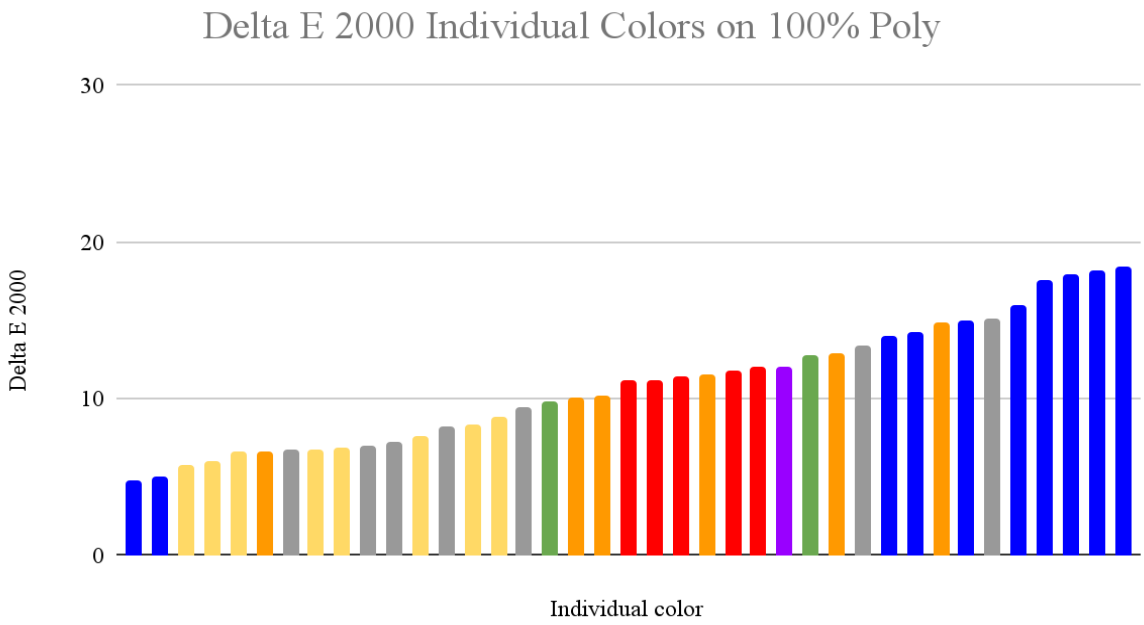

Figure 4: Average DE for each individual brand color on the 100% polyester fabric sample.

In comparison, the blue family read an average DE of 21.9 with a range of 7.18 to 27.28 over ten measured brand colors when printed on the 60/40 blend textile, Figure 5. Again both "Carolina Blue" and "Light Blue" brand colors were the only blues with relatively low DE values, DE=7.18 and DE=7.49 respectively. As with the 100% polyester samples, the yellow/gold and black/grey families were the most accurate tones when printed on the 60/40 fabric.

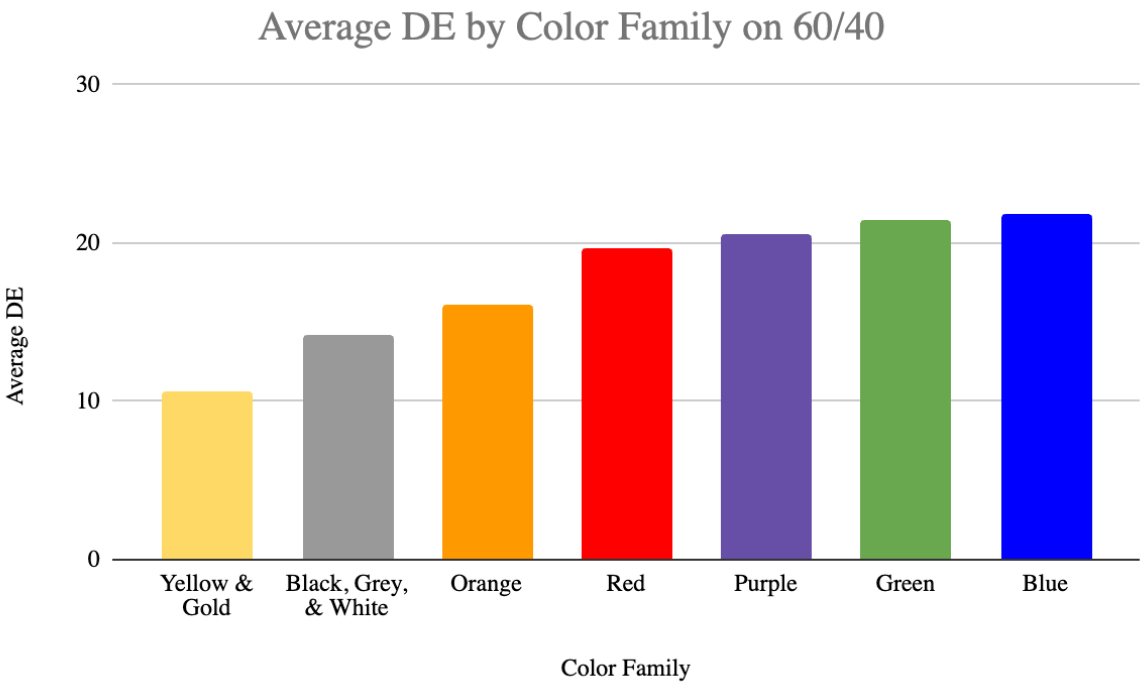

Figure 5: Average DE for each color family on the 60/40 polyester/cotton fabric sample.

4. DISCUSSION

Results are similar to the previous study and other previous research in dye sublimation with 100% polyester textiles performing the best in all color families even when all the fabric samples are pre-treated with the additional polymer coating. Warm colors such as yellows and oranges and neutral tones like blacks and greys performed better overall than cool colors including purples and blues, which is consistent with findings from the previous study, with the exception of two colors from the blue family on 100% polyester fabric "Carolina Blue" and "Light Blue." The researchers surmise that these two blues might be more similar in color range to light-tone greys than to the deeper or brighter blues like Navy or Royal Blue colors which might have resulted in better color accuracy for those two colors.
Delta E scores were mostly above 5, including on 100% polyester, indicating a noticeable, visual difference between the intended color and the printed color. This may be due to color profile accuracy when using manufacturer settings along with several other variables in this research such as quality of textiles and type of pre-treatments. The 60/40 blend performed worse than 50/50 in all color families with the exception of yellow/gold. The researchers speculate that this could be due to several factors, but suspect it could be due to the 60/40 fabric weight and weave. Though the same brand of textile samples were used for testing, the GSM (grams per square meter) of the fabrics was not available to the researchers. Other factors affecting the results include the polymer coating, both brand and application, and lighting consistency during measurements as measurements were taken under natural UV light.

5. CONCLUSIONS

Our primary research question was to determine if there are parts of the color spectrum that are more difficult to print consistently using dye sublimation and manufacturer recommendations on the three different textiles. This study revealed that yellows, oranges, blacks, and greys provided more accurate color reproduction than blues, purples, and greens. This would be an important consideration for manufacturers when printing brand-specific colors, particularly the ACC team colors tested in this study. This is also a beneficial lesson to pass along to students when working with textiles using alternative print methods and manufacturer provided color settings.
This study will serve as a starting point for additional research where custom-built color profiles can be created and tested for color accuracy. Further research may include expanding into different processes, such as direct-to-garment and direct-to-film printing. Other studies could expand into durability testing in both home and commercial laundering units. It would also be interesting to investigate durability with exposure to UV light and test the effects of laundering and stain treatments on color fastness. The researchers also recommend future testing to determine the impact of different fabric weights and thicknesses. Finally, this line of inquiry would benefit from additional research regarding the types of polymer coatings available on the market.

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COLOUR REPRODUCTION IN DRY OFFSET PRINTING FOR BEVERAGE CANS: A STUDY OF CONVENTIONAL AND VARIABLE PROCESSES

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Abstract:
In this research, we have examined the critical role of colour control in dry offset printing technology for beverage cans, emphasising its contribution to sustainable production. In the presented study, we have compared conventional and variable dry offset printing while maintaining identical manufacturing conditions, with a focus on the stability and precision of colour reproduction. Measurements conducted, ΔE2000, tone and gloss values, were obtained on a defined red colour reference patch. The first phase of the experiment involved printing without any prior colour management inputs. It resulted in inferior colorimetric values, underscoring the essential role of colour management, continuous measurement and process control. Through the second phase of the experiment, we have systematically monitored key colorimetric and surface parameters after the colour management procedure was applied. The results gained indicated that both printing methods are capable of maintaining colour reproduction within acceptable tolerance ranges, confirming their suitability for industrial applications. An interesting finding was that variable printing exhibited slightly greater uniformity in certain printed areas. Ink consumption was also assessed and remained within expected limits for both methods, reinforcing the principles of material efficiency and waste reduction. These findings demonstrate that stringent colour control directly supports sustainable production practices and indicate that variable printing represents a relevant and reliable alternative within the dry offset process. Future investigations should address more complex designs with higher technical demands and incorporate sampling of a broader range of colours, enabling a more precise characterization of the limitations and potential of this specific printing process through increased data quantity.

Keywords: *dry offset printing, colour control, variable printing, colorimetric parameters*

1. INTRODUCTION

In contemporary packaging production, color reproduction control plays a central role as a key factor of quality, consistency and brand identity preservation. Within the aluminum beverage can industry, this function becomes particularly critical, as the dry offset printing process relies on precisely defined spot colors rather than process colors. Maintaining the stability and predictability of color reproduction is therefore essential not only for visual uniformity but also for ensuring the technical sustainability of production [1,2]. In this context, color reproduction control serves as a direct bridge between print quality and process sustainability minimizing waste, setup time and deviations that lead to material losses or repeated printing cycles [3,4].
Modern packaging production must meet the demands of high speed, precision, and consistent quality, all under clearly defined color and process standards [1]. Without stable and predictable color reproduction control, it is impossible to achieve standardization and repeatability, both of which are fundamental requirements of technically sustainable and rational production [2]. Establishing consistent color reproduction control throughout the entire production chain not only that reduces waste and costs but also directly contributes to technical sustainability and overall production efficiency [3]. The consistency and frequency of production parameters contribute to visual coherence as well as to material

efficiency, reducing costs and losses through automated process monitoring and fewer make ready impressions [4].

The production of aluminium cans represents a multi stage process that integrates high speed forming, surface preparation, decoration, and coating. Within this sequence, dry offset printing serves as the core decoration technology, characterized by indirect image transfer from plate to blanket and from blanket to substrate. This method combines the speed of letterpress with the print quality of offset, making it ideal for non-absorbent surfaces such as metal [1,5]. The system operates at high line speeds, frequently exceeding 2000 cans per minute, and typically uses up to eight spot colors. Given these mechanical and chemical constraints, any small deviation in roller pressure, ink viscosity or blanket condition can result in visible color differences, underlining the importance of precise color control.

Dry offset printing is divided into two primary methods: conventional and variable. In the conventional process, all printing units operate with identical blanket configurations, transferring the same image repeatedly throughout the run. In contrast, variable dry offset introduces engraved blankets that enable multiple visuals to be printed within a single run, without replacing plates or halting the machine [6]. According to industry sources, this approach allows for the creation of individualized or regional designs within the same production batch, offering brands greater flexibility while maintaining throughput [7]. In fact, this technology enables printing of 24 different cans within a single production run [8]. However, engraved blankets also change the ink transfer characteristics, demanding stricter technical tolerances and more precise process control to maintain color reproduction accuracy and visual consistency.

Unlike conventional CMYK system, dry offset relies on spot colors, where every ink must match its defined spectral target. This makes spectrophotometric monitoring, calibration and process control critical elements for maintaining color reproduction accuracy. From the sustainability standpoint, color control directly affects the economic and ecological efficiency of can production. A process that maintains consistent color, minimizes ink consumption and ensures stable transfer characteristics over long runs, can be defined as technically sustainable. The introduction of spectral data as a complement to visual color assessment within the overall graphic process provides all participants in the production chain with a reliable tool for precise control of the color appearance on the can [10]. Therefore, the ability of variable dry offset printing to maintain such stability, despite multiple design variations within the same run, represents a critical question for both industrial practice and research.

The aim of this study is to evaluate the impact of color control on the stability and sustainability of variable dry offset printing for aluminium cans. Through a comparative analysis of conventional and variable methods, the study examines color deviations (ΔE2000), gloss levels, and ink consumption, under identical production conditions. The results aim to determine whether variable dry offset can maintain color stability and efficiency within tolerance ranges expected in standard production, thereby supporting both creative flexibility and sustainable manufacturing in the packaging industry.

2. MATERIALS AND METHODS

All materials used in this study originate from actual industrial production and therefore reflect realistic process behaviour and performance. The experiment was conducted on a Stolle Rutherford 8cd6-2200 decorator, an industrial scale dry offset press capable of printing up to 2200 aluminium cans per minute [11]. This type of equipment is widely regarded as a production standard in metal packaging and provides the necessary consistency and mechanical stability for reliable testing of both printing methods. Prior to printing, the machine was inspected and calibrated to ensure stable operation throughout the test. The materials that were used are aluminum substrate, a formed can, artwork files prepared for plates and blankets, printing plates, standard and engraved blankets and red spot ink. Artwork files for both the conventional and the variable method were prepared using Esko ArtPro+, following standard production specifications. The same blankets, Day Graphica 3000, were used for both printing methods. For the variable method blankets were engraved with SPG Thorium unit, to include specific variable design elements. Thorium DLE (Direct Laser Engraving), offers high-quality engraving for dry offset printing, using a CO_2 laser process without solvents, with a resolution of up to 10,160 dpi and special

dot structure and shaping [12]. In this configuration, the blanket becomes part of the printing form itself, transferring variable content directly from its engraved surface. Printing plates of type Toray DH2S83NM were used for both methods. Plates were imaged using the Esko Spark CDI 2530, followed by processing on a Dantex Aquaflex 480L system. This combination provides high imaging resolution and stable reproduction of fine graphic elements throughout the production run. Colour measurements were performed with an X-Rite Ci64 spectrophotometer, a device suitable for curved substrates such as beverage cans. Also, this device offers the ability to measure SPIN/SPEX values, allowing for an accurate assessment of the influence of gloss on color perception [13]. The instrument was calibrated before each session and maintained through monthly NetProfile calibration to ensure alignment with reference standards. Measurement data were recorded and analysed using X-Rite iQC, which supports Lab and LCh colour spaces, ΔE2000 calculations, gloss measurements (SRR Gloss), and the ink film strength parameter %STR-SUM.

2.1 Colour measurement parameters

The tested red ink, Figure 1, was defined by the following spectral values: L* = 52.2; a* = 55.41; b* = 28.73; C* = 62.42; h° = 27.4; SRR Gloss = 27.99. These parameters form the basis for comparing color deviations (ΔE2000) against the standard, both in the conventional and variable dry offset printing methods [14].

Figure 1: Red ink tested on aluminum can substrate, with variable element presented as an example

Because aluminium cans are highly reflective, gloss can significantly affect the visual appearance of the measured colour [15]. Therefore, all measurements in this study were performed using SPIN mode only, ensuring better comparability across samples. The %STR-SUM parameter from iQC was used to evaluate relative ink-film strength (target = 100%), reflecting tendencies toward oversaturation (>100) or undersaturation (<100) [16]. ΔE2000 tolerances followed industry standards: Upper limit: ΔE2000 = 3; Preferred operational limit: ΔE2000 ≤ 2 [17].

2.2 Sample groups

Three sets of printed samples were collected for analysis. The first set was comprised of samples gained using conventional dry offset printing. This set was serving as the baseline and reference for colour stability and ink consumption under optimal process control. The second set was made of samples printed with variable dry offset printing process using engraved blankets. Samples were evaluated against the colour reference and compared directly with the conventional method to assess differences in ΔE2000 behaviour, ink transfer and overall colour stability. The third set of samples was consisting of samples printed using variable printing process without initial colour measurement. This test intentionally excluded early-stage calibration to highlight the practical consequences of omitting colour control in a high-speed production environment. These three groups provide a comprehensive comparison of process stability, the impact of engraved blankets and the critical role of colour monitoring.

2.3 Measurement positioning, orientation and angle

Each can was measured at three standardised locations: middle, top and bottom, Figure 2. Although iQC allows averaging across measurement points, each point was treated separately to obtain a more detailed understanding of print uniformity along the vertical curvature of the can.

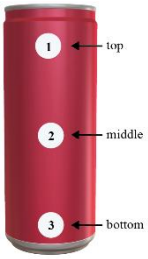

Figure 2: Measuring points on the printed can

Because measurements on cylindrical surfaces are sensitive to angular deviation, a fixed angle measurement holder was used to ensure identical positioning for every reading. This setup eliminates variations caused by inconsistent tilt or orientation of the curved surface relative to the spectrophotometer.

2.4 Measurement frequency and data collection in iQC

During production, samples were collected every 30 minutes. Each sample set was brought to the laboratory, where spectral values were recorded immediately to minimise the influence of surface contamination, curing variation or handling. The iQC software presented values both numerically and graphically, enabling real time tracking and later analysis of ΔE2000 deviations, L*, a*, b*, C*, h° variations, SRR Gloss, and %STR-SUM ink film strength. This systematic collection approach ensured consistent monitoring of colour stability across all three printing regimes and allowed the identification of short-term and long-term variations within the run.

3. RESULTS

3.1 Results of conventional (regular) printing measurements

The results of the reference red color measurements obtained through the conventional printing process are presented in Table 1. A set of colorimetric and additional parameters was monitored and compared to the standard red reference. The obtained results show that the color deviation values (ΔE2000) ranged between 0.76 and 2.10, with most samples within the desired industrial tolerance (≤2.0), and all within the general acceptance limit (≤3.0). The highest deviations were recorded for samples 4 (2.10) and 8 (2.05). Changes in lightness (ΔL) ranged from –2.05 to +1.20, while the shifts in the red–green (Δa) and yellow–blue (Δb) axes were more pronounced in several samples. Gloss values (SRR Gloss) varied between 28.45 and 34.57, indicating moderate surface variability. The %STR-SUM parameter ranged from 86.31 to 125.67, where extreme values indicated either excessive or insufficient ink transfer. Analysis of measurement positions (top, middle, bottom) showed that the highest stability was achieved in the middle area of the can, while deviations were more pronounced at the top.

Table1: Conventional printing – measurement results of red color reference

Sample	L	a	b	C	h	ΔL	Δa	Δb	ΔC	Δh	ΔE2000	SRR Gloss	%STR-SUM	Measurement positon
1	51.59	57.88	27.95	64.28	25.77	-0.25	2.47	-0.78	1.86	-1.8	**1.13**	33.3	**107.03**	middle
2	51.68	58.65	29.53	65.66	26.73	-0.52	3.23	0.81	3.25	-0.75	**1.07**	31.99	**113.42**	top
3	52.43	58.88	28.54	65.43	25.86	0.23	3.47	-0.19	3.02	-1.72	**1.25**	32.07	**106**	bottom
4	50.16	56.88	29.76	64.2	27.62	-2.05	1.47	1.04	1.78	0.24	**2.1**	31.8	**122.74**	
5	50.54	57.86	30.13	65.23	27.51	-1.66	2.44	1.4	2.81	0.12	**1.81**	30.91	**121.57**	
6	52.56	56.14	27.11	62.34	25.78	0.35	0.73	-1.61	-0.07	-1.77	**1.04**	31.45	**95.47**	
7	50.35	57.14	29.79	64.44	27.54	-1.86	1.73	1.07	2.03	0.15	**1.92**	31.76	**121.35**	
8	50.36	58.22	30.73	65.83	27.83	-1.84	2.8	2.01	3.42	0.48	**2.05**	30.2	**125.67**	
9	52.38	56.07	27.17	62.31	25.86	0.17	0.66	-1.55	-0.1	-1.68	**0.95**	33.71	**97.2**	
10	50.87	57.1	28.98	64.04	26.91	-1.34	1.69	0.25	1.62	-0.55	**1.42**	30.95	**115.22**	
11	52.15	56.34	27.67	62.77	26.16	-0.05	0.93	-1.06	0.35	-1.36	**0.76**	34.57	**100**	
12	53.4	54.84	26.22	60.79	25.56	1.2	-0.58	-2.5	-1.63	-1.98	**1.67**	34.25	**86.31**	
13	51.2	57.27	28.91	64.15	26.78	-1.01	1.86	0.18	1.73	-0.69	**1.16**	31.41	**113.08**	
14	50.6	57.35	30.1	64.77	27.69	-1.6	1.94	1.37	2.36	0.32	**1.71**	31.47	**120.38**	
15	50.86	57.36	29.81	64.65	27.46	-1.35	1.95	1.08	2.23	0.06	**1.46**	28.45	**117.5**	
16	51.66	56.53	27.42	62.83	25.87	-0.55	1.12	-1.31	0.41	-1.67	**1.08**	30.69	**105.27**	
17	51.38	57.32	28.89	64.19	26.75	-0.82	1.91	0.16	1.77	-0.73	**1.02**	31.37	**111.62**	
18	50.85	57.24	29.74	64.5	27.46	-1.36	1.82	1.01	2.08	0.06	**1.45**	28.51	**117.13**	

The ΔE2000 values throughout the regular printing process are illustrated in Figure 3.

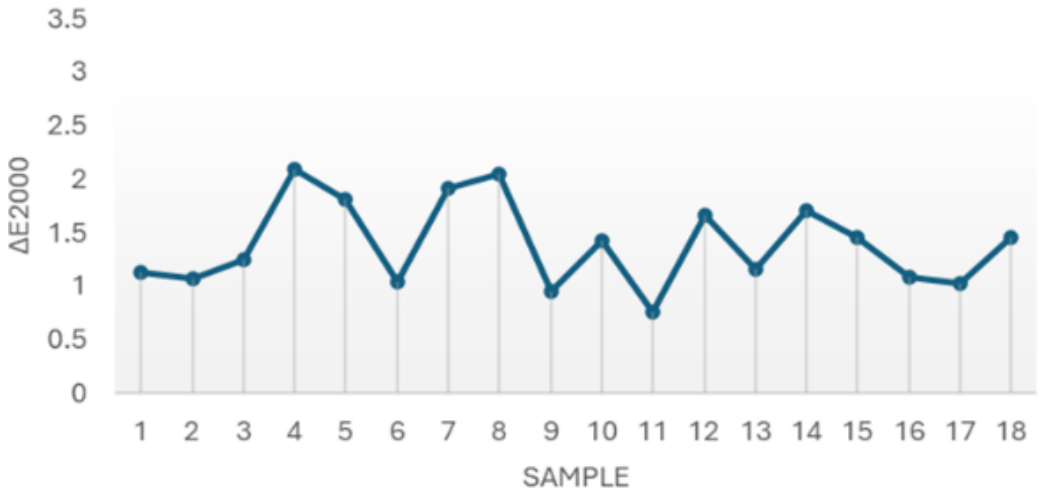

Figure 3: ΔE2000 values during the regular printing process

3.2 Results of variable controlled printing measurements

The results of reference red color measurements obtained through the variable controlled printing process are presented in Table 2. Compared to the standard reference, the obtained results indicate that the color deviation values (ΔE2000) ranged between 0.87 and 2.06, demonstrating very stable color reproduction within the variable process. The highest deviations were observed for samples 4 and 13, where ΔE2000 values reached 1.7–2.0. Gloss values (SRR Gloss) ranged between 23.7 and 33.9, indicating moderate surface effect variability. The %STR-SUM parameter varied from 95.6 to 121.4. Analysis of measurement positions (top, middle, bottom) confirmed that the middle section exhibited the highest stability, while greater deviations appeared at the top and bottom.

Table 2: Variable controlled printing – measurement results of red reference

Sample	L	a	b	C	h	ΔL	Δa	Δb	ΔC	Δh	**ΔE2000**	SRR Gloss	**%STR-SUM**
1	52	57.3	27.7	63.64	25.8	-0.21	1.88	-1.03	1.22	-1.76	**1.05**	27.94	**103.01**
2	52.39	57.77	27.69	64.06	25.61	0.18	2.36	-1.04	1.65	-1.98	**1.19**	30.3	**101.23**
3	52.4	56.91	27.84	63.36	26.07	0.19	1.5	-0.88	0.94	-1.46	**0.87**	29.95	**99.16**
4	50.2	57.22	29.11	64.2	26.96	-2	1.81	0.39	1.78	-0.48	**2.06**	23.79	**121.44**
5	52.12	57.96	27.41	64.12	25.31	-0.08	2.55	-1.31	1.7	-2.31	**1.35**	26.65	**103.42**
6	51.69	57.91	27.9	64.28	25.73	-0.51	2.5	-0.82	1.87	-1.85	**1.24**	33.98	**106.73**
7	51.1	56.78	27.23	62.97	25.62	-1.1	1.37	-1.5	0.56	-1.95	**1.54**	26.34	**108.04**
8	51.37	57.06	27.01	63.13	25.33	-0.84	1.64	-1.71	0.71	-2.27	**1.51**	31.03	**104.97**
9	50.81	57.2	27.5	63.47	25.67	-1.39	1.79	-1.23	1.05	-1.9	**1.76**	29.44	**109.61**
10	50.95	57.02	27.45	63.28	25.71	-1.25	1.6	-1.28	0.84	-1.86	**1.63**	24.21	**109.12**
11	51.49	57.4	27.33	63.58	25.46	-0.71	1.99	-1.39	1.16	-2.13	**1.41**	27.4	**104.99**
12	51.06	56.96	27.48	63.24	25.76	-1.14	1.55	-1.24	0.83	-1.8	**1.53**	26.91	**107**
13	51.72	54.88	25.35	60.45	24.8	-0.49	-0.53	-3.37	-1.96	-2.79	**1.71**	26.31	**95.63**
14	51.81	56.59	26.54	62.51	25.13	-0.39	1.18	-2.18	0.09	-2.48	**1.43**	25.03	**100.58**
15	51.55	56.29	26.75	62.32	25.42	-0.66	0.87	-1.98	-0.1	-2.16	**1.36**	26.23	**1001.38**
16	50.82	56.49	27.1	62.65	25.63	-1.38	1.08	-1.62	0.25	-1.93	**1.74**	24.52	**108.79**
17	50.81	57.05	27.49	63.32	25.73	-1.4	1.63	-1.24	0.91	-1.84	**1.74**	25.79	**110.81**
18	50.99	56.52	26.99	62.63	25.53	-1.21	1.11	-1.74	0.22	-2.05	**1.66**	25.41	**106.18**

Measurement positon
middle
top
bottom

The ΔE2000 values across the controlled variable printing process are shown in Figure 4.

Figure 4: ΔE2000 values during variable controlled printing

3.3 Results of variable uncontrolled printing measurements

Table 3 presents the measurement results for two reference red samples printed in a variable mode where no measurements were performed during the initial production interval. The absence of in-process measurements led to a notable deterioration in the obtained parameters. The color deviation values (ΔE2000) averaged between 2.0 and 2.7, exceeding the desired tolerance (≤2.0); thus, the color quality was marginal or outside specification. Gloss values (SRR Gloss) ranged from 45 to 49, significantly higher than in controlled runs. The %STR-SUM parameter ranged from 126 to 139, indicating instability and deviations from optimal printing conditions. Analysis of the measurement positions showed that the middle section maintained the most stable results, while greater deviations were observed at the top and bottom.

Table 3: Uncontrolled variable printing – measurement results of reference red

Sample	L	a	b	ΔL	Δa	Δb	ΔC	Δh	**ΔE2000**	SRR Gloss	**%STR-SUM**
1	51.11	60.39	30.4	-1309	4.97	1.68	5.19	-0.77	**1.76**	49.35	**126.73**
2	49.88	59.42	32.17	-2.32	4	3.44	5.15	1.16	**2.74**	45.24	**139.14**
3	50.54	60.08	31.32	-1.66	4.66	2.59	5.33	0.15	**2.14**	48.72	**132.56**
4	50.75	60.69	31.46	-1.45	5.27	2.74	5.94	0.01	**2.09**	46.44	**133.64**
5	50.3	58.98	31.12	-1.91	3.56	2.39	4.27	0.47	**2.21**	47.7	**130.43**
6	50.61	60.02	31.24	-1.59	4.61	2.52	5.25	0.11	**2.7**	47.21	**131.42**

Measurement positon
middle
top
bottom

The ΔE2000 values throughout the uncontrolled variable printing process are illustrated in Figure 5.

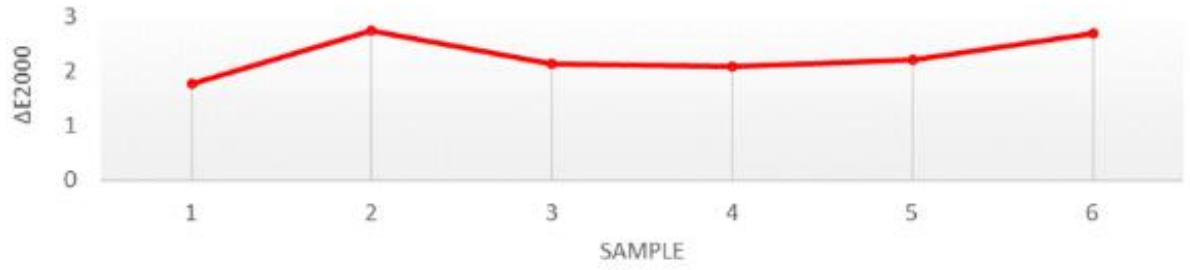

Figure 5: ΔE2000 values during uncontrolled variable printing

3.4 Printing speed and ink consumption in both modes

Ink consumption represents one of the key sustainability factors in production, as it directly influences cost efficiency, process stability and material waste. In the conducted experiment, Table 4, showed ink usage within normal and controlled limits for both printing methods, without deviations that could affect print quality or increase material loss. The standard consumption for conventional printing was slightly higher due to greater red area coverage in the artwork. Printing speed remained consistent at 2200 cans per minute for both methods.

Table 4: Ink consumption of standard red during conventional and variable printing

Red Ink	Standard/reference kg/milion	Live Production kg/milion	Deviation
Conventional Printing	31	30.55	-0.45
Variable Printing	31	30.45	-0.55

4. DISCUSSION

The results obtained for the conventional printing process confirmed a stable workflow and predictable color reproduction. The color deviations, expressed as ΔE2000, ranged from 0.76 to 2.10, with an average of 1.39 and a standard deviation of 0.40. All values were within the generally accepted tolerance of ≤3, confirming reliable and consistent color reproduction.

The %STR-SUM parameter, ideally close to 100, ranged from 86.31 to 125.67, with an average of 110.94. Although certain oscillations were observed, they remained within the acceptable technological limits. The SRR Gloss values ranged from 28.45 to 34.57, with an average of 31.60, slightly above the reference value of 27.99, yet without any visually significant deviation. These data confirm that

conventional dry offset printing provides a stable and predictable process with consistent color and gloss characteristics.
The variable controlled printing method demonstrated even greater uniformity compared to the conventional process. The ΔE2000 values ranged from 0.87 to 2.06, with an average of 1.49 and a standard deviation of 0.29, indicating lower dispersion and more consistent color maintenance during production. The %STR-SUM parameter varied from 95.63 to 121.44, with an average of 105.92, reflecting slightly improved control and efficiency compared to the conventional method. The SRR Gloss values ranged between 23.79 and 33.98, with an average of 27.29, nearly identical to the target reference (27.99). This confirms that the controlled variable printing process achieved both visually and technically optimal results.
In contrast, the uncontrolled variable printing process showed significantly higher deviations. The ΔE2000 values ranged between 1.76 and 2.74, with an average of 2.27, clearly exceeding the deviations recorded in both regular and controlled variable printing. The %STR-SUM parameter remained consistently higher, ranging from 126.73 to 139.14 (average 132.32), indicating excessive ink transfer and lower process efficiency. Likewise, SRR Gloss values were considerably elevated, between 45.24 and 49.35, with an average of 47.44, far from the target reference. These findings clearly demonstrate that the absence of in-process color monitoring in variable printing leads to reduced color reproduction accuracy, increased ink consumption, and compromised production sustainability.
For both printing methods, the standard ink consumption for the reference red was 31.0 kg per million prints. Measured value for conventional was 30.55 kg per million, representing a deviation of –0.45 kg, and for the variable printing process was 30.45 kg per million, corresponding to a deviation of –0.55 kg. These results confirm that both processes operated efficiently, with the variable method showing slightly better alignment with the expected standard due to more uniform ink transfer.

5. CONCLUSION

Based on the conducted measurements and analysis, it can be concluded that both conventional and controlled variable dry offset printing methods are capable of delivering results within defined safety and technological limits. The variable printing method under controlled conditions demonstrated even more uniform results compared to the conventional process, particularly in terms of ink laydown, gloss reproduction and material efficiency. Such consistency may be attributed to the inherent complexity of the variable process, which required operators to apply additional precision in machine setup, ink control and plate and blanket adjustments, effectively minimizing the potential for variation. This experiment therefore confirms that variable dry offset printing is a reliable and sustainable industrial process, capable of meeting modern production and color quality standards. Ink consumption in both processes remained within controlled limits, with minimal deviation from the target values. This indicates a high level of process stability and further supports the conclusion that variable printing can be implemented without compromising economic efficiency or sustainability. The uncontrolled variable printing phase, however, underlined the critical importance of integrated process monitoring. Without continuous measurement and color correction, material usage increases, color reproduction accuracy decreases and process sustainability deteriorates. Importantly, the engraved blanket used during the tests did not introduce any additional issues, nor did it negatively affect production speed or consistency, confirming its suitability for industrial applications. Beyond its technical merits, variable printing also provides distinct marketing advantages. The ability to personalize packaging, create limited editions and differentiate visual designs according to market needs adds tangible commercial value.
For future research, it is recommended to explore the performance of variable dry offset printing with more complex and visually demanding designs, where the technological limits of the process can be more rigorously evaluated. In such scenarios, the constraints related to plate and blanket file specifications, ink transfer, roller pressure and potential speed adjustments become more pronounced. This would offer a more comprehensive understanding of the capabilities and boundaries of variable dry offset printing within real world production environments and evolving market requirements.

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WOMEN IN THE GUTENBERG GALAXY

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Abstract
The aim of this study is to explore the situation of women in the printing industry. It examines the effects of their increasing participation in the industry. It also looks at the extent to which the principles of equal opportunities and equal treatment apply to them. Publications on the subject were identified through a systematic literature search based on Web of Science. The results of the literature review are organized around four themes. Numerous publications have appeared around the extraordinary and successful women who ran printing workshops before the industrial revolution after losing their entrepreneurial husbands or fathers. After the industrial revolution, i.e., the spectacular mechanization of industry, women mainly performed simpler, skilled work as folders and seamstresses, i.e., they were involved in the less prestigious and lower-paid tasks of book production. In addition, the works of art created by women and the innovations in their approach often did not receive the spotlight they deserved at the time. Throughout history, women in several countries have tried to break male dominance by joining forces in various ways. In England, for example, in response to the "threatening" behaviour of trade unions, women formed their own printing organization, the Women's Printing Society. Today, women's movements still exist in the printing industry, mainly in Anglo-Saxon countries. A targeted questionnaire survey of 32% of all employees in the Hungarian printing industry was conducted to assess the proportion of women employed in the printing industry by education and position. The aim and result of the study are twofold: to draw attention to the importance of the issue and to provide international examples to shape attitudes.

Keywords: *Women in Print, Publication about women, Women's movements*

1. INTRODUCTION

For decades, the issue of equal opportunities for women in the workplace has been a major social concern. Around the world, many initiatives are working to help women advance and to reduce the gender pay gap. It is well known that these disparities have not yet been bridged, and although the trend is improving, the pace is quite slow. The aim of this study is to examine the situation of women specifically within the printing industry.
The authors—as executives involved in the printing industry —aim to explore the situation of women in the Hungarian and international printing industries. They examine the extent to which the principles of equal opportunity and equal treatment are upheld. The rationale for the research is demonstrated by, among other things, the results of our own survey conducted among domestic printing companies. In the targeted questionnaire-based data collection, 17 Hungarian printing industry companies participated, thus 32% of all employees in the Hungarian printing industry were surveyed. The data showed that although women account for 43.8% of the total population in question, and the proportion of women with a college degree is also significant at 51.4%, despite these figures, women hold only 32.9% of senior management positions (Table 1).

In the sample examined, in terms of company size, number of employees, and job level, no significant difference can be observed regarding whether we are talking about small and medium-sized enterprises (SMEs) or large enterprises (LEs); the proportion of women shows a similar picture. A more significant difference can only be observed in terms of education: in the case of SMEs, the proportion of women with a higher education degree is lower, while the proportion of those without a degree is higher than in the case of large enterprises. The results of our own research are also reflected in the quarterly surveys conducted by GKI Economic Research Co. in the printing industry, which, based on research results published in December 2024, show that the proportion of women is 43%, while among managers (senior and middle managers) it is only 34% (Udvardi 2024).

Table 1. Proportion of women at each job and qualification level by industry sector

Percentage of women									
Sector	**Total employees**	**Senior managers**	**Mid-level managers**	**Team leaders**	**Sub-ordinates**	**With higher education**	**With high school diploma**	**Skilled worker**	**No formal education**
Printing industry	43,8%	32.9%	34,4%	31,2%	46,4%	51,4%	40,2%	45,3%	43,9%
LEs	43,7%	32,6%	37,1 %	25,0%	46,8%	54,0%	39,1%	46,0%	37,6%
SMEs	44,0%	33,3%	30,2%	35,6%	45,6%	47,5%	41,1%	44,,3%	54,2%

An increasing proportion of women are graduating from higher education programs in the printing industry, and an increasing proportion of female employees with higher education degrees are being hired by printing companies. According to the DPR AAE 2023 database requested from the Education Office, at the end of 2022, 60.4% of employees working in the printing industry who graduated with a higher education degree between 2014/2015 and 2020/21 were women.

If we look not only at the printing industry but at the entire Hungarian population, we can still see the trend observed for decades that women are graduating from higher education in greater proportion than men. In 2023, among the total Hungarian population, 34.7% of women held a higher education degree, while 24.9% of men did (KSH 2023). Furthermore, the average wage gap between men and women is not decreasing, neither among manual nor among white-collar workers. The gap remains significant, ranging between 20% and 30% (KSH 2024). Despite all international efforts and attention, companies still tend to prefer hiring men over women for leadership positions, a trend often driven by ingrained biases and stereotypes that emerge during the selection process (Tatár – Kiss 2021).

The relevance of this topic and the fact that it affects many people is demonstrated by the existence of women's movements in the printing industry that mobilize many individuals and seek to support women's opportunities for advancement. These are primarily found in Anglo-Saxon Western cultures. For example, the Women in Print Alliance, founded in the U.S., is dedicated to advocating for women's interests through community building, communication. To increase recognition of women in the industry and raise awareness of discrimination against them (Women in Print Alliance 2024). Girls Who Print (GWP), an online movement that also originated in the U.S., is now represented in Africa and Europe as well. It started as a circle of friends with women in the printing industry who face similar challenges but has since grown into a community of 10,000 members. It now includes numerous female leaders who set an example for their younger female peers and help them advance (Girls Who Print2024). One of the main goals of the Australian Women in Print movement is to build a community of women within the industry, which is intended not only to facilitate the sharing of information but also to enable network members to support one another in their career development.

From the perspective of this topic, it is important to define the concept of feminism. In many cases, successful women themselves deny being feminists because numerous negative prejudices and ideas are attached to this concept, while many actually do not know what the concept means (Hoskin et al. 2017). We will highlight two widely recognized definitions available in the literature. Bell Hooks (2014) views feminism as a struggle against the ideology of domination, with the aim of ensuring that human self-development takes precedence over economic power interests. In Mies (1991)'s approach, feminism

seeks to study and combat the oppression and exploitation of women. The first approach addresses broader, more general human rights.

2. RESEARCH METHODOLOGY

Publications concerning women in the printing industry were identified through a systematic literature review. As part of this process, the publications identified via a Web of Science search were analysed using the PRISMA method (Liberati et al. 2009). For the search, we used the following keywords: "wom* AND print*". The selection of keywords involved a multi-step process. Whenever we expanded the search terms or made them more specific, the number of results narrowed to such an extent that it rendered the search meaningless. Therefore, we stuck with the two most characteristic concepts of the topic: women and printing/ print.

With these search terms, we obtained 355 results (Figure 1). They were first validated based on the abstract, thereby excluding 332 studies. In the case of the majority of publications excluded from the study, the term "print" referred to the print media, and dealt with women appearing in the print media, and the manner of their appearance. In the case of the publications filtered as relevant, "print" appeared in the printing industry sense. Each of the remaining 23 publications was analyzed individually for relevance. This left 19 relevant publications, which specifically deal with women working in the printing industry, and most of them originate from English-speaking countries. For the relevant publications, we conducted further literature research by reviewing the publications cited in the given publication. This allowed us to include an additional 19 publications in our analysis, which the Web of Science search did not yield, but which are nevertheless relevant to the topic.

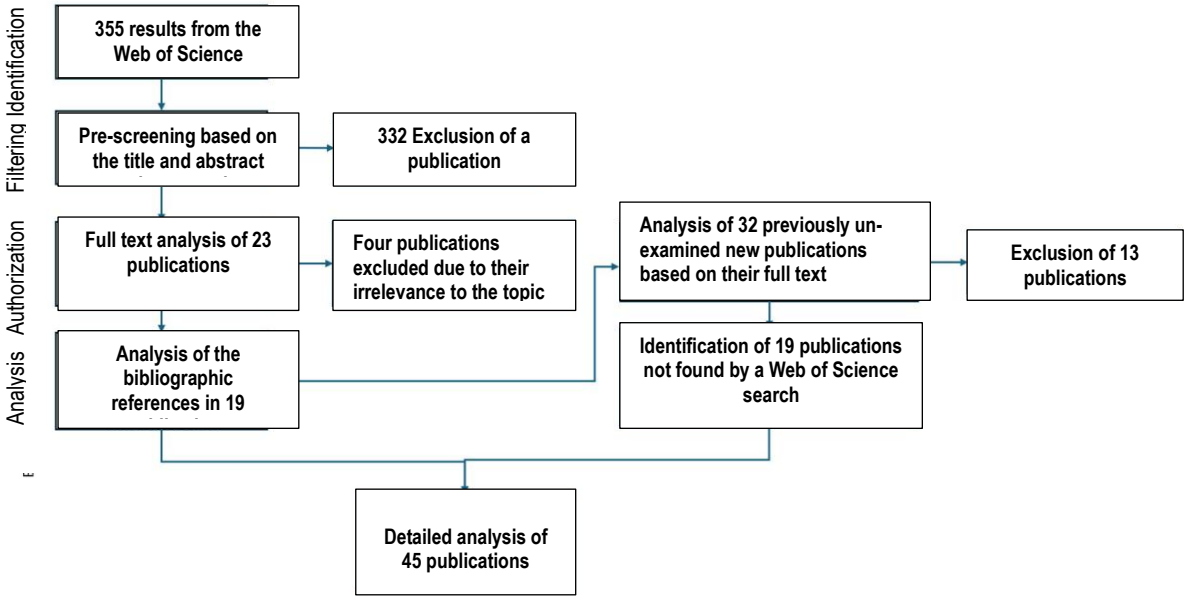

Figure 1. PRISMA flow chart for systematic literature search
Source: compiled by the author (2024)

The first publications on this topic appeared as early as the late 1970s and early 1980s (Figure 2). In recent years, interest in the topic has increased somewhat, but overall, it cannot be said that a significant number of publications have appeared.

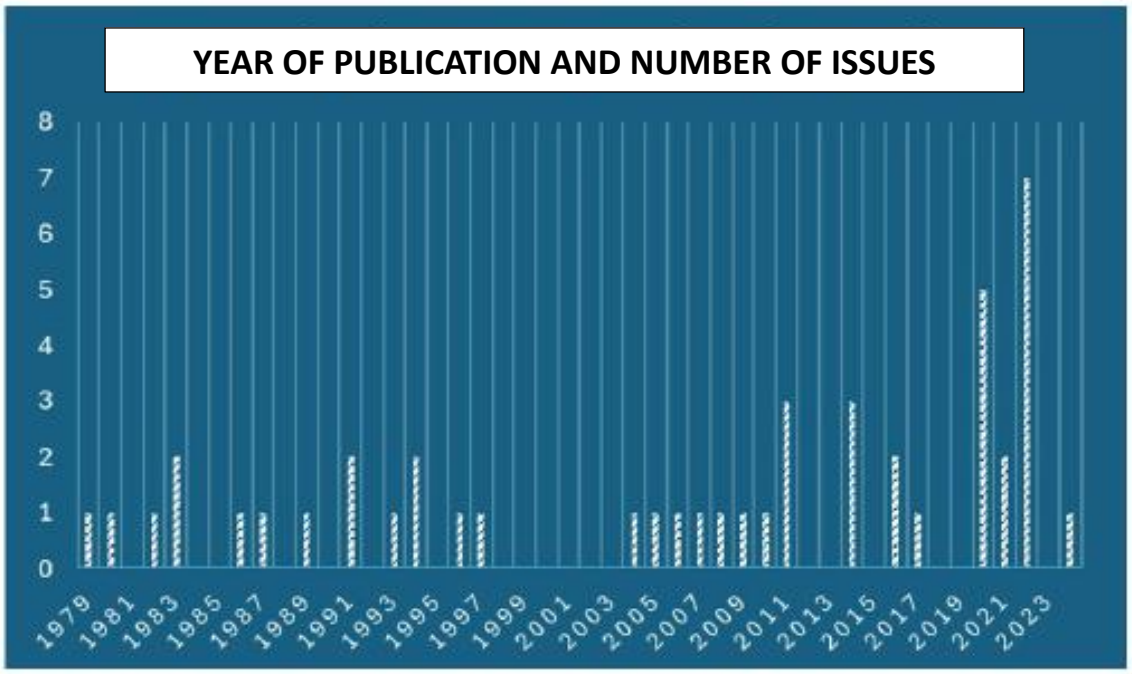

Figure 2. Year of publication and quantity of publications relevant to the topic

We analysed the content of the relevant publications using the grounded theory approach (Glaser & Strauss 2017), meaning we conducted the analyses without formulating any preliminary hypotheses. The grounded theory methodology is suitable for providing an explanation of a social phenomenon or process without relying on prior assumptions. process. Its theoretical basis is the process of data collection, coding, and analysis, so the results are strictly data-driven, making it a flexible methodology capable of exploring complex social phenomena. After reading the publications, we coded the emerging themes using open coding. Then, using the axial method, we compared the codes with one another and organized them into larger groups, naming these larger groups based on the most tangible content according to their substance. Using this methodology, we were able to identify 4 major thematic areas into which a significant portion of the publications could be classified.

3. RESULTS

Based on the content analysis and categorization of publications found in the literature on women and the printing industry, the following four major themes have been identified: women heirs; the role of trade unions; women as creators; and women's movements.

3.1 The role of women in industry before the Industrial Revolution

Numerous publications have been written about those exceptional and successful women who, prior to the Industrial Revolution, ran printing workshops after losing their entrepreneur husbands or fathers, and thus inherited the family business, feeling a sense of responsibility to keep it running to support their families. The stories of such successful women have been of interest to scholars studying female printers since the first half of the 1900s and have inspired them to compile bibliographies on women business leaders in the fields of book manufacturing and publishing; an example of this is Stowel (1979), who compiled a list of successful female entrepreneurs in the American book manufacturing industry. Another example from the United States is Walker's (1987) collection on outstanding female entrepreneurs, which features more than a dozen courageous women who successfully ran their printing businesses. In an article published in a historical journal, Beech (1983) lists numerous successful

Parisian women who ran printing businesses through their husbands or fathers. Their success was significantly driven by the effectively inherited network of connections. However, the business life cycle exhibited different dynamics for women, as remarriage could mean that a new husband took over the management of the company. Charlotte Guillard's compelling story of a prominent Parisian Renaissance lady inspired Goldstein (2019), while Jeffery (2020) and Limbach (2022) examined similar events and figures in the German-speaking world. Before the Industrial Revolution, women's opportunities and fates were similar regardless of country, or even continent.

3.2 The role of trade unions in the development of gender inequality

Following the Industrial Revolution and the dramatic mechanization of the industry, women nevertheless primarily performed semi-skilled work as folders and seamstresses—that is, they were engaged in lower-prestige, lower-wage tasks within the bookmaking process (Hunt 1983, Coutrap & McQuin 1996). The reasons leading to this situation have been examined by several researchers, such as Burr (1993), Frances (1991), Thomson (1994). Summarizing their findings, it can be concluded that the activities of male-dominated trade unions contributed significantly to the emergence of inequality. For example, Christina Ann Burr (1993) of the Department of History at the University of Windsor examined whether, between 1850 and 1914, printing industry unions employed exclusionary strategies toward women in their operations and negotiations, which may have contributed to the development of a specific division of labour between men and women, and this could have become entrenched in the long term. Through an analysis of historical documents, Burr demonstrated that men secured better-paid positions at the expense of women, using the institution of the trade union to do so, so that within the organization, gender interests prevailed over class interests. Furthermore, employers were also unwilling to pay female workers the same wages as male skilled workers. According to surviving historical evidence, there were instances in America where, when an employer would have hired a woman for a higher-prestige position, male coworkers refused the job (Thomson 1994). This may explain why, although the proportion of women, for example, in the American printing industry in the United States increased significantly after the Industrial Revolution—from 40.8% to 55.8%—the proportion of women in higher-paying, more prestigious printing positions did not even reach 1% (Thomson 1994).
Ava Baron (1989), who revealed in her work how employers in America "exploited" the female and child labour force to weaken the workforce and power of male workers, such as to break the 1835 printers' strike. Naturally, men resented the presence of women and children in their workplaces, as they felt their livelihoods and their roles as breadwinners were threatened, and thus viewed them as enemies. Surprisingly, the situation has not changed much since the early 1900s, as examined by Burr (1993), during union negotiations. In her research, Dawson (2014) examined the situation in the 2000s. According to the findings, issues regarding women's equal opportunities and equal pay had not been adequately incorporated into union negotiations even by 2010. Even when the topic was placed on the agenda, the negotiation process effectively ensured that the issue remained invisible.

3.3 The role of trade unions in the development of gender inequality

The question arises as to whether we should discuss women and their roles in the printing industry solely on the basis of the positions they hold. Or whether we should adopt a significantly broader, feminist approach to discussing women as creators and their inspirational influence, as well as their power to shape society. Sarah Werner draws attention to in her 2020 article. In the history of the printing industry, we must not simply talk about the history of women, but about feminist printing history. With her feminist approach, Werner examines not only female publishing professionals and printers, but the entire process of printing/ publishing and the social impacts of women's participation in it. In other words, how this differs from the history of women and printing. In her article, she presents historical excerpts showing how women contributed to creative processes as well.
Significant works created throughout history, as well as innovations in perspective, often did not receive sufficient attention in their own time. It also happened that outstanding works were published under the

names of women's husbands, because this made them more "marketable." In recent years, several researchers, historians, and editors have sought to introduce these works, which were sinking into oblivion, and these exceptional women to the general public. Numerous publications and articles have appeared on the subject. In their book Aims and Objectives, Levy & Kandice (2020) compiles bibliographic data on female authors who received little or no publicity, as well as editors, translators, and publishing staff who were part of the creative process. In her book, edited in 2021, Briar Levy presents the biographical stories of lesser-known women from the Harlem Renaissance period onward who earned their living through graphic design, created outstanding works, and thereby shaped public taste. Fanni et al. (2020) compiled their book *Natural Enemies of Books – A Messy History of Women in Printing and Typography, a book designed with sophisticated graphics and typography, introduce the reader to female printers, illustrators, writers, typographers, and typesetters who, through their own narratives, shed light on the inequalities in the printing industry.

2.4 Women's solidarity and movements

Attempts had already been made in 19th-century England to break the dominance of men. Since the dominant trade unions portrayed female printers as a threat to the wages of "breadwinners," the women responded by founding their own printers' organization. The "Women's Printing Society," established in 1876, employed both working-class and middle-class women as printers. When distributing business profits, they took into account the interests of both investors and employees, which is why they proved to be very successful (Tusan 2004). We can say that women's full social sensitivity was evident here as well, because they did not prioritize the interests of a single interest group. The organization published its own weekly periodical titled "Women's Penny Paper," where women could make their voices heard (Alexiou 2022). The publication was designed and produced by women and spoke to women in a unique way, thus allowing them to showcase and draw attention to women's talents. A similar women's movement also emerged in 19th-century America. The Boston weekly newspaper titled "The Olive Branch" employed exclusively women for publishing and printing tasks. In defiance of the prejudices of the time, which sought to confine women to the "kitchen" (Roman 2022). This publication platform enabled women to express their own creative voices during this era.
Within the so-called "Second Wave" feminist movement launched in the second half of the 20th century changes also began in the printing industry, which aimed at women's liberation, so that women would not be undervalued workers. Within this framework, in the 1980s in England, numerous offset printing shops founded and run by women were established, but unfortunately, due to their lack of capital, they did not survive for long. For those who participated in the movement, the initiative played a life-changing role. It is important to note that the common operational model of feminist printing presses was a collectivist- democratic form. Generally, everyone handled every task; they were less specialized than in male-led businesses, because they viewed this as consistent with radical democratic and feminist ideals (Baines 2022).

3. CONCLUSIONS

A review of the literature shows that throughout history, the principle of equal opportunity for women has often been violated. Although women demonstrated their talent before the Industrial Revolution, when they successfully ran the businesses, they had inherited and were thus recognized in their own time and held in high esteem, even if, upon remarriage, the new husband took over the company's management duties. But with the Industrial Revolution, mass production, and the struggle for survival, they were outmatched by men's bargaining power and authority and were thus pushed into lower-prestige jobs. Men, as "breadwinners and family providers," fought for higher wages for themselves, which severely undermined the principle of equal pay. This phenomenon is still evident today, and not just in the printing industry. Female printers, in the face of clear discrimination, formed movements and coalitions, and used the media to make their voices heard with varying degrees of success. Women's means of self-expression, and the display of their talent, also manifested in creative work; numerous

works have survived by female writers, graphic artists, artists, and book editors. These received only limited attention in their own time due to strong stereotypes and discrimination.
Today, compared to the historical facts presented, a significant improvement can be observed in this area, but further research could focus on assessing the current situation in the printing industry regarding the extent to which gender stereotypes still exist, the extent to which women hold lower-prestige positions, whether the principle of equal pay is realized, and whether their works receive the same attention in creative work. The practical outcome of this research is that it draws attention to the challenges women face regarding equal opportunity and the importance of combating stereotypes. In the face of these challenges, women's movements and coalitions play a significant role in the resolution processes and can prompt company leaders to improve selection processes and implement equal opportunity measures.

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COMPARATIVE TESTING OF THE CARRYING CAPACITY OF PAPER SHOPPING BAGS

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Abstract:
Environmental awareness and sustainability are playing an increasingly important role in everyday life. With increasingly stringent regulations and social expectations, the importance of recyclable and biodegradable materials is growing. Paper bags are important for their packaging function and are also symbols of sustainable shopping habits. The popularity of paper bags has grown rapidly in recent years. The use of paper bags contributes to the creation of an environmentally conscious image. At the same time, there are a number of questions regarding the practical usability of paper bags, such as their durability, water resistance, and contribution to sustainability goals. During our everyday shopping, we often encounter paper bags of varying quality and reliability. Therefore, we examined how well these bags meet different consumer needs and conditions of use. We explored how willing where costumer to pay extra for sustainability. The aim of our research was, on the one hand, to review the historical, environmental, and sustainability aspects of paper bags. We analyzed the experiences and habits of paper bag users through a questionnaire survey. In addition, we conducted various physical and mechanical tests focusing on the load capacity, moisture resistance, and durability of paper bags. The aim of the research is to provide a comprehensive overview of how paper bags meet sustainability and practical expectations.

Keywords: *paper bag, shopping bag, paper-based packaging, paper bag capacity, carrying capacity, environmentally conscious shopping, sustainable packaging*

1. INTRODUCTION

During our everyday shopping, we often encounter paper bags, the quality and reliability of which vary greatly. This was partly what motivated us to examine how well these bags meet different consumer needs and conditions of use. We analyzed how willing useres are to pay extra for sustainability and how these expectations are reflected in the range of products available on the market. Following a historical overview of paper bags, we analyzed their environmental and sustainability aspects. By evaluating the results of various physical and mechanical tests, we demonstrated the practical applicability of paper-based packaging materials.

2. PAPER BAGS AS TRANSPORTATION MEDIA

2.1 Historical overview

The development of paper bags began during the Industrial Revolution. The first major breakthrough came in 1852 with Francis Wolle's patented paper bag making machine, which made production faster and more efficient, paving the way for the spread of paper bags in the United States and Europe. [1] In 1871, Margaret E. Knight invented and patented the first machine for manufacturing flat-bottomed bags, which made paper bags more stable and easier to handle. This made it possible to transport heavier items safely. Walter Deubener added handles to paper bags. By the 1910s, shoppers could use these to

conveniently carry their purchases *(Figure 1).* This type became known as "Deubener's Shopping Bag" and quickly spread to department stores. [2]

Figure 1: Charles Stilwell's patent for the SOS paper bag [2]

From the mid-20th century onwards, paper bags were pushed into the background by the emergence of lighter and cheaper plastic bags. Recently, however, environmental concerns and the demand for sustainability have brought paper bags back into the spotlight. Modern paper bags are made from sustainable raw materials, such as paper certified by the Forest Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification (PEFC). The popularity of paper bags in grocery stores is growing steadily as shoppers increasingly prefer environmentally friendly packaging solutions over plastic bags. In addition to being practical, paper bags also emphasize sustainability. Paper bags can also play a prominent role as a popular marketing tool. The Big Brown Bag *(Figure 2)* is an excellent example of how a simple paper bag can become a well-known trademark.

Figure 2: Macy's iconic "Big Brown Bag" [2]

It has become a symbol of the Macy's chain of stores and represents sustainability, elegance, and practicality all at once. The popularity of paper bags in recent years is due not only to their environmentally friendly properties, but also to increasingly stringent regulations.

2.2 Raw materials and manufacturing process of paper bags

The kraft paper, is made from long-fiber cellulose fibers. This structure ensures the paper's high tensile strength and flexibility. Sulfate paper is naturally brown in color but is also available in a bleached version. It is popular for advertising and premium bags. It is also outstanding in terms of sustainability, as it often comes from FSC or PEFC certified forests, which ensure that the raw material comes from a sustainable source. Recycled paper has weaker mechanical properties than kraft paper, making it ideal for packaging lighter products such as gifts and smaller items. The production of recycled paper requires fewer natural resources, thus reducing the ecological footprint. Coated papers can be used for a variety of purposes. Waterproof coatings prevent moisture from seeping through, making them ideal for packaging baked goods and other products exposed to moisture. Grease-resistant coatings prevent oily or greasy foods from damaging the paper, so they are often used in fast food or bakery packaging. Compostable coatings are made from natural, plant-based materials that ensure the bags biodegrade while providing an environmentally friendly alternative. [3] The production of paper bags is a complex, mechanized process that can be divided into several stages:

– preparation of raw materials,
– printing,
– shaping and gluing,
– forming handles,
– quality control and packaging.

3. QUESTIONNAIRE SURVEY

We conducted a non-representative questionnaire survey (199 respondents) to identify the habits and problems associated with the use of paper bags. We compared the responses with the measurement data of the paper bags tested. 78.4% of the respondents were middle-aged women (between 35 and 50 years old). Based on the answers to the question "How often do you reuse paper bags?", 40.6% of respondents reuse paper bags frequently. Only 8.6% of respondents said they never reuse them. The answers to the question "How suitable do you think paper bags are for everyday use?" show that the majority of respondents, 54.3%, consider paper bags less suitable for everyday use. 29.9% of respondents consider them suitable for everyday use, while 12.7% consider them completely unsuitable. Interestingly, only 6 people, or 3.1% of respondents, consider paper bags to be very suitable for everyday use. The data also highlighted the limitations and reservations associated with the everyday use of paper bags. Responses to the question "What problems have you encountered when using paper bags?" included the following: paper bags weaken more easily when exposed to moisture and are not durable enough for everyday use *(Figure 3).* In other words, the physical weaknesses and limitations of paper bags are the main problem. The majority of respondents, 54.3%, therefore consider paper bags to be less suitable for everyday use.

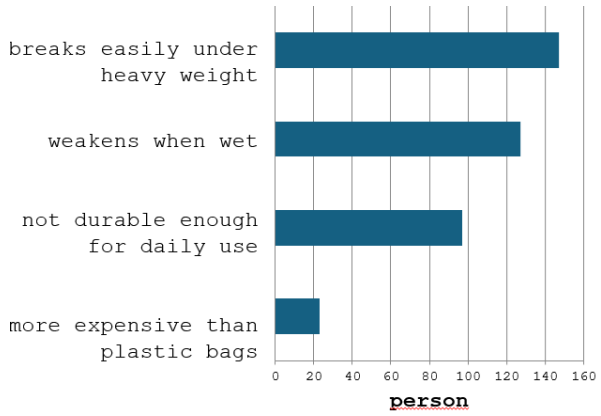

Figure 3: The most common problems associated with the use of paper bags

4. PAPER BAGS AND THEIR PHYSICAL TESTING

For the test, we selected six paper bags of different sizes and load capacities, representing a wide range of products available on the market *(Table 1).* We determined the performance of the bags as their load capacity, moisture resistance, and mechanical stability. This was done in order to confirm or refute user concerns with the measurement results.

Table 1: Parameters of the paper bags tested

sample	designation	size* [cm]	max.load capacity [kg]
1	Tesco brown ribbon-handled shopping bag	32 x 16 x 43	8
2	Traditional brown twisted-handle paper bag	32 x 12 x 41	3-4
3	Ribbon-handled brown shopping bag	32 x 17 x 46	12
4	Rossmann ribbon-handled white shopping bag	32 x 14 x 45	8
5	White twisted-handle paper bag	32 x 12 x 41	3-4
6	White ribbon-handled paper bag	28 x 14 x 35	5

*(width x depth x height)

4.1 Determining the volume of paper bags using filler material

The volume of paper bags was determined in accordance with the provisions of standard MSZ EN 13590:2003, which provides precise guidelines for measuring the volume of packaging units. The bulk density of the plastic granules used to determine the volume of the paper bags was also calculated according to the above standard. [4] During the test, the volume of 5 samples from each of the 6 types of bags described above was measured *(Figure 4), (Table 2).*

Figure 4: Volume measurement of sample 3

Table 2: Parameters of the paper bags tested

sample	calculated volume [l]
1	27.62
2	15.74
3	24.61
4	20.16
5	15.74
6	13.72

The volume of the bag was calculated using formula (1)

$$\mathbf{V} = \frac{\boldsymbol{m}}{\boldsymbol{\rho}} \tag{1}$$

where:
ρ: the bulk density of the granules (kg/m³),
m: the mass of the granules (kg),
V: the volume of the cylinder (1 liter = 0.001 m³).

The volume measurement tests provided a comprehensive overview of the capacity and functionality of different paper bags. The results showed that the volume of the bags can vary significantly, which can serve different purposes. The bags with the largest volume (samples 1 and 3) are suitable for transporting larger and heavier items, which can be advantageous when transporting food or clothing products, for example. These bags allow for multifunctional use due to their high load capacity and large storage capacity. The smaller bags (samples 5 and 6) are ideal for smaller products such as medicines, cosmetics, or small gifts due to their smaller size.

4.2 Maximum load capacity test

The purpose of the maximum load capacity test is to determine whether the paper bags comply with the maximum load capacity specified by the manufacturer. The test was performed in accordance with standard MSZ EN 13590:2003. The bags, filled with plastic granules to their maximum load capacity, were placed on a lifting machine, suspended by both handles. The lifting machine raised the bag to its highest position and then began the repetitive lifting and lowering movement specified in the standard (10-10 up and down movements). We observed when the bag began to tear or deform. A maximum crack length of 30 mm was allowed during the movement. If the crack exceeded 30 mm or the handle broke, the bag was classified as defective. The results obtained in kilograms were compared with the maximum load capacity specified by the manufacturer. The bags showed no significant cracks or damage to the handles during the tests, so all samples met the carrying capacity requirements. The tests confirmed that the paper bags can be used safely within the values specified by the manufacturers and meet customer requirements.

4.3 Overload testing

The purpose of the overload test was to assess how paper bags react when the maximum load specified by the manufacturer is exceeded. This test is important because users often overload bags, which can affect their lifespan and reliability.

The bags were first tested with a load 25% greater than the maximum load capacity specified by the manufacturer, and then with a 50% overload. We examined the structural stability of the bags, looking for signs of tearing or deformation. Based on the test results, we can conclude that all bags successfully withstood the 25% and 50% overload exceeding the manufacturer's specifications. This shows that the structural stability of the bags is adequate for extreme loads that may occur during everyday use. The tests were performed under dry conditions. The behavior of paper bags may differ in wet environments.

4.4 Moisture effect and load capacity test

The way paper bags react in a wet environment, especially when their maximum load capacity is exceeded, simulates real-life situations where bags often come into contact with moisture. We sprayed of 12 ml and 24 ml of water onto the inner surface, side walls, and bottom of the bags. After 2 minutes, when the water had been absorbed and the strength of the paper material had adapted to the effects of moisture, we tested the bags' maximum load capacity with a 25% overload. The bags were subjected to repeated lifting and lowering movements every 30 seconds for 10 minutes. During this time, we documented changes in the strength of the material and signs of structural weakening or tearing *(Table 2).*

Table 2: Parameters of the paper bags tested

sample	12 ml water spray tear time [min]	24 ml water spray tear time [min]	note
1	540	192	the bottom part tore
2	no tear	no tear	the bag remained intact
3	no tear	no tear	the bag remained intact
4	no tear	162	the bottom part tore
5	138	-	the bottom part tore
6	102	-	the bottom part tore

During the tests, we found that the performance of paper bags varies significantly under the combined effects of moisture and load. The 12 ml water spray caused varying degrees of structural weakening and tearing in samples 1, 4, 5, and 6, while samples 2 and 3 were more resistant. Under the effect of 24 ml of water spray, the tear time decreased further, especially for samples 1 and 4, whose lower parts tore after an average of 3.2 and 2.7 minutes, respectively. Samples 5 and 6 did not survive the entire test time even with 12 ml of water spray, breaking after an average of 2.3 and 1.7 minutes, respectively *(Figure 5).*

Figure 5: Visual inspection after moisture effect and load capacity testing

4.5 Cobb$_{120}$ test (water absorption capacity)

Moisture significantly affected the stability of the bags, typically at the bottom. Paper bags are often exposed to wet environments, and it is necessary to understand how they behave in such situations. We used the Cobb$_{120}$ test to examine the water absorption capacity of paper bags. We focused primarily on the surface water absorption capacity of the paper used as the raw material for the paper bags. The test was performed in accordance with the ISO 535:2023 standard, which specifies the water absorption capacity of paper and cardboard. Lower Cobb values generally indicate better water resistance, while higher values indicate greater water absorption and poorer moisture tolerance. We observed different results for each sample, reflecting the relationship between water absorption and material weakening. The numerical data and textual evaluation of the observations of the test are presented in *Table 3.*

Table 3: Evaluation of the Cobb test

Sample	Coob value [g/m^2]	Observation
1	33.77	The bottom tore, but not at the folds; the material weakened on its own
2	34.19	Remained stable, but the gluing weakened due to moisture
3	32.98	The most stable sample; no material weakening or tearing occurred
4	33.70	Both the bottom and the folds tore; both the material and the folds weakened
5	31.28	The bottom and shoots tore quickly
6	24.73	The bottom and shoots tore quickly

Low Cobb value and water resistance – Sample 6 showed the lowest Cobb value (24.73 g/m²), indicating good water resistance. However, this sample was not durable during testing, as structural weakening led to rapid tearing. This suggests that a low Cobb value does not necessarily guarantee bag stability if the material strength is poor. Medium Cobb value and stability – despite its medium Cobb value (32.98 g/m²), sample 3 was the most stable, with no tearing or material weakening. This suggests that, in addition to water absorption, the structural design and material quality of the bag are also key factors. Higher Cobb value and adhesive weakening – despite the high Cobb value (34.19 g/m²) of sample 2, it did not tear, but the adhesives weakened under the influence of moisture. This suggests that appropriate structural elements can improve the durability of the bag, even if the material has a high water absorption capacity. High Cobb value and rapid weakening – the higher Cobb values of samples 1, 4, and 5 (31.28–33.77 g/m²) led to weakening of the lower parts and folds. When exposed to moisture, these bags tore quickly, especially at the folds. A low Cobb value does not guarantee durability, as mechanical strength is also key. Medium Cobb values (32–34 g/m²) generally offer a good balance between water resistance and stability, while high Cobb values can result in poorer moisture tolerance, especially due to structural weakening of the folds and bottom sections. To improve the performance of paper bags, it is recommended to reinforce these critical areas and use more water-resistant materials and adhesives. [5]

4.6 Square meter mass testing and evaluation

Determining square meter mass is essential for evaluating the quality of paper bag material, as the density and thickness of paper directly affect its mechanical properties, such as load-bearing capacity and water resistance. We used the ISO 536:2020 standard, which specifies the procedures for measuring square meter weight. [6]

Square meter weight can be determined using the following formula:

$$\mathbf{V} = \frac{\boldsymbol{m}}{\boldsymbol{\rho}} \tag{2}$$

where: ρ is the mass per square meter (g/m²),
m is the mass of the test piece (g),
A is the area of the test piece (m²).

Determining the square meter weight of the raw material of the paper bags tested revealed the extent to which the density and thickness of the material affect the durability, water resistance, and load capacity of the paper bags *(Table 4).*

Table 4. Evaluation of square meter weight test

sample	square meter weight [g/m²]	observation
1	85.33	The bottom tore, but not at the folds; the material weakened on its own
2	108.33	It remained stable, but the bonds
3	123.33	The most stable sample, with no material weakening or tearing were weakened
4	105.33	Both the bottom and the folds tore, with both the material and the folds weakening
5	107.33	The bottom and folds tore quickly
6	102.33	The bottom and folds tore quickly

Low basis weight and poor mechanical stability – the low basis weight of sample 1 (85.33 g/m²) resulted in poor mechanical stability. During testing, the material weakened independently and the bottom tore, while the folds remained intact. This suggests that the low basis weight is less suitable for long-term load-bearing capacity, especially when exposed to moisture.
Medium basis weight and balanced performance – Sample 2 (108.33 g/m²) and Sample 4 (105.33 g/m²) had medium basis weight, which showed more stable performance. Sample 2 remained stable, but the adhesives weakened, while Sample 4 both broke and the material and the folds broke. This means that although medium basis weight generally shows better performance, the weaker adhesive and fold sensitivity degrades the overall durability.
High basis weight and excellent stability – Sample 3 (123.3g/m²) had the full basis weight and showed excellent performance in the tests. Neither appeared discontinuous, suggesting that stability for mechanical water resistance cannot be achieved with the higher basis weight.
Average weight and poor performance in wet conditions – despite their average weight per square meter, sample 5 (107.33 g/m²) and sample 6 (102.33 g/m²) showed poor performance in wet conditions. In both samples, the bottom and folds quickly tore, indicating that the composition of the material and the quality of the adhesives greatly affect the stability. This suggests that weight per square meter alone is not enough to ensure the durability of the bag.
Based on the tests, the cracking always occurred at the bottoms and along the folds, where the effects of moisture and load were concentrated, with only the 105–120 g/m² range proving to be the most balanced in terms of Cobb tests and mechanical stability. It is recommended to improve the performance of paper bags by reinforcing the bottoms and folds, and by using more water-resistant adhesives, materials and water-repellent coatings.

5. CONCLUSION

The aim of the research was to investigate the durability, water resistance and practical applicability of paper bags, with particular attention to sustainability aspects. The results of the physical and mechanical tests show that the load capacity of the paper bags generally meets expectations, and in some cases even proved to be stable under overload. Even at 25% and 50% increased loads, they showed significant pressure, which demonstrates the reliability of the paper bags in everyday use. However, the performance of the bags is significantly reduced, especially with poorer material quality or weaker adhesive patterns. This suggests that although the paper bags perform well in dry conditions, their resistance to moisture is limited, which may be a problem in certain application areas. The results of the Cobb test showed that bags with low water absorption are not always more durable if the bag is prone to rapid tearing due to structural weakness of the material. In contrast, samples with medium Cobb values generally showed better stability, indicating that not only water resistance, but also material strength and structural design are key factors in the design of paper bags. These factors open up further development opportunities for manufacturers, especially in the areas of moisture resistance and structural stability. The results of the research can contribute to a broader understanding of the applicability of paper bags.

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A FUTURE BUILT ON TRADITION - MODERN PRINTING KNOWLEDGE AND TRAINING CENTRE IN BÉKÉSCSABA

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Abstract

The southeastern region of Hungary has a long tradition of printing. Békéscsaba has been considered a "printers' town" for a century and a half. There are more than a hundred printing and graphic design companies operating in the area, all of which require well-trained professionals. Printer's training has been taking place in the city since 1964. It was therefore not surprising that in 2018, Békéscsaba allocated a significant part of its financial framework for the "Modern Cities" government supported program to the creation of a knowledge and training centre that provides a supply of skilled workers for this industry, which is so important to the city, in a state-of-the-art technological environment and with educational methods that reflect the future.
The institution, which was implemented according to the original strategy and handed over in 2021, provides secondary education covering the entire spectrum of the printed communications business. The study presents and analyses the extremely successful, nationally recognized, future-focused training provided here from the perspective of students, teachers, and printing companies alike. They also strive to ensure the transfer of knowledge in the international arena for their students who excel in professional competitions.

Keywords: *printer's town, printing education, future-focused training, "Modern Cities" program*

1. INTRODUCTION

As the deputy director of the Albert Szent-Györgyi Technical School at the Békéscsaba Vocational Training Center, my responsibilities include overseeing printing industry training and the operations of the Printing Industry Knowledge and Training Centre. In this article, I present the educational and professional work carried out at our institution, while also sharing numerous thoughts and ideas that summarize the results and lessons learned from the printing training conducted here. This allows us to provide positive answers to many questions that may arise among those who are sceptical about our profession.

2. WHY BÉKÉSCSABA?

Békéscsaba is a small town of 60,000 people located 200 km southeast of Budapest, near the Romanian border. One might rightly wonder why such a centre of learning and training was established here, in this remote corner of the country. Békéscsaba is a true printing town. The region has a long tradition of printing, following in the footsteps of the renowned Kner and Tevan printing dynasties. There are more than 100 printing and graphic design companies operating in the city's catchment area, ranging from one-person businesses to multinational companies with hundreds of employees.

Figure 1: Where exactly is Békéscsaba?

In addition to production, education also has a long tradition. Secondary-level printing training has been available in Békéscsaba for 60 years, and it is known as one of the best training centres in the country in terms of enrolment, quality, and professional standards. Currently, 10 full-time instructors and 3 technicians strengthen the professional team, whose combined knowledge covers almost the entire spectrum of the printing industry, from preparation to finishing.
Anyone who works as a printer or operates a printing company in this city is tasked with and undertakes to preserve the heritage and build the future. In the 2010s, key players in the region recognized that the industry had no future without a skilled workforce, so they lobbied consciously and strongly for the promotion of training and the future of the industry. As a result, the training centre was established.
The implementation, operation, and future of young professionals have now become a common cause for the entire printing industry in the country. Although our partners are competitors in the market, they support education as one. For several years now, the Federation of Hungarian Printers and Papermakers treated secondary education and the training centre in Békéscsaba as a strategic issue and has supported them.

3. THE RESULT OF A SUCCESSFUL COLLABORATION

As a result of successful professional cooperation, the Printing Industry Knowledge and Training Centre was completed in the fall of 2020 with a budget of nearly €5 million as part of the Modern Cities Program of Hungarian Government.
The construction was preceded by several years of planning and preparation to ensure the best possible working conditions for printing students. The city of Békéscsaba also considers supporting printing industry training to be a priority.
Local printing experts and supplier partners also invested a great deal of energy in planning, and the facility is a true "love child" of the profession.

Figure 2: Printing Industry Knowledge and Training Centre

3.1. Technological infrastructure

The Knowledge Center is a well-equipped printing facility with five conventional and three digital printing presses for offset, flexo, electrophotographic, and inkjet printing.
Post-printing processing is made possible by a **cutting table**, die-cutting machine, **adhesive binding unit**, folding machine, collating equipment, stapling machine, and manual **bookbinding workshop**.
The design and technical preparation of publications is carried out on **55 iMac** computers in rooms equipped with **huge digital boards**.
We use Adobe and Alwan software for our professional work, which our partners supplement with special pro bono software (pre-press, CAD, Esko programs, and plug-ins).
Students can also prepare printing plates for offset and flexo printing in our own CTP studio.
In addition, a well-equipped colorimeter and materials science laboratory also help students acquire sound professional knowledge.

3.2 Education at the knowledge centre

The Knowledge Center operates as part of the Szent-Györgyi Technical College, thus serving the needs of secondary-level printing training.
In Hungary, printing industry training belongs to the **creative sector**.
It can be acquired at two professional levels.
"Printer" (level 4): over the course of three years, students learn the profession with very little general knowledge content and many hours of instruction; the final exam tests only professional knowledge, and students can start working immediately (typically at the assistant or machine operator level). They then could obtain a high school diploma in evening classes.
"Printing technician" (level 5): Over the course of 5 years, students take both a high school diploma exam and a professional qualification exam, after which they find employment or begin higher education.
Compared to level 4, the professional part is supplemented with knowledge related to process organization and management, production planning, and quality assurance, among other things.
Special training for certified technicians, in which students also take university courses in their final year. Students with good and excellent results are automatically admitted to the Óbuda University's Light industry engineer academic program, where their studies are credited with 32 credits.

Our school's main profile is full-time training following primary school, but we also start groups for students who have already graduated from another school or even already have a profession. They can study full-time until the age of 25, and there is no age limit for evening classes.
Students can complete their training at companies in their final year. In this case, the company and the students sign a vocational training contract. The student learns at the company as a quasi-employee, acquiring knowledge in an industrial environment through close cooperation between the school and the company. They receive a salary during their studies but are not "tied" to the company after the exam.

3.3 The process of vocational training

Students participate in basic vocational training at level 4 in the first year and at level 5 in the first two years.
During the basic sectoral training, students gain a comprehensive overview of the fundamentals of the printing industry.
During this period, we **lay the foundations** for further studies and find out which activities the students enjoy the most and in which they feel skilled and interested.
We design postcards, notebook covers, labels, and calendars by hand and on the computer, then print and process them to create "real" printed products.
During these activities, we learn about the programs used in the graphic design industry (Adobe Photoshop, Illustrator, InDesign), **familiarize ourselves** with how printing machines work, and **experience** how materials behave in practice. We **create** blocks, notebooks, books, and boxes with our own hands to experience the joy of a job well done.
For the basic exam, students create a two-page publication in InDesign and Photoshop, which must be digitally printed and presented in detail.
Starting this school year, the basic exam also includes the presentation of a portfolio of completed works.
This is followed by vocational training, where they will have more and more vocational classes over the years.
Technicians take their final exams and vocational qualification exams at the end of the 12th and 13th grades.
During the printing industry training, after the basic exam, students can continue in three professional fields:

- pre-press operator
- printing press operator
- finishing (post-press) operator

4. EDUCATION AND OUTPUT REQUIREMENTS

In the training and outcome requirements, a “sub-profession” can be defined as a distinct, independent component of the profession that enables the acquisition of the competencies necessary to perform at least one specific job role.

4.1 Education of pre-press operators

The pre-press operators **learn the rules of publication design** and use them to **design aesthetic and practical publications.** These can be flyers, books, newspapers, posters, boxes, bags, labels, decorative foil, flags—in short, anything that can be printed. They learn the rules of typography and graphic design, **become familiar with the technical capabilities of various printing techniques**, and prepare graphic designs in such a way that they can be implemented, printed, and processed on the given machine. To this end, they are in constant contact with the other participants in the printing process. If necessary, they can print the publication themselves on a digital printing press.

If the publication planned/prepared by the student is to be printed from a printing plate, the plate must also be prepared using the platemaking or cliché-making equipment available at the Knowledge Center. Our students who can work independently as pre-press operators are in high demand in the region.

4.2. Education of printing press operators

The printing press operators take the printing plate from the pre-press section and insert it into the printing press. They then make the necessary adjustments, insert the printing medium, and produce the first copy of the required quality. Their tasks are then to ensure that every single print is of the same quality.
In addition to printing from printing plates, students must also have a solid knowledge of digital printing techniques. Fortunately, in addition to offset and flexographic printing, the Knowledge Center also has laser and inkjet digital printing machines, so that well-rounded, well-prepared professionals can enter the job market. We supplement their knowledge with color management, materials science, and laboratory testing skills.

4.3. Education of finishing (post-press) operator

The sheets and rolls coming off the printing press are given their final form by the finishing operator. The Knowledge Center can only cover a few areas of the diverse world of print processing.
We have stapling, collating, and folding machines, as well as cutting machines, and our color digital printing press is also equipped with an in-line saddle stitching device.
The most exciting feature is the book-making equipment connected to the digital printing machine, which, once set up, performs the printing, gluing, and trimming operations without any intervention.
It is important that we can also provide our students with practical knowledge in label processing, as our flexographic printing machine is equipped with both upper and lower die cutting.
In the well-equipped manual bookbinding workshop, students can learn the basic techniques and complete the creative process. The workshop is equipped with a collator, stapler, folder, laminator, spiral binding machine, and manual bookbinding tools.

5. THE KNOWLEDGE CENTRE IS BOTH A PART OF AND A DRIVING FORCE FOR THE DOMESTIC PRINTING INDUSTRY

Thanks to its extensive network of contacts, the Knowledge Centre is an integral part of the domestic printing industry. The Federation of Hungarian Printers and Papermakers and the Technical Association of Paper and Printing Industry provide our teachers and instructors with free participation in professional conferences and various professional forums. They supported the participation of our two colleagues at DRUPA 2024. Our students can participate in professional exhibitions; we represented the next domestic generation with nearly 100 students at the recent PPD Expo. In addition, it conducts educational activities for elementary schools and actively supports our school enrolment events.
In addition to the Associations, several domestic companies support our activities with financial, professional, and in-kind support, provide us with up-to-date information, and help us cope with the daily challenges of our plant. In their honour, we have created a sponsor wall in the lobby of the Knowledge Centre.
Our partners visit us regularly and hold free training sessions for our students on the latest technologies. Most recently, representatives from Heidelberg visited us and gave a three-hour presentation on the multicolour system. We also regularly visit printing houses in several cities across the country, where students are warmly welcomed and everything is done to further increase their commitment to the profession.
In the first half of the school year, during the fall semester, our most active partners can get to know our students during a fun day. As part of the Andor Day competition, student groups solve fun professional tasks at stations set up by the companies. At the end of the day, the many small and large gifts that the

printing companies give to our students find their owners. For me, this event best symbolizes the spirit of the Knowledge Centre and printing education in Békéscsaba: establishing a living, personal relationship between students and companies as early as possible, so that after their exams, there is no question that they will begin their adult careers in the printing industry.
Networking continues in the spring, when companies come up with specific offers for vocational training contracts or employment during career orientation days. The greatest recognition of our work and also the best measure of its success is when our students find employment and/or continue their studies in the domestic printing industry, because this means that we have passed on our love of the profession to them and successfully shaped their vision for the future. However, the greatest joy is seeing our former students at professional conferences or in a work environment, as they often become our biggest supporters. It is a particular pleasure that some of our instructors were also Szent-Györgyi printing students (me included), and the technicians who perform the operational tasks are all enthusiastic young professionals who were "trained in-house."

5.1 Training consulting and cooperation

In addition to the printing industry, we are also closely linked to the domestic vocational training system. We perform expert, advisory, and examination tasks, liaise with state bodies responsible for vocational training, and participate in the development of training requirements and the examination system, thus acting not only as implementers but also as shapers of printing industry education.
One of our most important tasks is to maintain contact with other domestic training institutions, as the unique infrastructure in Békéscsaba must serve the interests of the entire domestic industry. To this end, we organize sector-specific professional days and consultations, provide the venue for the national professional study competition, and implement student exchange programs. We regularly assist each other with daily tasks or larger projects under the professional leadership of other institutions.
Together with Óbuda University, we have developed a certified technician program that ensures the most talented students' direct access to university engineering training.

5.2 Achievements of students

Our students regularly test their skills in various competitions. One of their favourite competitions is Best Print Hungary, which is essentially a competition for players in the Hungarian printing industry. Every year, companies compete with their best and most sophisticated products for the Best Print Hungary award, which requires them to meet strict criteria during the professional judging process. The competition has a junior category, where secondary and higher education institutions can also compete. Every year, we submit several entries, and the jury regularly awards our students' work with bronze, silver, or gold medals.
The largest and most important competition is the national professional study competition, better known as "Szakma Sztár" (Star of Profession). Following the interactive selection process, the preliminary and final rounds take place at the Knowledge Centre, where students and teachers from schools across the country come to showcase their knowledge. Every year, students from Békéscsaba finish on one (sometimes more) of the podium places, which we are very proud of. The highlight of the event is the "Szakma Sztár" Festival at Hungexpo Exhibition Centre, where 20,000 primary school students can learn about the opportunities offered by the printing industry, among other things, over the course of three days. The event requires a lot of preparation and investment from both the industry and the schools, but it is still considered the most eagerly awaited professional event of the spring. During the days spent here, our best students, together with the most enthusiastic sponsors, promote the profession at the stand, and by the end of the event, the boundaries between students and companies have been broken down. At the end of the competition, the best students receive significant financial support from the sponsors and are invited to job interviews at many companies.

To sum up, our most important mission, in addition to providing quality vocational education, is to lay the foundations for our students' professional commitment, launch their careers, and meet the needs of the labour market.

5.3 International relations

The Vocational Training Centre of Békéscsaba places great emphasis on building international relations and invests significant resources in this area. Although there are few partner companies in the printing industry, we managed to participate in an exchange program in Estonia as part of the Erasmus program. Within the framework of the Erasmus program, four students and two teachers took part in a professional trip to Tallinn, where we gained experiences that will last a lifetime. In addition to cultural programs, we also visited a printing plant and spoke with the president of the Estonian Printing Industry Association. Our students spent three weeks training at the Estonian printing plant.
In return, we also welcome Estonian students to the Knowledge Centre, where we strive to provide them with useful professional and practical experiences. Such opportunities are a great source of motivation for today's young people, and we hope to have the opportunity to participate in similar programs in the future.

6. CONCLUSION

Finally, allow me to share personal insight. In 1998, I had no idea what went on in a printing house; all I knew was that I wanted to work with books, computers, and people in my adult life. So, training as a publishing editor at the predecessor of today's Szent-Györgyi Technical College, the Tevan Andor Printing Industry Vocational School, seemed like a good choice. In the 27 years since then, I have earned degrees in light industry engineering, engineering education, and public education management. In the meantime, I worked at DTP Studio, then started teaching at Szent-Györgyi. Finally, in 2019, I got my dream job: to contribute to the creation of the Knowledge Centre, the development of the teaching team, the operation of the printing training program, and finally to join the domestic printing industry with this facility. This job is better than I ever imagined.

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THE IMPACT OF IMAGE-BASED LEARNING ON PROFESSIONAL SKILL DEVELOPMENT IN BEAUTY AND HAIRDRESSING EDUCATION AS PART OF FASHION EDUCATION

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Abstract:

This study investigates the impact of image-based learning (IBL) on professional skill development in beauty and hairdressing education as part of fashion education. Employing a quasi-experimental design with 120 practitioners in Taiwan, participants were divided into experimental (IBL) and control (traditional) groups. Key competencies—including technical skills, creativity, emotional regulation, and stress management—were assessed pre- and post-intervention. Results revealed significant improvements in the experimental group across all domains, with large effect sizes (Cohen's d = 1.12–1.57). These findings highlight IBL as an effective pedagogical tool for enhancing both technical expertise and emotional resilience in vocational fashion training programs.

Keywords: *Image-based learning, Beauty and hairdressing education, Fashion education, Emotional regulation, Stress management*

1. INTRODUCTION

The beauty and hairdressing industry is an ever-evolving and highly competitive field, influenced by shifting consumer preferences, technological advancements, and a growing demand for high-quality service [1,2]. As part of the broader fashion education ecosystem, beauty and hairdressing professionals are required to stay up-to-date with the latest trends, techniques, and innovations, while continually developing both technical skills and emotional resilience to meet the demands of client-facing roles. The beauty and hairdressing sector is defined by its rapid pace, and professionals must adapt quickly in order to maintain their competitive edge. The beauty industry is characterised by its fast-paced nature, where practitioners must adapt quickly to maintain competitiveness. Traditional training works well, but it might not suit everyone's way of learning or meet all their changing needs. [3] This indicates the importance of exploring alternative training methods that can enhance skill acquisition and emotional adaptation. Image-based learning (IBL), which uses visual stimuli such as images and videos, has emerged as a promising approach to support professional development and help practitioners meet these demands.

IBL is based on the cognitive theory of multimedia learning, which posits that learning is more effective when information is presented through both verbal and visual formats. By engaging multiple cognitive channels, IBL can enhance understanding, retention, and the ability to apply complex concepts [4]. In the context of fashion education, research has shown that multimedia and visual learning tools are effective in improving practical skills and increasing engagement among students [5,6]. Existing research has predominantly targeted students, leaving a gap in the literature regarding how IBL can be used for continuous education and skill enhancement for professionals in the field. Previous studies have

primarily targeted student populations, with limited exploration of how IBL can be used to support the continuous education and skill enhancement of professionals established in their careers.
This research gap is particularly relevant within Taiwan's beauty and hairdressing sector, which forms a vital component of the broader fashion education framework. The sector is marked by intense competition and a rapid pace of change, meaning that professionals must regularly update their skill sets to remain competitive. Traditional training may no longer be sufficient to address the diverse needs of the workforce. As such, this study seeks to investigate the impact of IBL on the professional skill development of beauty and hairdressing practitioners in Taiwan, a sector that would greatly benefit from flexible, innovative approaches to training.
The aim of this study is to bridge the gap by evaluating the effectiveness of IBL in improving essential areas such as technical skills, creativity, emotional regulation, and stress management. These areas are vital for learners to excel in their careers and to manage the emotional and physical demands of their work. By integrating IBL into vocational training and professional development programmes, this research will provide valuable insights into how visual and interactive learning can enhance skill acquisition, emotional resilience, and stress management within Taiwan's beauty and hairdressing sector as part of fashion education. The findings from this study are expected to inform future training practices, offering a more flexible and effective approach to continuous learning for professionals in this ever-evolving field.

2. METHODOLOGY

This study examines the impact of Image-Based Learning (IBL) on the professional development of beauty and hairdressing practitioners in Taiwan, specifically within the context of beauty and hairdressing education as a part of fashion education. A quasi-experimental design was employed to assess the effectiveness of IBL in improving key areas such as technical skills, creativity, emotional regulation, and stress management. The following section outlines the participants, the intervention, the data collection methods, and the analytical techniques used in this research.

2.1 Participants

The study included 120 participants, equally divided between the experimental group (60 participants) and the control group (60 participants), to ensure sufficient statistical power for detecting medium to large effects. The experimental group participated in a 6-week IBL programme, while the control group received traditional, non-IBL training methods. Participants were recruited from two vocational beauty and hairdressing institutions in Taiwan, which are integral parts of the broader fashion education system, and the sample size was determined through a power analysis, which indicated that 120 participants would provide 80% power.

To be eligible for participation, individuals were required to have at least one year of professional experience in beauty or hairdressing, with no history of severe mental health conditions (such as depression or anxiety), and a willingness to participate in the training programme. Participants were randomly assigned to either the experimental or control group, ensuring an even distribution of age, gender, and years of professional experience across both groups to minimise demographic biases. Furthermore, job roles (e.g., hairstylist versus beautician) were balanced between the groups to facilitate fair comparisons.

2.2 Image-Based Learning Program

The image-based learning programme for the experimental group was designed to enhance technical proficiency, creativity, and emotional regulation. It consisted of three key components: (1) Digital tutorials and video demonstrations, which included high-quality, step-by-step instructional videos showcasing various beauty and hairdressing techniques (such as cutting, colouring, and styling). These

videos acted as visual guides, aimed at improving participants' skills; (2) Virtual simulations, which featured interactive 3D simulations of client interactions and salon scenarios, enabling practitioners to practise techniques in a controlled, simulated environment while also engaging in problem-solving tasks; and (3) Hands-on practice with feedback, where participants applied the techniques demonstrated in the videos and simulations. During these practice sessions, instructors provided real-time feedback, which helped participants refine their technical skills and improve their emotional regulation.
The control group, by contrast, continued with traditional training methods. This involved face-to-face instruction, instructor-led demonstrations, and practicing on mannequins, with no multimedia content incorporated. The traditional methods included practical demonstrations, manual exercises, and basic role-playing activities designed to simulate client interactions, but they lacked the visual and interactive elements available to the experimental group.

2.3 Data Collection

Data were collected at two points in time: before the training programme (pre-test) and immediately after the completion of the 6-week programme (post-test). The following methods and tools were employed to gather the data:

Technical skill assessment
To assess participants' technical proficiency in beauty and hairdressing tasks (such as cutting, styling, and colouring), a practical exam was conducted both before (pre-test) and after (post-test) the 6-week programme. The exam focused on key skills including precision, creativity, and problem-solving. Scoring was based on a detailed rubric, which included categories like precision, creativity, and problem-solving, developed by industry professionals and trained assessors. Multiple assessors participated in the grading process to minimise bias and ensure consistency in the evaluation.

Emotional regulation and stress management
Participants' ability to manage and regulate emotions in high-pressure scenarios was assessed using the Emotional Regulation Questionnaire (ERQ). This tool measures two key dimensions: emotional reactivity and the ability to control emotions. In addition, the K10 Mental Health Scale was employed to assess general psychological distress, including symptoms of anxiety and depression. The K10 scale consists of 10 questions regarding symptoms experienced in the past 30 days, with higher scores indicating greater distress. These assessments were crucial in evaluating participants' emotional resilience and their ability to manage stress.

Attention and focus
Participants' attention was assessed in three categories: visual attention (e.g., focusing on client details), auditory attention (e.g., listening to instructions and client requests), and kinesthetic attention (e.g., performing tasks with physical precision). Instructors rated attention using a Likert scale (1 = not focused, 5 = highly focused) during each session. Objective data collection was also employed using eye-tracking and EEG (electroencephalography) devices to monitor attention levels during task performance. These devices ensured that attention was measured accurately, not solely relying on self-reports, providing a more objective assessment of participants' focus.

Participant self-report
At the conclusion of the 6-week programme, participants completed a survey to assess their satisfaction with the image-based learning programme. This survey measured perceived improvements in technical skills, emotional regulation, and overall engagement with the learning method. Additionally, participants provided qualitative feedback through open-ended questions, sharing challenges or positive experiences they encountered during the learning process. This qualitative data provided valuable insights that were not fully captured by the structured assessments, offering a deeper understanding of participants' experiences with the programme.

Sub-subsection
To assess participants' technical proficiency in beauty and hairdressing tasks (such as cutting, styling, and colouring), a practical exam was conducted both before (pre-test) and after (post-test) the 6-week programme. The exam evaluated key skills such as precision, creativity, and problem-solving. The scoring was based on a detailed rubric developed by industry professionals and trained assessors, ensuring consistency and minimising bias. Multiple assessors were involved in the grading process to ensure fair and reliable evaluation.

2.4 Data Analysis

Descriptive statistics
Descriptive statistics were calculated to summarise the data and provide a general overview of the results. For all variables, including technical skill scores and emotional regulation scores, mean scores, standard deviations, and ranges were computed. These statistics helped to describe the distribution of the data, offering a clear understanding of participants' performance and the variability in their scores.

Paired samples t-test
A paired samples t-test was conducted to compare pre-test and post-test scores within each group (experimental and control). This analysis aimed to determine whether there were significant changes in technical skills, emotional regulation, and stress management following the intervention. For example, a paired t-test was performed to assess the technical proficiency scores of the experimental group, comparing the pre-test score ($M = 72.3$, $SD = 5.1$) with the post-test score ($M = 81.2$, $SD = 4.4$). The result showed a significant difference, $t(59) = -8.35$, $p < 0.01$.

Independent samples t-test
An independent samples t-test was used to compare post-test scores between the experimental and control groups. This analysis examined whether the experimental group demonstrated significantly greater improvements in technical skills, emotional regulation, and attention compared to the control group. For instance, the independent samples t-test revealed that the experimental group ($M = 81.2$, $SD = 4.4$) scored significantly higher than the control group ($M = 75.4$, $SD = 5.3$) on the technical proficiency post-test, $t(118) = -3.71$, $p < 0.01$.

Effect size
Effect size was calculated to assess the magnitude of the differences between the experimental and control groups, providing insight into the practical significance of the findings. Cohen's d values were used to classify the effect sizes as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$), which helped to interpret the meaningfulness of the differences observed in the results.

Qualitative analysis of participant feedback
Thematic analysis was performed on the open-ended responses from the survey to identify recurring themes and insights regarding participants' experiences with the image-based learning programme. This qualitative data helped to complement and explain the quantitative findings, offering a deeper understanding of how IBL impacted participants' emotional regulation and skill development within the context of beauty and hairdressing education as part of fashion education. By examining participants' personal feedback, the analysis enriched the study's findings, revealing nuanced aspects of the intervention's effectiveness.

3. RESULTS AND ANALYSIS

This section presents the results of the study, integrating both quantitative assessments and qualitative feedback to evaluate the impact of IBL on the professional development of beauty and hairdressing practitioners in Taiwan. The analysis focuses on four key areas: technical skills, creativity, emotional regulation, and stress management. Additionally, subgroup analyses are conducted to determine whether variables such as gender, professional experience, and job role moderated the effectiveness of the intervention.

Quantitative Results

Improvement in technical skills

The primary objective of the intervention was to enhance participants' technical proficiency in beauty and hairdressing tasks. The results clearly show a substantial improvement among those in the IBL group.

Technical skill scores (pre-and post-test)

Group	Pre-test mean (SD)	Post-test mean (SD)	Mean difference	t-value	p-value	Cohen's d
Experimental (n=60)	72.3 (5.1)	81.2 (4.4)	+8.9	-8.35	< 0.01	1.12 (large)
Control (n=60)	70.2 (5.7)	74.8 (5.9)	+4.6	-5.10	< 0.01	0.61 (moderate)

The experimental group demonstrated a statistically significant increase in technical skill scores ($p < 0.01$), with a large effect size, indicating that the practical improvements were not only measurable but also meaningful. Although the control group also showed improvement, the gains were considerably smaller. This enhancement suggests that the visual and interactive elements of IBL fostered a more profound understanding of complex techniques, such as colour blending, sectioning precision, and tool handling—skills that traditional methods may not have fully captured or conveyed.

Moderating variables

To determine whether the impact of IBL varied across different practitioner characteristics, we analysed the effects by gender, years of experience, and job role.

Moderation effects on technical skill improvement (Experimental group)

Moderator	Subgroup	Pre-test mean	Post-test mean	Difference	p-value	Cohen's d
Gender	Male (n=28)	72.8	81.5	+8.7	<0.01	1.08
	Female (n=32)	71.9	81.0	+9.1	<0.01	1.15
Experience	1–3 years (n=33)	71.2	80.3	+9.1	<0.01	1.21
	>3 years (n=27)	73.5	82.1	+8.6	<0.01	1.05
Job Role	Hairdresser (n=30)	72.6	81.8	+9.2	<0.01	1.17
	Beautician (n=30)	72.0	80.7	+8.7	<0.01	1.09

The findings suggest that IBL was effective across all subgroups, with relatively consistent improvements observed. However, slightly greater benefits were noted among female participants, those with less experience, and those working as hairdressers. This could reflect a higher level of adaptability to new methods among less experienced practitioners, as well as a closer alignment between the content of the IBL programme and the highly visual, sequence-driven nature of hairdressing procedures.

Creativity and problem-solving

The capacity to generate creative solutions and adapt styling approaches is fundamental in beauty-related professions. Participants' creativity was assessed through structured tasks requiring personalised styling responses and problem-solving in simulated client scenarios.

Creativity scores (Pre- and Post-Test)

Group	Pre-Test Mean	Post-Test Mean	Mean Difference	t-value	p-value	Cohen's d
Experimental	65.5	76.4	+10.9	-9.42	< 0.01	1.31 (large)
Control	63.1	68.5	+5.4	-6.21	< 0.01	0.84 (moderate)

Participants in the IBL group showed a marked improvement in creativity, suggesting that visual exemplars and scenario-based learning stimulated more innovative and personalised approaches to service delivery. These gains were more pronounced than those seen in the control group, further supporting the role of IBL in fostering non-linear, adaptive thinking.

Emotional regulation and stress management

Given the emotionally demanding nature of beauty work, improvements in emotional regulation were a major focus of this study. The Emotional Regulation Questionnaire (ERQ) and Kessler Psychological Distress Scale (K10) were employed to measure changes.

Emotional regulation and stress levels

Group	ERQ Pre	ERQ Post	K10 Pre	K10 Post	ERQ Δ	K10 Δ	t-value	p-value	d
Experimental	24.8	34.6	27.1	18.5	+9.8	-8.6	-10.13	< 0.01	1.57 (ERQ)
Control	23.7	27.3	26.3	23.5	+3.6	-2.8	-3.29	< 0.01	0.45 (ERQ)

The data suggests that IBL contributed significantly to emotional resilience, enabling practitioners to manage workplace stress and challenging client interactions more effectively. This is a particularly relevant finding, as burnout remains a persistent issue in customer-facing professions.

3.2 Qualitative Findings

To further support the quantitative findings, participants in the experimental group were invited to provide feedback through open-ended questions, revealing several key themes that highlighted the effectiveness of the IBL programme. A prominent theme was engagement through interactivity—many participants found the visual simulations and video-based scenarios far more immersive and practical than traditional instructional methods. One beautician remarked, "Seeing real situations unfold helped me prepare for things we don't always get to practise in class," reflecting the heightened relevance and applicability of the content. Increased confidence also emerged as a significant benefit, with several participants noting how the IBL-based emotional training made them feel more composed and capable when interacting with clients, especially in stressful or high-pressure situations. Furthermore, the reflection and feedback component of the programme was highlighted as particularly valuable. Participants appreciated the opportunity to review their performance through video playback, which allowed them to identify areas for improvement and receive targeted feedback. This process, they noted, contributed significantly to reinforcing their skills and enhancing their confidence in real-world applications. These qualitative responses align closely with the statistical data, underscoring the importance of IBL not only in advancing technical skills but also in fostering emotional growth, thereby making practitioners more adaptable, confident, and resilient in their professional roles.

3.3 Practical Significance

The improvements observed in this study go far beyond just numerical gains; they carry significant real-world implications for beauty and hairdressing professionals. The 8.9-point increase in technical proficiency suggests that practitioners are now more skilled in executing complex tasks with greater precision, which is likely to enhance client satisfaction, reduce complaints, and foster stronger brand loyalty. Additionally, the gains in creativity enable practitioners to offer more personalised and trend-sensitive services, which is crucial for retaining clients in a highly competitive, style-driven market. The improved emotional regulation observed in participants also indicates a reduction in workplace conflicts, less stress-related absenteeism, and greater career sustainability, all of which are essential for long-term success in the profession. Furthermore, the reductions in psychological distress, as indicated by the K10 scale, suggest that IBL may contribute to better mental health outcomes, which are vital in an industry known for its high levels of stress and fatigue. In sum, image-based learning demonstrates clear advantages not only in educational metrics but also in the day-to-day experiences and long-term career prospects of beauty and hairdressing professionals.

3.4 Discussion

The results of this study clearly demonstrate that Image-Based Learning (IBL) has a significant impact on the professional development of beauty and hairdressing practitioners, particularly within the context of fashion education. The improvements observed in technical skills, creativity, emotional regulation, and stress management align with previous research on multimedia learning in vocational education (Lin et al., 2018; Chen & Lee, 2019). These findings suggest that IBL is a more effective approach compared to traditional methods, especially for skills that require practical application, creative thinking, and the ability to respond dynamically to the needs of clients, all of which are critical in fashion-related professions.

Impact on technical skills

The substantial improvement in technical skills within the experimental group indicates that IBL provides a more immersive and engaging learning experience than traditional, face-to-face instruction. The integration of digital tutorials, video demonstrations, and virtual simulations allowed participants to interact with the learning material in ways that traditional methods cannot replicate. This aligns with Mayer's cognitive theory of multimedia learning, which suggests that learning is more effective when information is presented through both visual and verbal channels. The opportunity to practice skills in a virtual environment, receive immediate feedback, and make real-time adjustments likely contributed to the improvements in technical proficiency, particularly in tasks central to beauty and hairdressing, such as precision cutting, styling, and colouring. These skills are fundamental in fashion education, where the application of techniques must reflect current trends and client preferences.

Impact on creativity and problem-solving

IBL also had a significant impact on participants' creativity and problem-solving abilities. The use of multimedia content, particularly virtual simulations, allowed participants to experiment with different approaches to client interactions and service delivery, fostering innovation without the fear of making mistakes. This approach is grounded in constructivist learning theory, which values active learning and experimentation. By offering practitioners the freedom to explore new techniques, IBL enhanced their creativity and problem-solving skills, critical for adapting to the diverse demands of the fashion and beauty industries. In beauty and hairdressing education, where every client poses a unique challenge, this ability to innovate and resolve problems is invaluable for professionals seeking to offer personalised and trend-sensitive services.

Emotional regulation and stress management

One of the most significant improvements observed was in emotional regulation and stress management. These skills are essential in the beauty and hairdressing industry, where professionals frequently deal

with high-pressure client interactions and time-sensitive tasks. IBL provided practitioners with the opportunity to practice emotional regulation strategies in a controlled, virtual environment, helping to build psychological resilience. The ability to manage emotions and stress effectively is crucial for maintaining professionalism, job satisfaction, and overall well-being in the beauty and hairdressing profession, which is a vital component of fashion education. The improved emotional regulation observed in participants suggests that IBL can contribute to reducing burnout and enhancing long-term career sustainability in the fast-paced fashion industry.

Psychological resilience

The reduction in psychological distress observed in the experimental group suggests that IBL can positively influence the mental health of practitioners. The beauty and hairdressing profession is mentally demanding, with professionals often experiencing high levels of stress due to client-facing work and tight schedules. By incorporating emotional regulation and stress management training, IBL offers a holistic approach to professional development, addressing not only the technical skills required in beauty and hairdressing but also the mental well-being of practitioners. This approach has the potential to reduce absenteeism, improve job satisfaction, and contribute to longer career longevity in the beauty and hairdressing sector, which is deeply intertwined with fashion education. Enhancing psychological resilience is crucial for ensuring that practitioners remain adaptable and sustainable in their careers, especially in an industry characterised by rapid trends and constant innovation.

4. CONCLUSION

This study provides compelling evidence of the positive impact of Image-Based Learning (IBL) on the professional skill development of beauty and hairdressing practitioners in Taiwan, particularly within the context of beauty and hairdressing education as part of fashion education. The significant improvements observed in technical skills, creativity, emotional regulation, and stress management highlight IBL's potential as a valuable tool in vocational training for the beauty and hairdressing sector, which is closely integrated into the fashion education system. The findings suggest that IBL not only enhances technical proficiency but also strengthens emotional resilience, leading to improved job performance, higher client satisfaction, and greater career sustainability. Despite these promising results, several areas for future research remain. While the current sample size was sufficient, expanding it could improve the generalisability of the findings. Additionally, the long-term effects of IBL on skill retention, emotional resilience, and career longevity should be explored further in future studies. Longitudinal research would provide valuable insights into the sustained impact of IBL in vocational education within the beauty and hairdressing field, particularly as part of fashion education.

Future research should also aim to explore the broader applicability of IBL across different cultural and geographical contexts and assess its impact over extended periods. It will be crucial to identify specific factors that may moderate its effectiveness, such as technological access or learner characteristics. Furthermore, more detailed statistical analyses could reveal the interplay between various factors influencing professional development, such as gender, years of experience, and job roles. The integration of IBL into ongoing professional development programmes should also be examined in greater depth, as this approach shows promise not only in enhancing technical skills but also in promoting mental health, emotional resilience, and overall career satisfaction among practitioners. Ultimately, the findings from this study suggest that the adoption of IBL could contribute to more sustainable and fulfilling careers in the beauty and hairdressing industry, enabling practitioners to adapt to industry changes while maintaining their well-being and enhancing their professional growth within the framework of fashion education.

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PRACTISING ENGAGEMENT FOR TRANSITION DESIGN

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Abstract:
The present study focuses on stakeholder engagement within Transition Design, examining the consumer perspective on textile provenance, with particular attention to participants' knowledge and skills related to textiles. Building on the work of Stefano Boeri, the study investigates how participatory, embodied mapping can elicit distributed and individual perspectives on provenance, while also analysing how the act of map-making may serve as a phenomenological basis for experiencing emerging, incomplete, or absent knowledge and skills more deeply.
The paper draws on a series of pilot workshops entitled Co-creating an Eclectic Atlas of Cloth, conducted across different geographical and community contexts as part of a larger doctoral research project. In these workshops, participants contributed personal textile items and were invited to trace their provenance, prompting reflection on supply chains, cultural histories, and personal attachment. This process revealed how consumer behaviour, purchasing patterns, and cultural values shape sustainability narratives and supported the articulation of radical visions for future textile practices through facilitated discussion.
While the wider doctoral research explores Transition Design across multiple geographical focal points and textile-practising communities, the research presented here specifically investigates participatory engagement methods as tools for stakeholder involvement. Working with Transition Design approaches such as systems thinking and co-design, the study positions designers as facilitators of systemic change in response to complex, "wicked" problems. The outcomes contribute practical insights into how embodied, participatory methods can be designed and situated to support systems-level transformation within the textile industry.

Keywords: *Transition Design, Ethnography, Sustainability, Textile Industry, Co-Design*

1. INTRODUCTION

As the second biggest emitter of greenhouse gases, the Global Textile Manufacturing sector faces ongoing pressure to adopt more sustainable practices, and while here are different ways of defining and measuring textile industries, the total contribution of the textile and fashion sector is estimated to make up for 2% of the world's GDP [1]. In the UK, there are 88,000 people working towards a near $80 billion US dollar (£62 billion) output per annum [2] whereas in Europe, where the economic contribution is almost 200 billion US dollars (€170 billion), more than 14 times the amount of people, 1.3 million people work in the industry [3]. These figures highlight that in The United Kingdom less people are employed but they tend to work in higher value parts of the sector than is average for their European neighbours. Consumption of new clothing is also estimated to be significantly higher in the UK than it is in many European countries, 26.7kg in the UK to 12.6kg per person in Sweden in 2018 (Used Textile Collection in European Cities, European Clothing Action Plan, March 2018, cited in [4]) and this paper thus focuses on the role community engagement may have within transition design in the nationally important UK textile sector.

9. TRANSITION DESIGN (TD)

Whilst the core principles of transition design were first published formally in 2015, they had been muted by Irwin and Tonkinwise since the beginning of the decade and in some sense present a

convergence of co-design, grassroots and community engagement methodologies that should be seen alongside other emerging design theories like speculative design and ontological design. All these theories are working towards trying to answer the question of what constitutes meaningful design [5], with transition design placing particular emphasis on the concept of cosmopolitan localism, or how we can give agency to distributed systems, grassroot organisations, and connectivity between system stakeholders. It advocates that real change can only start from the local level while being connected, informed or even scaled up globally.

"Design has changed from an activity often undertaken by an individual professional designer to a highly collaborative, co-design activity that involves a variety of actors, including professional designers, experts from other fields and disciplines and users/co-creators" [6, p. 57].

Terry Irwin posits that "Transition Design challenges existing paradigms, envisions new ones, and leads to radical, positive social and environmental change" [7, p. 8] which means TD works on fixing problems within existing system, trying to find a point for well-informed intervention. [8] wrote that if we fail to intervene, "we will continue to live from our culturally installed operating system and perpetuate our current reality" [8, p. 2], and the aim of involving stakeholders is not to simply replace a system but to find a point for intervention to lever a positive future that is geographically grounded, co-created and therefore able to change the postures of the communities touched by the change. A key point to TD is to do research within and with communities, to meaningfully contribute and co-create answers to current social and ecological crises. This emphasizes a significant change in the modern designer's role as it considers designers as facilitators for systemic change [9]. The role designers take in the industry is an ongoing debate, and while some (e.g. [10] and [11]) advocate for a more expert approach, where designers are considered as the decision makers, there are many voices arguing for a more user-centred approach ([6], [12] and [13]), with TD falling squarely within this part of the debate.

TD emphases the role of collaboration, specifically transdisciplinary collaboration. The need to bring in different disciplines (inter/trans disciplinary and technology transfer) is not a new idea, co-creation and co-design have been mentioned as early as the late 1960s. One of the most influential early examples of participatory design can be traced back to the 1970s in Scandinavia. [14] gives us a glimpse into important projects in Scandinavia, leveraging important pillars in participatory design, highlighting three key characteristics: "deep commitments to democracy and democratisation; discussions of values in design and imagined futures; and how conflict and contradictions are regarded as resources in design" [14, p. 62]. These points can be clearly seen in parallel with values of TD in which there is an important emphasis on the involvement of the end users and stakeholders and giving everyone a voice, in the belief that design must facilitate social innovation. Scandinavian Participatory design is built strongly on helping people realise attainable futures, and positions future users as co-designers in some cases. A well-known example is the "Swedish DEMOS Project" [14] from the late 1970s which emphasised workplace democracy and co-determination. Alongside Scandinavia, there have been other places that have benefitted from participatory and community-led design approaches during the same period. [15] gives us a brief introduction to the history behind the Coin Street redevelopment in London from the 1980s. The Coin Street Project is a social enterprise that is on-going to this date. By 1977 The "Coin Street Acton Group" [15] has formed and together with other organisations transformed its neighbourhood.

Transition Design was first formulated into an educational framework (figure 1) by Terry Irwin, Gideon Kossoff and Cameron Tonkinwise at California's Carnegie Mellon University in 2015.

This framework is meant to help educators, designers, practitioners, to implement transition design methodologies in their own work. The four important pillars of the framework are "visions for transition, theories of change, posture, mindset and new ways of designing" [16].

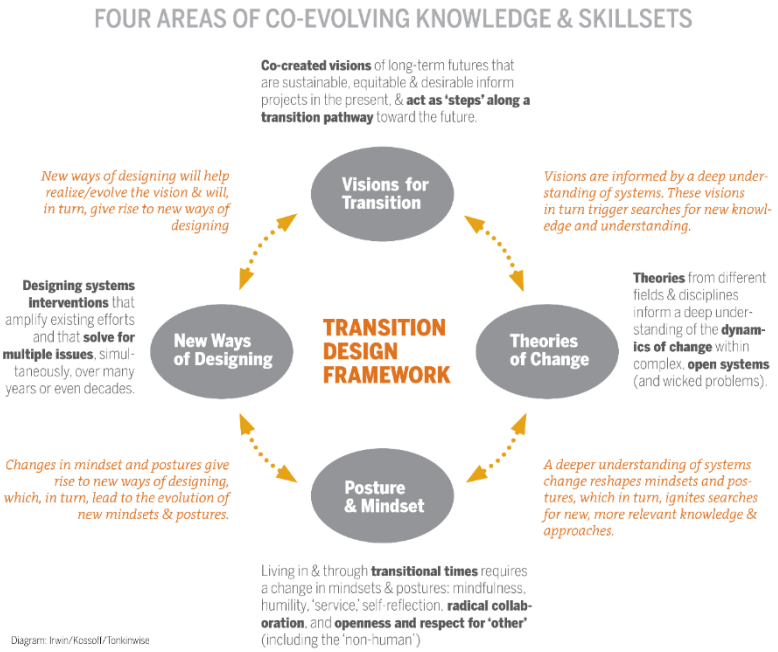

Figure 1: The Transition Design Framework (Transition Design Seminar CMU, 2019)

Workshop and community consultation

Workshops consistently come back as an important if rather informal aspect of the TD methodology, and we considered the systematic use of planned workshops as a point of departure to inform transition design goals in the textile industries. In other words, it is not just important to have a workshop but as a transition designer we need to think about the positioning of the workshop within the systems matrix, the potential stakeholders connected to the so-called wicked problems, based on the observations of the symptoms of the system's ills. As a transition designer, developing an effective workshop methodology needs to be a point of focus and we therefore, developed and undertook a series of pilot studies, entitled, *Co-creating an Eclectic Atlas of Cloth,* with three workshops so far following different intentions with a diverse range of participants.

10. METHODOLOGY

The workshop format was inspired by the "eclectic atlas" that Stefano Boeri employed in urban planning in the early 21st century to incorporate multiple gazes about a place [17]. We re-imagined these co-created maps as tools to elicit and document knowledge on provenance of personal textiles, adding the physical stitching of buttons and threading of yarns to encourage an embodied experience of data and wicked problem discovery.

3.1 Workshop 1

The first workshop was planned as part the international doctoral program "Transformations in European Societies" with a group of ethnographic Doctoral students and their professors united in their commitment to understanding the world from a people's point of view. These participants not having a background in textiles was important, as they were sampled as European textile **consumers** from 7 countries, and as ethnographers, committed to the agency of participants in research. Ages ranged from mid twenty to around 50.

All participants were informed and agreed to data generated in the workshop being used in refining transition design co-creation methodologies with stakeholders.
The aim of this workshop was also to bring together people whose standard mode of engagement is not material led, and to see how it works, how it is received, and if it creates a rich space for engagement and to elicit radical ideas for future practice.
We took the eclectic atlas literally and printed an outline of the world map using sublimation printing onto deadstock fabric and using colour coded buttons and yarns sewn onto the fabric during as part of the workshop activities.
We began the workshop with a presentation on Transition Design, with particular emphasis on mindsets, seeking to fully inform participants on context and aims of the workshop, while a previously sent out email to all participants did not yet reveal transition design as a central concept, encouraging instead reflection on personal attachments to textiles:

1. Explore as much as you (easily) can of the provenance of one or two items of clothing that you were about to pop into the suitcase for your trip to Murcia. Provenance here describes the origins and history of the textile, from its materials to its culture to the people involved in its making, distribution and use.
2. Add an extra item of clothing or cloth to your suitcase that holds special importance for you, whether because of its provenance or due to a very personal relevance.
3. Bring to the table visions of cloth production and consumption that are (radically) different to our currently prevailing (fast) fashion system. Perhaps you are aware of an initiative in your neighbourhood, or have studied a long-forgotten heritage practice, or maybe you are already living or imaging a better future for our relationship with textiles [18].

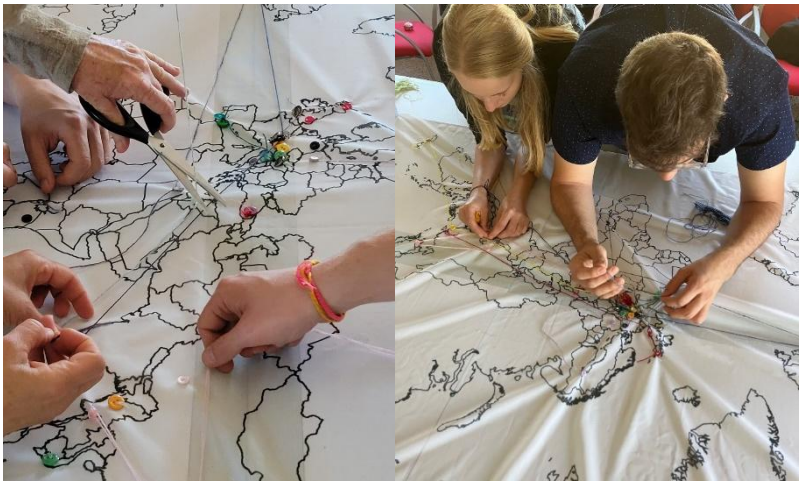

Figure 2: Workshop activities

The tasks followed these three prompts to map individual impacts of clothes with non-traditional, embodied modes of data collection. Signalling their own location in the world by one button participants sought and traced provenance of items by an additional button connected by physical supply chains, allowing the group to later collectively consider our “textile footprint” (figure 2 and 3).

Figure 3: Mapping our impact and relationship to our clothing in Murcia, Spain

We asked the participants to provide further reflections on the textile items they had chosen to bring, to add cultural provenance and personal relevance to our data (table 1). The task encouraged deep thinking about textile items of daily use.

Table 1: Example of feedback entry

White Tunic	Embroidered Pillow Cover
BLUE	-
Notes on supply chain provenance	Notes on supply chain provenance
Probably made in India, not sure where! but it resembles Indian products; travelled to the States, and brought back to Croatia	Came from Konavle Region in Croatia; present sent to a woman who used to live in Sisak (Croatian town); gifted second time to me by descendant of a first owner. Now kept in Zagreb as a souvenir. Base cloth is what we call PANAMA textile; thread is/was produced in Croatia (can't read this); but the cotton is Egyptian. Time of production around 60s.
Notes on cultural provenance	Notes on cultural provenance
Indian women's tunic, white cotton long shirt with blue flower imprints 'coloured blue'. Bought in ethnic shop 'HINDI' in San Francisco.	Croatian national embroidered pillow cover: so, called 'Levantin stitch' or locally known as 'Konavoski vez' (the stitch from Konavle region).
Notes on personal connections	Notes on personal connections
Bought in 2006, with Hindi speaking friend, kept as a reminder of a stay in America; nice to wear, cool feel; especially in summer.	A family piece given to me by father-in-law; belonged to his mother who was given the cloth by her relative from the Konavle region.

The third part of the workshop centred around the sharing of radical ideas about future textile consumption practices to mitigate provenance and footprints issues uncovered in the mapping exercise. Conducted in two smaller groups led by one of the researchers each, they interestingly elicited a wealth

of personal encounters with existing “green shoot” practices from across the European origins of this group.
We observed how the embodied nature of data collection in the physical mapping served as a base for futuring that was committed to extracting good information from lived and observed experience. That solid data base manifested in questions such as: Who made my clothes? What are the oldest items in my wardrobe? As not everyone wanted to answer these questions, our research observed potential generational and certainly personal differences in emotional connections to our clothes. An older member of the group described her own wardrobe as consisting of a few key items, we noted cyclical developments as what she described was essentially a *capsule wardrobe*, which is currently a rising trend among Gen Z ([19] and [20]).
Observation of behaviours and skills during the completion of the button sewing task offered a second valuable source of data for researchers and participants in transition design. A frequent lack of basic skills related to textiles, from threading a needle to sewing a button, gendered and generational to some extent, had not been anticipated and therefore not been mitigated by the researchers, but in the event created a useful distance and appreciation for the very objects that were being mapped.
The workshop was received by participants with great enthusiasm, indicating the value of non-traditional ways of eliciting data and affording tie and place for lively and deep discussions before, during and after the hour-long physical mapping exercise. A fair amount of sharing basic skills and co-speculating or investigating provenance created a sense of belonging amongst the group of stakeholders.

3.2 Workshop 2

The Murcia trial was followed up by another workshop in Orkney, Scotland a few weeks later, when transition engineers, software engineers, circular economists and designers came together to explore different modes of engagements around Transitions. The very international composition of the group resulted in a map that offers a more global picture of textiles provenance and consumption. From a TD methodology point of view, this underlined strongly how important the consideration of different geographies is in making transition design engagements relevant to the communities it seeks to serve (figure 4).

Figure 4: Mapping our impact and relationship to our clothing in Orkney, Scotland

Workshop 2 was distinct in that its participants, as members of a transition engineering and design network at Heriot-Watt University, all have experience in collecting data for transition scenarios, with case studies ranging from transportation to energy and housing. One of these methodologies is the InTIME cycle employed by Prof Susan Krumdieck’s team in Orkney that also seeks stakeholder

engagement to inform radical visions for future practice [21]. Running and discussing the eclectic map workshop with this transition-experienced group of participants foregrounded an opportunity to develop a complete design futuring programme initiated by the embodied exercise of eclectic mapping, and including provisions for directed futuring, testing and scenario building.
A third workshop was run with Scottish and English schoolchildren aged 15, as a follow-on exercise to a short presentation of sustainability in fashion and textiles as part of their sustainability project week. The discussions and activities were received with enthusiasm and engaged attention. The third workshop is the only one of the three delivered within a specific community or region, whereas the previous workshops had a wide range of international attendees.
The workshops function as situated experiments within a broader transition design process rather than as endpoints in themselves. Their value lies in the insights they generate when read in combination with other tools and processes, and in how their outcomes can be critically reflected upon, compared, and iteratively developed over time. The following section discusses key findings relevant to stakeholder engagement and transition-oriented practice.

11. FINDINGS AND DISCUSSION

The purpose of co-creating eclectic atlases of textiles provenance in our workshops was to trial embodied or phenomenological ways in which stakeholders can be engaged in the data collection and visioning phases of transition design. The ultimate aim was to test if personal engagement of this kind might be helpful in achieving design-led or enabled social change.
We learned that it is useful to work with groups of participants that are part of a shared community, be that in outlook, in demographic or geographical.
We found that geographically truthful maps can be physically tricky to work with as provenance and location of community of stakeholders leads to bunching in certain areas, but that this could also be considered an asset as it illustrates the uneven distribution of consumption and production very well.
A further workshop is currently being prepared for a community of textile makers in Oradea, Romania, to test how the methodology works within communities that are both highly skilled in the area of investigation and geographically distinct.
“Globalization is at the root of many wicked problems to which localism has been a common response. However, such problems are usually too complex and interconnected to be resolved at the local level. (…) Cosmopolitan Localism is the theory and practice of inter-regional and planetwide networking between place-based communities who share knowledge, technology, and resources” [22, pp. 51-52].

Following up from the textile mapping workshops, we are planning to lean into different design challenges and stakeholder groups, looking at the younger generations as possible, future shapers. Connecting with the school run project in Orkney [23] we are exploring how a hands-on mapping workshop can help the very youngest stakeholders to visualize their own ways of getting to school, seeking ways to engage children and the younger generations as ambassadors of change, to become net zero heroes.
To sum up, we realised that these workshops must be used intentionally and as part of a bigger effort to inform and effect transitions, not independently but strategically positioned within a specific context. We recognised also that these workshops can have different levels of output quality based on their regional context and the skills and knowledge levels of the participants. We posit that observing these differences can yield valuable data on who might be the hardest stakeholder groups to engage in transitions to preferred design futures. For long term change the workshop must be built around a fuller framework that integrates multiple dimensions of data collection and forms part of a connecting thread between stakeholders and systems within a wicked problem.

12. CONCLUSION

In conclusion, we have assessed that the method used in the workshop has been an interesting tool for the researcher and interesting, unconventional type of engagement for the stakeholders, where thoughts and ideas were generated in an unexpected way that delivered a sense of *safe environment* for self-expression as well. The hope is that for future applications the workshop can we adapted to work within more complex systems with a diverse stakeholder base, and to work in different regional contexts.
There are various emerging paths in the industry within the research context. An important part of the research is to now look at stakeholders within the industry, and to test different engagement methods for diverse environments and lifestyles and knowledge levels. It is important that we establish a network of varied contributors and shape with them a methodology of embodiment, physical engagement suitable for them.
We believe the eclectic atlas has broadly been a success in bringing non experts to the table, to hear everyone's ideas and voices and empower consumers to really become part of a community of change for better textiles futures. It is important to note that in our preliminary workshops, we are engaging with imperfect data in the sense that the sampling of participants was largely opportunistic, making it important to widen the workshop trials intentionally to further stakeholders' groups in order to establish best practice for different communities.
Transition design values local knowledge as much as it seeks visions for globally connected design futures, and a backdrop to our work has been the significant built environment presence of an industry that has since declined, and with people living in these environments no longer showing widespread knowledge or skills connected to goods formerly manufactured locally. The former mills and factories point sharply to the fact that these communities once but no longer operate effectively as local systems and have lost their importance and connection to global scenarios.
We consider them as interesting sites to turn the tide towards better design futures where cosmopolitan localism might find traction on account of their histories, residual knowledge and memories of a working system of production. An oral history project of Mill Memories is underway, and there is advanced planning to deliver a two-and-a-half-day workshop in Oradea, Romania, involving local stakeholders, featuring international collaborators from Hungary and Scotland. The aim is that this workshop will deliver the necessary adaptation requirements to determine the success of a progressed version of the workshop, involving local crafters (within the textile context), non-profit organisations with close links to the city council as well as internationally recognised individuals in their field of expertise to help deliver an experience that'll hopefully provide a vision for the future of stakeholders in the city.
This project will run under the name *Wandering Threads*, piloting in April 2026 (figure 5).

Figure 5: Call for Artifacts for upcoming Wandering Threads Project

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THE RISE OF MYCELIUM-BASED MATERIALS ACROSS INDUSTRIES: A REVIEW

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Abstract:
Mycelium-based materials are an interesting area of research, several industries are involved in exploring the possibilities. This review aims to identify the main industries and product group. Not only the most popular areas are mentioned, such as architecture, fashion and packaging. We also collected some special applications where these materials could be used in the future. This material family have several advantageous properties, but their application also faces many challenges. Our collection of precedents includes good and questionable examples, to draw attention to the need of further research.

Keywords: *biodesign, mycelium, biocomposites, sustainable materials, bio-manufactured products*

1. INTRODUCTION

Is it possible to think of our everyday objects in a way that serves not only us, humans, but also the environment? We sought to address the question of sustainable industry through biodesign. Biodesign explores both new and traditional technologies that enable nature to be involved in design and production [1-2]. This process can be done by plants, algae, and microorganisms, such as bacteria and fungi [3].
Mycelium, the network of fungal filaments (hyphae), has attracted significant interest in the fields of biodesign and sustainable materials research [2-6]. Scientists, designers, and engineers are exploring the potential of cultivating materials, structures, and everyday products through collaboration with this living organism.
It is a biodegradable, renewable, and highly adaptable material family. These characteristics position them as promising, environmentally responsible alternatives to conventional materials [7]. The global market for mycelium-based products is experiencing rapid expansion, with an estimated value of USD 2.9 billion in 2024 and projections reaching up to USD 5.2 billion by 2034 [4]. This growth is driven by environmental regulations, increasing demand for circular-economy models, and rising investments in research and development for sustainable innovation [4-6].
Despite these advances, several challenges have to be addressed. On one hand, the need for standardised production methods, scalability of manufacturing, technical benchmarking against established industrial materials, and market regulations [4-6]. On the other hand, consumer acceptance, aesthetic values, and unfamiliarity with the new materials [2, 8]. Addressing these issues calls for continuous research, cross-sector collaboration, and effective communication of the material's benefits to both producers and consumers.

2. REVIEW METHOD

The following sections of this review will examine mycelium's diverse applications, current technical challenges, and its broader implications for industry and society. By integrating insights from market data, design and research, this paper provides a comprehensive overview of the ongoing rise of mycelium-based materials across industries. This review is based on an analysis of peer-reviewed

articles, design case studies, books and industry reports focusing on the use of mycelium-based materials in market-ready products and experimental use cases.
We explore the whole landscape of mycelium-based materials, both composites and pure mycelium materials. Mycelium-based composites are composed of a substrate material (mostly lignocellulosic waste) and the mycelium as the binder of the substrate's particles [2; 7-8]. Pure mycelium materials are separated from their substrate, they can be grown on solid substrates as composites, and in the end, peeling off the fungal part [7], or on liquid cultures [8].

3. PRECEDENTS

More and more individual artists and designers have been involved [9] in exploring mycelium and mushrooms as sources of materials. Their artworks and experiments contributed to a better understanding of the material and to raising awareness and increasing its popularity.
Based on patents, available products, and collaborations [10], the most active and successful company in the field of mycelium-based solutions is Ecovative LLC. They are very clear about their activities and operations, making all information available on their website [11]. Ecovative researches new mycelium capabilities, then develops applications with sector specialists, and ultimately spins these into focused businesses that work directly with brands and designers. Their patents and public materials govern the entire chain, from substrate and growth-environment engineering through harvesting, post-processing, and applications. Their Open Patent Program and collaborations with both large and small companies, as well as individual designers, promote open innovation. [11]

3.1 Architectural aspects

Mycelium-based composite materials exhibit several properties that make them well-suited for architectural applications (see Fig. 1). They can have low thermal conductivity [12], making them good thermal insulators. Excellent sound absorption and acoustic insulation properties [12-13] enable their use in interior applications. Fire performance is still under investigation, but research suggests promising potential compared to petroleum-based materials [12, 14]. Some fungi species can develop hydrophobic surfaces with high water contact angles, and their surface wettability can be tuned chemically [12].

Figure 1: From left to right: 1) Ecovative's Grown.bio building bricks [16]; 2) The Living Studio: Hy-Fi Tower, led by David Benjamin, built from Grown.bio building bricks building bricks [12]; 3) Op't Oog columns, 3D printed [19]

Mycelium composites can be used in architecture as building bricks [11-12; 15-16], insulation panels and sheets [12-13; 15; 17], panelling and flooring [12; 17], furnishing [15], injection moulded parts [12], 3D printed parts [18-19], mycelium-based elements merged into a framework [20], sandwich panels [21], and self-healing materials, such as self-healing concrete [22].

3.2 Product Design and Consumer Applications

Furniture is a popular area for mycelium-based design, with several examples, many of them unappealing in appearance (see Fig. 2). Grown furniture found in the literature mostly includes chairs, stools, tables and lamps [8-9; 15; 23].

Figure 2: 1) Ivanova & Cox:Projet MYCELIUM + TIMBER [9]; 2) 'Yamanaka Furniture' by Phil Ross [9]; 3) Olle Sahlqvist: Zwampen mycelium stool&chair [23]; 4-5) Eric Klarenbeek: Mycelium Chair [9]; 6) Ecovative x Atelier la Gadoue: Lucid chair [16]

One of the most successful areas of application is the **fashion industry**, which started numerous experiments and product development processes to replace leather with mycelium-based alternatives [9]. Mycelium "leather" is made by engineering fungal mycelium into dense, sheet-like structures. Companies such as MycoWorks (Reishi) [24], Ecovative (Forager) [11; 25], and Bolt Threads (Mylo) [26] have developed controlled growth and finishing processes to achieve the strength, durability, and surface quality expected in fashion [9]. Mycotech, an Indonesian company, published a detailed paper on the development of their mycelium leather, called Mylea [27-28]. Chosun University and Korean research institutes also wrote a paper about mycofabricating leather-like materials [29]. An increasing number of publications detailing the fabrication processes of mycelium-based materials highlights the importance of open knowledge exchange.

Packaging applications are also a developed and commercialised area of myco-matrials [9]. Most of the examples concern protective packaging that can replace styrofoam [8; 30], but there are also experiments with mycelium composite food containers to replace single-use plastics [31].

In the **automotive industry**, mycelium-based composites currently appear most promising for interior, non-load-bearing automotive applications, such as the replacement of conventional textiles, panels, and polymer foams. Their good fire resistance, sound-absorbing and impact-energy-absorbing capabilities suggest potential use as bio-based foam materials in bumper inserts, door and engine-bay liners, as well as seat and trunk inserts [32-33].

However, their durability still raises concerns, particularly for long lifespan products such as cars. These materials are sensitive to moisture and weather [7; 33], which can be partly mitigated through surface treatments and coatings, but this area requires further development. Despite numerous patents and studies [10; 34], practical automotive implementation remains largely at the concept stage.

Ford is among the frontrunners [10; 33] to develop mycelium-based biocomposites that can replace conventional synthetic foams in automotive components [32]. Kia has also embarked on experiments with mushroom-derived materials in collaboration with the Bulgarian company Biomyc [35], focusing on durable, visually exposed interior elements grown from mycelium.

3.3 Specialised Applications

Paul Stamets describes mycelium, drawing on the ideas of Gaia theory, as a **manifestation of nature's living intelligence**. According to this view, mycelium weaves through the soil, forming a sentient membrane that can sense the footsteps of other living beings, as well as changes caused by weather or pollution, and is able to respond to them. He is also the originator of the concept of "mycorestoration," which he divides into four main areas: mycopesticides, mycoremediation, mycoforestry, and mycofiltration. Mycofiltration refers to a method in which fungal mycelium functions as a biological filter, removing various pollutants from water, soil, or air. [36]
The application of fungi in **biofiltration** is an increasingly researched field, as both filamentous and non-filamentous fungi have shown the ability to degrade pollutants present in the air. Further research is needed to establish the safe and effective use of them [37]. The Biopod project (see Fig. 3) is a good example of how mycelium-based composites can be used in biofiltration. It was developed by students and researchers at the Rhode Island School of Design (RISD) along the Providence River in the United States. The aim of the project was to create a biodegradable, floating filtration system based on a mycelium composite, which naturally purifies polluted water through the combined action of plants and microorganisms, helping the restoration of wetland habitats. [38]

Figure 3: Rhode Island School of Design (RISD): Biopod project [38]

By leveraging the biodegradability of mycelium-based materials, the company Loop Biotech has developed fully biodegradable, toxin-free funeral solutions. The company has established a product portfolio that includes both **coffins** (see Fig. 4) **and urns**. According to the manufacturer, these products are designed to accelerate natural decomposition processes and to nourish the soil, thereby contributing back to the ecological cycle. [39].
Building on Stamets's earlier assertion that mycelial networks are capable of sensing and responding to their environment [36], a further potential field of application has emerged: the concept of the **fungal computer** [40]. Mycelium and living mycelium-based composites can behave as logical circuits and unconventional computers by transforming electrical inputs into complex, non-linear electrical outputs that implement Boolean functions [41]. These studies indicate that mycelium may one day serve as a living material for embedding computation, opening the possibility of bio-based, low-energy computing systems. One of the greatest difficulties in this area is that the constantly growing mycelium reconfigures itself as it is growing [41].

Figure 4: Loop Biotech: Loop Living Cocoon™ [39]

Researchers at NASA also have high expectations about mycelium-based materials. The Mycotecture Off Planet project aims to develop **buildings for Lunar and Martian missions** using fungal mycelium-based materials, instead of transporting heavy, pre-built habitats. They investigated various material mixtures, including mycelium with bacterial and algal partners, and they also tested sand and regolith simulants to see if future habitats can be built using local materials found on the Moon or Mars. The technology is still at proof-of-concept stage and needs much more development before use. The main advantages would be mass savings, in-situ fabrication, and potential for self-healing and bioengineered functions. The key challenges include sterilisation, structural optimisation, and long-term reliability. [42]

In the field of **biomedicine**, mycelium-based materials also have good potential. Researchers found that Ganoderma l. and Pleurotus o. are biocompatible and support skin tissue repair in preclinical wound models [43]. Additional studies are required before such materials can be translated into clinical practice.

4. CATEGORIES

In order to systematize the potential application domains of mycelium-based materials, we categorized their functional roles across major industry sectors as on *Table 1*.

The use of mycelium-based materials is expanding across industries, especially in packaging, textiles, automotive, construction, and environmental protection. The most successful areas, that have marketed, industrialised products are packaging, textiles and insulation.

Typically, the primary objective is to replace petroleum-based materials. This is a challenging objective, as petroleum-based synthetic polymers are highly diverse. One of the most significant advantages of mycelium-based materials is their modifiability, but this is also one of their challenges. Material properties depend on substrate composition, fungal species, growth conditions, surface treatment, porosity, thickness, and other factors. Designers also have to consider locally available waste materials and which fungal species can most effectively colonise them to achieve the desired properties.

Table 1: Application areas of mycelium-based materials

1. Architecture and Interior Design	**2. Product Design**
1.1. Structural and semi-structural elements	2.1. Furniture
1.2. Insulation materials	2.2. Decorative objects
1.3. Decorative elements and claddings	2.3. Functional everyday products
1.4. Self-healing concrete	2.4. Funerary applications
3. Packaging Industry	**4. Fashion and Textile Industry**
3.1. Void-filling and cushioning elements	4.1. Footwear
3.2. Molded protective packaging	4.2. Garments
3.3. Food packaging	4.3. Accessories
3.4. Plantable (biodegradable and soil-integrable) packaging	4.4. Upholstery, covers, and surface textiles for furniture
5. Environmental Protection, Biofiltration	**6. Bioelectronics**
5.1. Air filtration	6.1. Circuits and logic gates
5.2. Remediation of aquatic habitats	6.2. Unconventional computing systems
5.3. Degradation of plastic polymers	6.3. Biosensors
7. Automotive Industry	**8. Biomedicine**
7.1. Interior design components	8.1. Wound care and dressing materials
7.2. Technical parts and components	

5. CONCLUSIONS

An analysis of the examined precedents indicates that the advantageous properties of mycelium-based materials would, in principle, enable a wide range of applications. At the same time, it must be acknowledged that not all application domains are equally successful. In the case of furniture, for example, it is not necessarily evident that well-established materials such as wood, metal, and textiles should be replaced. Beyond aesthetic considerations, questions also arise regarding their resistance to long-term mechanical use and wear. Even in sectors where mycelium-based products have already reached the market and demonstrated commercial success, important issues remain open, particularly with respect to durability and behaviour under exposure to moisture. Consequently, research and development in mycelium-based materials requires an explicitly interdisciplinary approach, involving coordinated collaboration across multiple scientific and professional fields. The participation of biologists, engineers, materials scientists, and designers is essential to address both the technical and functional challenges of these emerging materials.

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ASPECTS AND ATTITUDES OF CREATIVE THINKING: COGNITIVE AND NEUROAESTHETIC PERSPECTIVES IN DESIGN PRACTICE

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Abstract:
This paper examines creativity as both a personality trait and a cognitive process, with a focus on its manifestation in art and design. It introduces the Cognition–Apperception–Limn (CAL) framework, which describes the mental–manual transformation of perception into material form.
Drawing on the theories of Guilford, Alexander, Csíkszentmihályi, and Ramachandran, the study situates creative thinking at the intersection of divergent cognition, design methodology, and neuroaesthetic mechanisms. Guilford's model of divergent thinking—fluency, flexibility, originality, and elaboration—frames creativity as a multidimensional and adaptive skill. From a neuroaesthetic perspective, the paper examines how perceptual and emotional responses influence artistic experience. Two complementary modes of creative cognition—top-down (knowledge-driven) and bottom-up (data-driven)—interact to produce both continuous engagement (Flow) and moments of sudden insight (Aha effect).
Manual sketching supports these states by allowing spontaneous ideation, while digital tools often constrain them. Integrating cognitive and experiential dimensions, the paper argues that creativity emerges from the dynamic interplay between perception, cognition, and manual expression, offering valuable insights for contemporary design education and interdisciplinary research. Understanding this process enriches both design pedagogy and interdisciplinary research in art, science, and technology, highlighting the evolving relationship between human creativity, cognitive mechanisms, and the aesthetic mind.

Keywords: *Art & Design, Creativity, Design Methodology, Neuroaesthetics, Flow State, Aha Effect*

1. INTRODUCTION

The process of creativity, as an outstanding human activity, is essentially related to symbolic and abstract cognition, and 'artistic performance' of the brain, and is at the centre of interest of different research theories. Specific areas of the brain which control and process the visual information have been localised by scientists. Brain regions responsible for diverse art-related mental functions were also identified. Still, questions arise from the cognitive and neuroaesthetic perspectives on the effect of these cognitive processes on the quality of the final work and their application in design methodology.

Concerns of this research are:

1. How is the inspiration transmitted into the artwork?

Goal: To identify the effect which flows as an invisible substance between the artwork and the host.

2. How do visual aspects determine the cognitive process?

Goal: To model the physiological pathway that ensures the connection between vision and the hand-driven drawing tool.

3. What qualitative differences arise in terms of the cognitive process types and tools used?

Goal: To identify the differences between the types of cognitive processes caused by the different states, and tools used, and their effect on the creative work.

2. THEORETICAL EXAMINATION OF THE CREATIVE PROCESS

What does creativity mean: Creativeness? Inspiration? Ingenuity? Good problem-solving ability? The embodiment of artistic inclination? Innovativeness? ***What is this?***

- Is it an attribute born with us?
- A capability?
- Inborn gene?

None, and all at once... According to Wikipedia, *Creativity is a specific feature of personality, encompassing traits of thought and specific skills that enable certain types of creative work. The person's environment influences them and manifests in their behaviour.*

2.1 Etymological examination of the concept of creativity – From Antiquity to the 18th Century

The concept of creativity has undergone a profound transformation throughout the history of Western thought. In ancient Greece, the act of artistic or intellectual innovation was attributed not to the individual but to divine inspiration. The Muses, regarded as the sources of all artistic and intellectual endeavour, were believed to bestow the gift of expression upon mortals. Significantly, the Greek language had no direct equivalent for the modern term “create”; instead, the verb poiein—meaning “to do” or “to make”—was used to describe acts of human production. (Fig. 1)

In Latin, a linguistic distinction emerged through the verbs facere (“to make”) and creare (“to bring forth” or “to produce”), reflecting a growing awareness of different forms of generative activity. During the Christian era, however, the notion of *creatio* became reserved exclusively for the divine act of creation, while facere retained its association with human craftsmanship and labour. Thus, creation in its true sense was considered the prerogative of God alone.

The Renaissance marked a pivotal shift in this perception. The Renaissance individual recognised the autonomy of human intellect, the freedom of artistic expression, and the originality inherent in human thought. This period witnessed the emergence of the idea that the artist is a creator in his own right—an originator of beauty and knowledge, rather than a mere imitator of divine or natural forms.

By the eighteenth century, creativity became increasingly linked to the faculty of imagination and the formation of novel concepts. This evolution laid the foundation for modern understandings of creative thought as an innate human capacity, integrating aesthetic sensitivity, intellectual innovation, and the pursuit of originality.

*Figure 1: Paraphrase of Baldassare Peruzzi's artwork "Apollo and the Muses" ¤ Copyright AI experiments by edit@**2025*

2.2 Creativity in Modern Science

In modern scientific discourse, creativity is recognised as a fundamental cognitive and cultural process underlying discovery, innovation, and problem-solving. No longer confined to the arts, creativity in science is understood as the capacity to generate original and valuable ideas that transform existing knowledge structures. Contemporary research across psychology, neuroscience, and cognitive science identifies creativity as a dynamic interaction between divergent and convergent thinking, enabling individuals to explore multiple possibilities and integrate them into coherent, testable solutions.

From the formulation of hypotheses to the design of experiments and the interpretation of data, creative thinking drives scientific advancement by fostering flexibility, intuition, and the reconfiguration of established paradigms. Moreover, interdisciplinary studies highlight that creativity in science is both an individual and a collective endeavour—emerging through collaboration, technological mediation, and the continuous negotiation between imagination and empirical rigor. Thus, in the context of modern science, creativity represents not merely the generation of novelty but the construction of meaning and the expansion of human understanding.

"Creativity is a paradox..." In terms of modern science, creativity can be examined from multiple perspectives:

- behaviour and social psychology,
- psychometrics,
- cognitive science,
- artificial intelligence,
- philosophy,
- history,
- economics,
- design,
- business and management, etc.

Figure 2: (left to right) L. Vygotsky, F. Barron, A. Maslow, T. Amabile, P. Romer and J.P. Guilford

Vygotsky emphasises the significance of social interactions in development, as well as the roles of play and language in learning and developing creative skills. [1]

Frank Barron (1922-2002), a pioneer in creativity psychology, highlights that Creative people are usually curious. They are characterised by a high degree of thirst for knowledge, autonomy and self-motivation, self-confidence, and emotional stability. They are nonconforming person with a wide range of interests, responsiveness, abstract thinking, and intellectual activity. **Abraham H. Maslow** (1908-1970), American psychologist, inventor of the Maslow Pyramid, considers creativity to be a facet of self-actualisation. The creative person feels a strong inner urge to develop their creative personality.

Joy Paul Guilford (1897-1987), American psychologist, is most famous for his psychometric research on human intelligence. In his still-popular theory, he emphasises that creativity is not a single ability but a set of cognitive skills. His model distinguished between convergent thinking (arriving at a single correct solution) and divergent thinking (generating multiple possible solutions), where divergent thinking was identified as the foundation of creativity. He characterised the nature of the intellect by describing divergent abilities, which can be summarised in these 4 categories:

1) **Fluency:** The spiritual lightness, rapidity, fertility and facility; ability to generate many ideas.
2) **Variety and Redefinition**: Cognitive flexibility and adaptability in generating, reorganising, and evaluating ideas.
3) **Novelty:** The unexpected and unusual preference, the associative capacity indicators; novelty
4) **Problem Sensitivity and Elaboration:** Ability to detect and correct flaws, with a preference for detailed analysis and refinement of ideas.

Other researchers, such as **Theresa Amabile**, have found that innovation starts with a creative idea. *"The creativity of the individuals and the group is a starting point for the innovation. The first one is necessary, but not a sufficient condition for the second"* [2]. A 2018 Nobel Prize winner, **Paul Romer,** sees creativity as a producer of capital. Creativity involves reassembling existing elements with new technologies to develop innovative products. As a result, there is economic growth. Paul Romer's theory posits that creativity, defined as the rearrangement of existing elements into new products and processes facilitated by new technologies, drives economic growth [3].

2.3 Creative Thinking

Creative thinking is the process of generating new, original, and innovative ideas by looking at problems from a fresh perspective. It involves moving beyond conventional thought patterns to find unique solutions, solve challenges in unconventional ways, and adapt to new situations. This skill is not limited to artistic fields and is applicable in areas such as problem-solving, innovation, and decision-making across various professions. **Key aspects of creative thinking are:**

- **New perspectives:** To view the situation from a different perspective, uncovering new possibilities.
- **Originality:** Novel and surprising conclusions or new ways of doing things.
- **Problem-solving:** Presenting unique solutions to problems, both common and complex.
- **Innovation:** Development of new ideas and systems that can increase productivity.
- **Open-mindedness:** Curiosity, asking questions, exploration and taking risks with new ideas.
- **Connecting ideas:** Finding new relationships between existing objects, symbols, or ideas.

2.4 Types of Creative Thinking

Five common types of Creative Thinking include (Fig. 3):

a) Divergent Thinking refers to the cognitive process of generating multiple, diverse ideas or potential solutions in response to a given problem or stimulus. It facilitates open-ended exploration and postpones judgment, allowing for the free flow of associations and unconventional possibilities. The approach is characteristic of brainstorming sessions, where the initial objective is to maximise the number of ideas before evaluation takes place [4].

b) Convergent Thinking involves systematically narrowing down numerous alternatives to identify the most effective, logical, or feasible solution. It typically follows a divergent phase, serving as a process of analysis, synthesis, and refinement. Through critical assessment and comparison, convergent thinking ensures that selected ideas are coherent, practical, and applicable within a specific context [5] [6].

c) Lateral Thinking involves addressing problems through indirect, creative, and non-linear methods that challenge conventional patterns of reasoning. It encourages individuals to reframe problems, explore unexpected connections, and consider seemingly unrelated concepts to arrive at novel insights. This form of thinking disrupts habitual cognitive pathways, fostering innovation and originality in problem-solving [7] [8].

d) Abstract Thinking refers to the ability to engage with concepts and ideas that are detached from immediate physical or sensory experiences. It enables the comprehension of complex, symbolic, or theoretical constructs, and plays a crucial role in disciplines such as mathematics, philosophy, and the sciences. Through abstraction, individuals can manipulate ideas at a conceptual level, form hypotheses, and construct theoretical models that transcend empirical observation [9] [1].

e) Aesthetic Thinking is a mode of creative cognition that focuses on the perception, appreciation, and creation of beauty, harmony, and emotional expression. It is integral to artistic and design practices, where form, composition, and sensory experience are central to the creation of meaning. This form of thinking involves sensitivity to visual, tactile, and auditory qualities, as well as to the affective and experiential dimensions that influence audience perception and engagement [10] [11] [12].

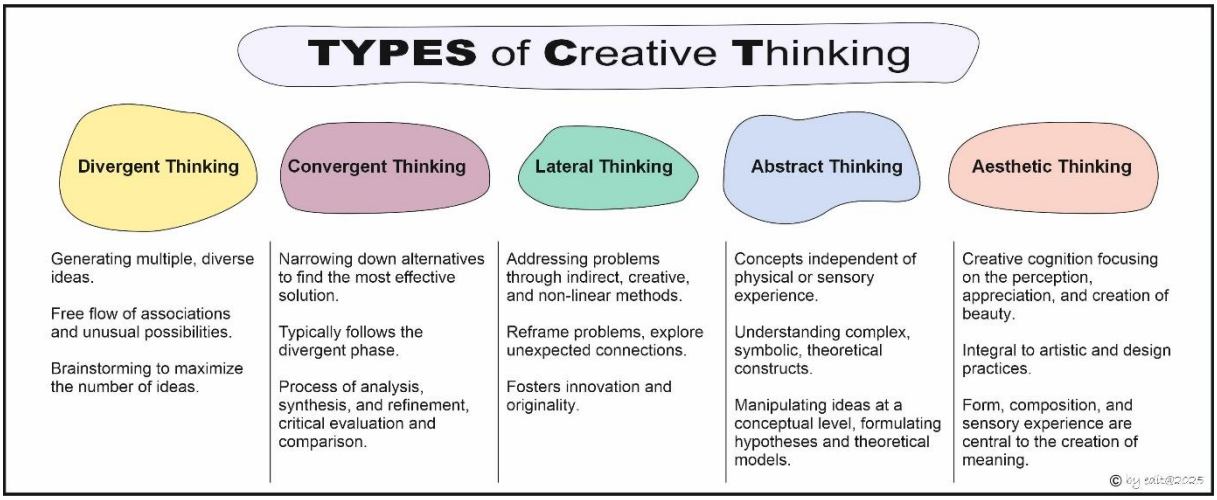

Figure 3: Types of Creative Thinking

3. THE MEANING OF CREATIVITY AND INNOVATION

Creativity is a mental activity that involves implementing new ideas and concepts, as well as creating new associations between existing ideas or concepts, or forming new ideas based on these existing ones. In the scientific approach, creative thought (often described as divergent thought) features novelty and conformity. The creative process involves combining the existing elements with a new approach and incorporating the previously hidden attributes. By the standard definition, creativity is a process that results in an original and valuable creative product. Thus, creativity can be considered an activity in which something new is created. Often confused with the term innovation, **creativity is considered a process of generating new ideas, while innovation is the act of implementing those ideas to create value and solve a problem.** (Fig. 4)

Figure 4: Thomas Heatherwick: The Friction Table (Adjustable table) – 2021 edition

3.1 Design as a Human Act

Creativity can also be considered as the implementation of "unexpected coexistence." **Christopher Wolfgang Alexander** (1936-), a highly influential architect and design theorist, says:

"Design is the generation of a form, creating new fitness between form and environment. (...) Creativity emerges when we discover the new within a structure that is already latent within the present. It is our respect for what is that leads us to the most beautiful discoveries".

To create a new product, we need to have some knowledge, but we must also forget this knowledge to realise the novel, unexpected relationships between things.

Why is it challenging to design? By Alexander, because *"If you change something, everything changes."* There are many types of connections between design and performance variables. (Fig. 5)

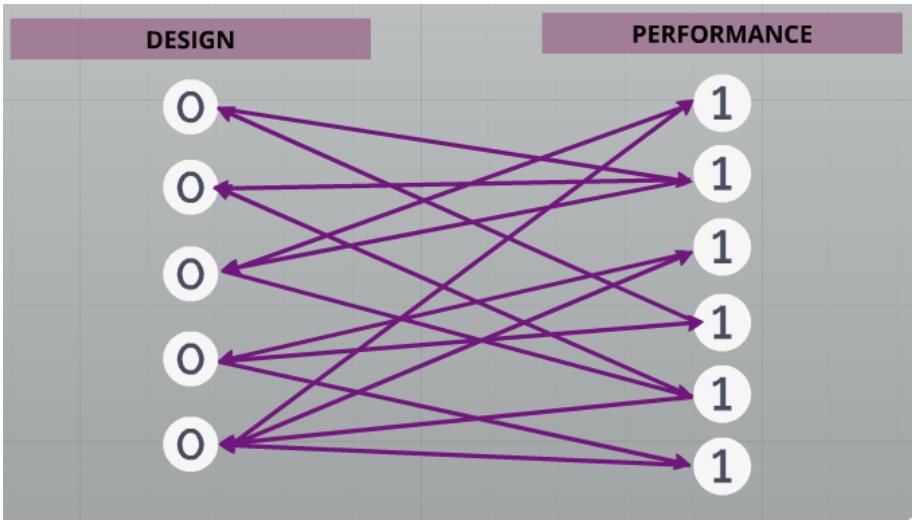

Figure 5: Design and performance variables

3.2 The Process of Creative Cognition – The Creative Idea

The process of creative cognition is somewhat unconscious and characterised by a high degree of adaptation. The creative process is a mental process based on the interaction between analysis and imagination, characterised by consciousness, passion and commitment.

Cristopher Alexander states that any reasonable person who has researched a design problem will identify similar variables. Once the process is objective, similar conclusions will be drawn.

Cognitive and Perceptual Mechanisms

Contemporary research conceptualises cognitive functions as hierarchically organised processes within the brain. At the top of this hierarchy are the cerebral cortex and, within it, the prefrontal cortex—regions located in the frontal lobes that govern complex cognitive operations such as perception, decision-making, and memory. These areas also contain the nuclei of *mirror neurons*, which play a role in imitation, empathy, and social learning. Of particular relevance is the orbitofrontal cortex, situated just behind the eyebrows, which is critically involved in the cognitive evaluation and regulation of decision-making processes. The hypothalamus, along with other neural structures, plays a crucial role in memory

formation and regulation. Emotional processing, however, is primarily mediated by the left and right amygdalae, which integrate memory, emotional response, and decision-making. The left amygdala is associated with the brain's reward system, supporting positive emotions such as joy, euphoria, and pleasure, as well as operative cognition, associative learning, and short-term memory. In contrast, the right amygdala is linked to negative affective states and declarative (long-term) memory. The refinement of these interconnected skills is fundamental to adaptive cognition and social behaviour. (Fig. 6)

Figure 6: Freehand Drawing I - 2021_22_I (Classwork): Studying and Memorising the Features

Perceptual constancies represent another crucial aspect of cognitive processing. **Size constancy** allows the perception of an object's size to remain stable despite variations in distance. **Shape constancy**, similarly, ensures that perceived form remains consistent when viewed from different angles. **Colour constancy** reflects the brain's capacity to maintain stable colour perception across changes in illumination—an outcome of complex unconscious computations within the central nervous system. **Lightness constancy** preserves the perception of an object's brightness under varying lighting conditions. **Distance constancy** governs the perceived relationship between apparent and physical distance, while **location constancy** maintains spatial stability between observer and object. Despite retinal changes due to movement or parallax, stationary objects are perceived as fixed in space, demonstrating the brain's remarkable ability to achieve perceptual coherence amid dynamic sensory input.

3.3 Visual Perception and Cognitive Processing in Creative Practice

Vision constitutes the dominant channel of human cognition: approximately seventy percent of all knowledge is visually derived. The visual system—comprising the eye, optic nerve, lateral geniculate nucleus (LGN) within the thalamus, and the visual cortex—is the most extensive and complex neural network in the brain. This system processes vast amounts of information to construct a coherent visual experience. Yet perception is not a simple act of recording reality; it is a sophisticated interpretive

process shaped by the perceiver's expectations, prior experiences, and the contextual information contained within sensory stimuli. (Fig. 7)

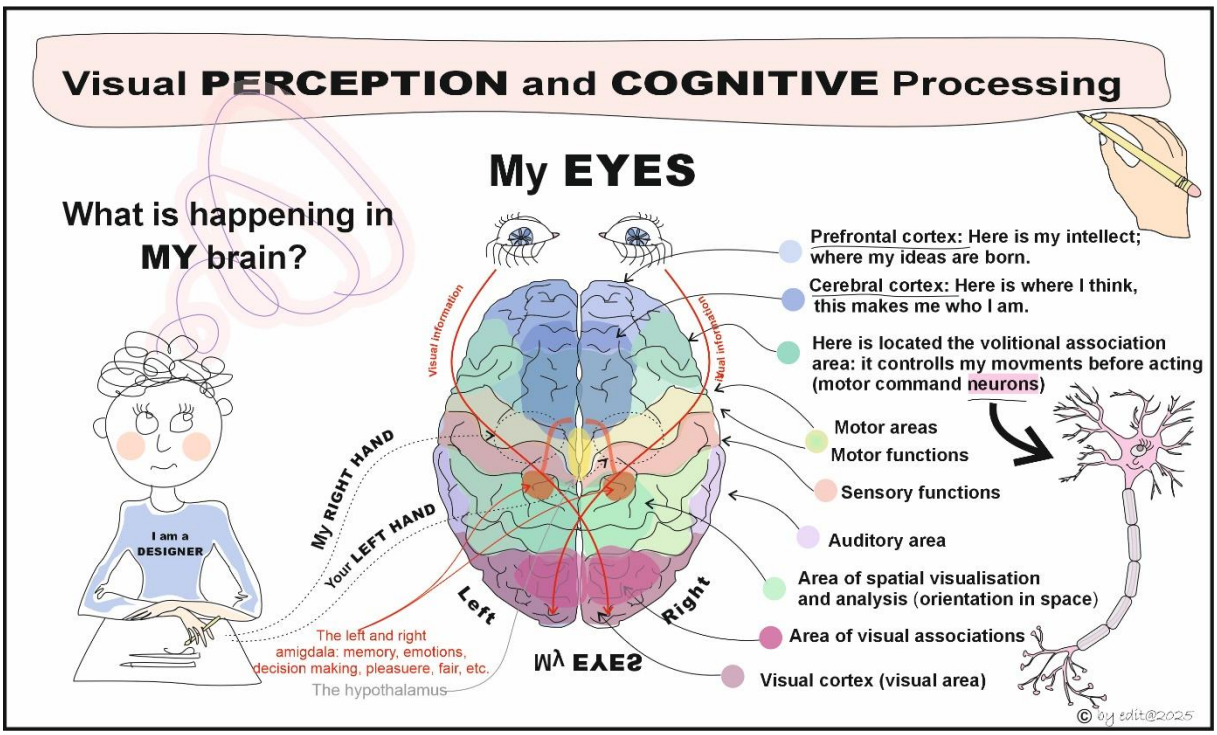

Figure 7. Visual perception and cognitive processing

Two complementary theories provide a framework for understanding how visual information is processed and interpreted.

Top-Down Processing: According to Richard Gregory's (1970) theory of *top-down processing*, perception functions as a hypothesis-driven act—an interpretive "best guess" derived from the brain's existing knowledge and conceptual frameworks. Rather than passively registering external stimuli, the brain actively constructs perceptual meaning by drawing on memory, experience, and learned associations. This process, however, is prone to perceptual biases and illusions, which Gregory viewed not as flaws but as evidence of the brain's creative engagement with the world. From a design-theoretical perspective, the top-down approach parallels *stepwise design*: a method based on decomposition and abstraction. Complex systems are divided into smaller subsystems or elemental components, allowing designers to work from conceptual understanding toward tangible form. In this sense, "errors" of perception—misreadings, distortions, or unexpected interpretations—can become generative sources of creativity, stimulating imaginative reconfiguration and innovation.

Bottom-Up Processing: In contrast, J. J. Gibson's (1966) theory of *bottom-up processing* emphasises data-driven perception. Here, information flows from sensory input ("the bottom") to higher cognitive interpretation ("the top"). The perceptual system, in this model, relies directly on the available sensory data to construct visual meaning—an approach often summarised as *"What you see is what you get."* Within design theory, the bottom-up model corresponds to an *information-centred* or *compositional* process: perception begins with discrete details and progressively integrates them into coherent structures. Designers applying this approach often rely on observation, analysis, and iterative synthesis, building meaning and form through the accumulation and organisation of empirical data. Thus, understanding visual perception not only enriches cognitive science but also deepens insight into the

epistemology of design. Creativity, seen through this lens, emerges as a neurocognitive dialogue between expectation and experience, between what is imagined and what is seen.

The process of creative cognition

Where does the creativity come from? What happens in the brain? Fantasy, like ideology, is based upon subjective, egoistic ideals of unity, self-sufficiency, and control. Creativity exists in the imagination: it is a subconscious, uncontrollable and unmanageable process. A kind of 'daydreaming': activity of a very active brain, which is manifested in communication between the frontal and back of the brain. The communication is intensive, and fully 'private'. The "errors" of perception (inability to focus), cognition (mixture of the taught), and apperception, the process of understanding by which newly observed qualities of an object are related to experience, result in the diverse ideas, upon which the artistic products (artworks) are born. (Fig. 8)

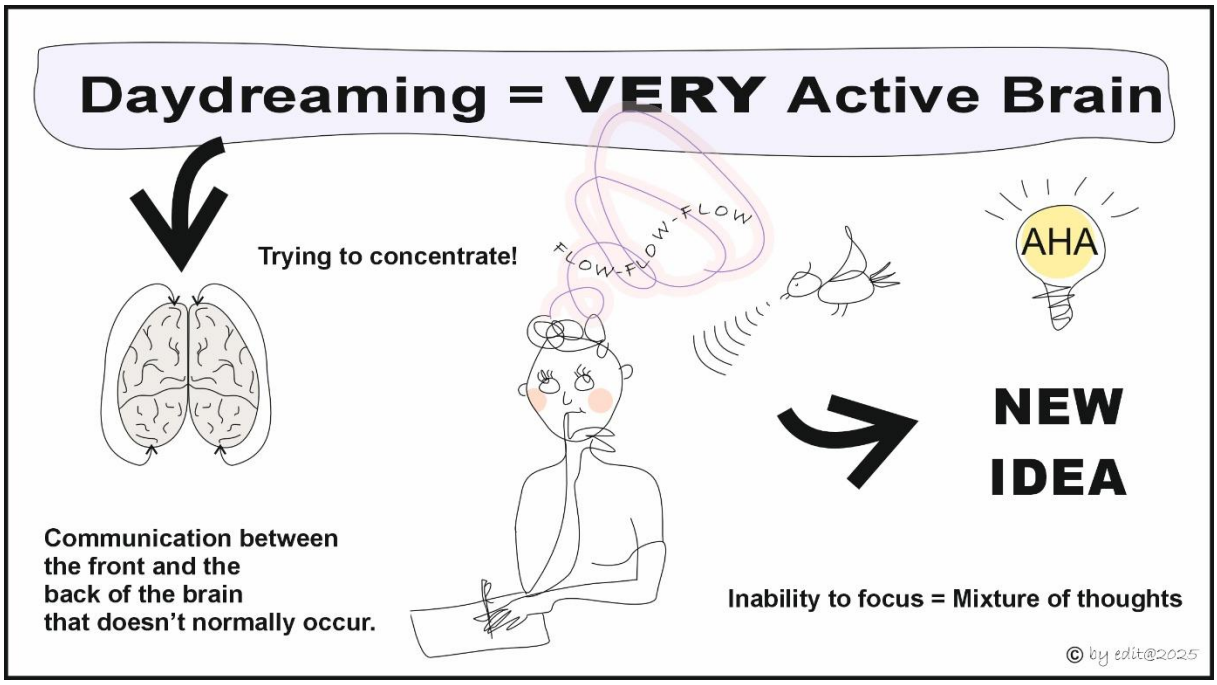

Figure 8: The process of the Creative Imagination

As a unique human activity, fantasy is based upon subjective ideals of unity, self-sufficiency, and control. Focusing on the stage of apperception raises several questions: *How is the cognitive process influenced by visual aspects? What is the physiological pathway that ensures the connection between the vision (eye) and the hand-driven drawing tool? What appears on the paper form of graphite, ink, coal, or colour, as a manifestation of the pure idea?*

The content of an artwork and the method of its representation are a display and a reflection of the aesthetics of the age and the society in which it is created. Art, as a form of interpretation of existence, does not exclusively mean artistic creative activities, but any others that result in a material or spiritual product. These terms seem to be inseparably linked, since thought became visible just in a physically perceptible-visible, audible or tactile form.

4. ART AND THE BRAIN

Art is considered to be a subjective field of human activities that reflects one's experience, knowledge, preference, and emotions. Balthasar Gracian (1601-1658), Spanish-born Jesuit priest, says: *"Art is the completion of nature, as it were a second Creator..."* As an interpretation of existence, art does not exclusively mean artistic creative activities, but any others that result in a material or spiritual product. These terms seem to be inseparably linked, since thought became visible just in a physically perceptible-visible, audible or tactile form. However, *whose competence is to identify what effect flows as an invisible substance between the artwork and the host made up?* [13]

4.1 Ramachandran's Neuroaesthetic Theory

The relationship between art and the brain has long intrigued both scientists and philosophers. In recent decades, the emerging field of **neuroaesthetics** has sought to explain aesthetic experience through the lens of neuroscience, investigating how the brain perceives, interprets, and responds to artistic stimuli. Neuroaesthetics is an interdisciplinary field combining neuroscience, psychology, and aesthetics to explore the biological foundations of artistic perception and creativity. It investigates why certain visual or auditory patterns are universally appealing, and how the brain encodes notions of beauty, harmony, and emotional expression. For instance, understanding how the brain responds to form, colour, and rhythm can inform therapeutic environments, enhance emotional well-being, and guide aesthetic decision-making in product and fashion design. Linking neural processing to aesthetic experience demonstrates that creativity and perception are deeply intertwined at the biological level. Art, in this sense, operates not merely as cultural expression but as a form of cognitive communication—one that speaks directly to the architecture of the human brain.

Among the leading figures in this discipline is **Vilayanur S. Ramachandran**, whose work has been instrumental in linking visual perception, neural activity, and aesthetic pleasure. Ramachandran's broader research explores the brain's remarkable ability to construct and sustain perceptual realities—a capacity that is also fundamental to the art experience. Ramachandran's approach to art and perception is grounded in the idea that artistic practices exploit the brain's innate mechanisms of visual and emotional processing. According to Ramachandran, art functions through **exaggeration**—a process that intensifies perceptual signals and elicits stronger neural responses. Certain exaggerated features can *hyperactivate* specific neurons, producing an amplified perceptual and emotional effect. In art, similar exaggerations—whether in form, colour, or expression—provoke heightened aesthetic engagement. Ramachandran suggests that artistic experience capitalises on fundamental principles of **visual processing**, such as grouping, contrast, symmetry, and isolation of key features. These mechanisms are part of the brain's natural strategy for simplifying complex sensory input and identifying meaningful patterns. Artworks that effectively manipulate these principles successfully activate neural pathways associated with pleasure, recognition, and emotional resonance.

4.1.1 The Eight Laws of Aesthetic Experience

Together with William Hirstein, Ramachandran (1999) articulated the **"Eight Laws of Aesthetic Experience," a framework that describes** how visual art stimulates and satisfies the perceptual system. These laws include principles such as *peak shift*, *grouping*, *contrast*, *isolation*, and *perceptual problem-solving*, all of which govern how the brain extracts and interprets visual meaning. By engaging these neural mechanisms, art evokes aesthetic pleasure through the dynamic interaction between expectation and perception.

4.1. 2 Mirror Neurons and Empathy in Art

A further component of Ramachandran's theory concerns **mirror neurons**—cells that activate both when an individual performs an action and when they observe another performing the same action. These neurons are believed to play a crucial role in empathy and emotional contagion. Through this mechanism, art becomes a shared emotional experience, bridging the gap between artist and audience at the neural level. (Fig. 9)

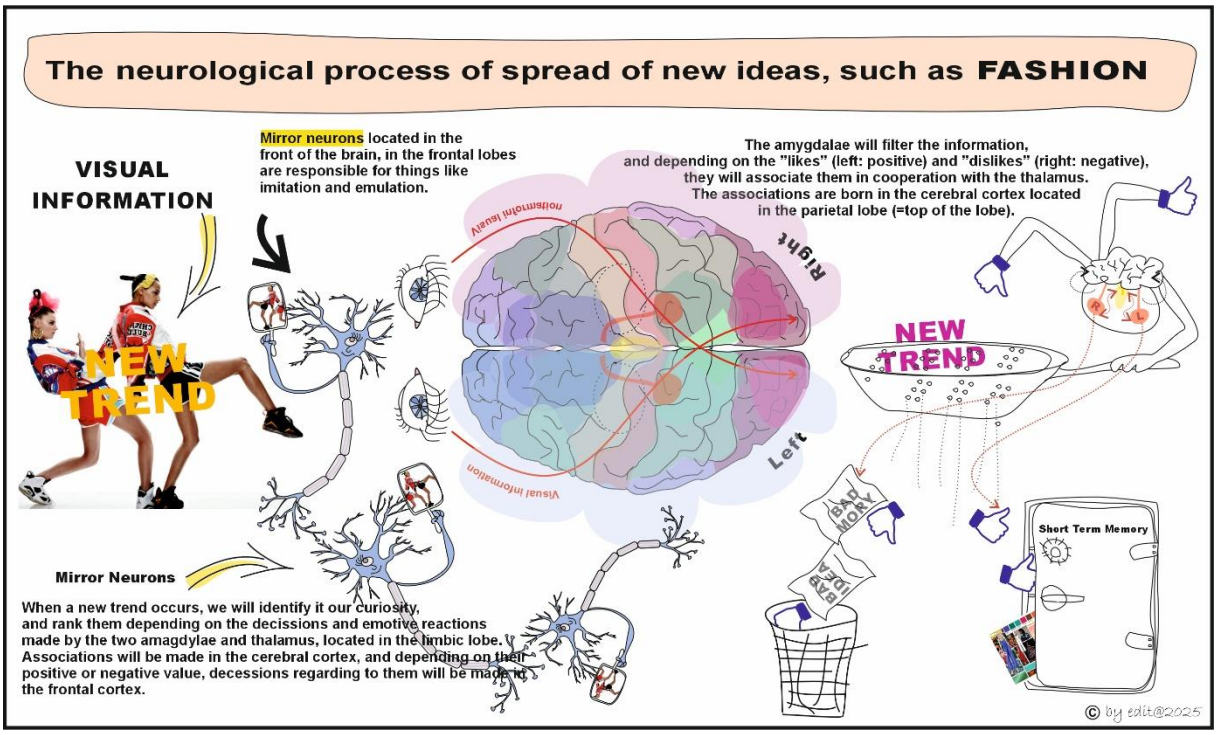

Figure 9: The neurological process of the spread of new ideas, such as fashion

5. DISCUSSION: THE FLOW AND THE AHA EFFECTS

An artist must be completely *in tune* with the art object to enrich its creation. [14] As the piece of art progresses during the creative process, so does the artist. In positive psychology, this mental state is known as FLOW. It is a mental state in which *"a person performing an activity is fully immersed in a feeling of energised focus, full involvement, and enjoyment in the process of the activity. In essence, flow is characterised by complete absorption in what one does."* The concept is highlighted by the name of Mihály Csíkszentmihályi [12], and it has been widely referenced across various fields. It can be considered the main mover engine of artistic (designer) activities in the design process: this mood is the 'tool' that flows through the pathways managing the different brain regions during the CAL [13] process.

The effect, which is known as the sudden insight, or the AHA! effect, is characterised by the sudden appearance of a solution to a problem. This occurs in 4 of the insights:

1) **Suddenness:** the experience is surprising and immediate.
2) **Ease:** matched to the difficulties experienced before, the solution proceeds smoothly and easily.
3) **Positive affect:** insights produce a confident experience.
4) **The feeling of being right:** problem solvers judge the solution as being true and have confidence in this judgment.

The AHA! effect can be compared to the **bottom-up processing approach**, as problem-solving is stimulated by an insight. This insight, as a data-driven process, is motivated by a positive cognitive experience of problem-solving, which is often present in the Computer-Aided Design. (Fig. 10)

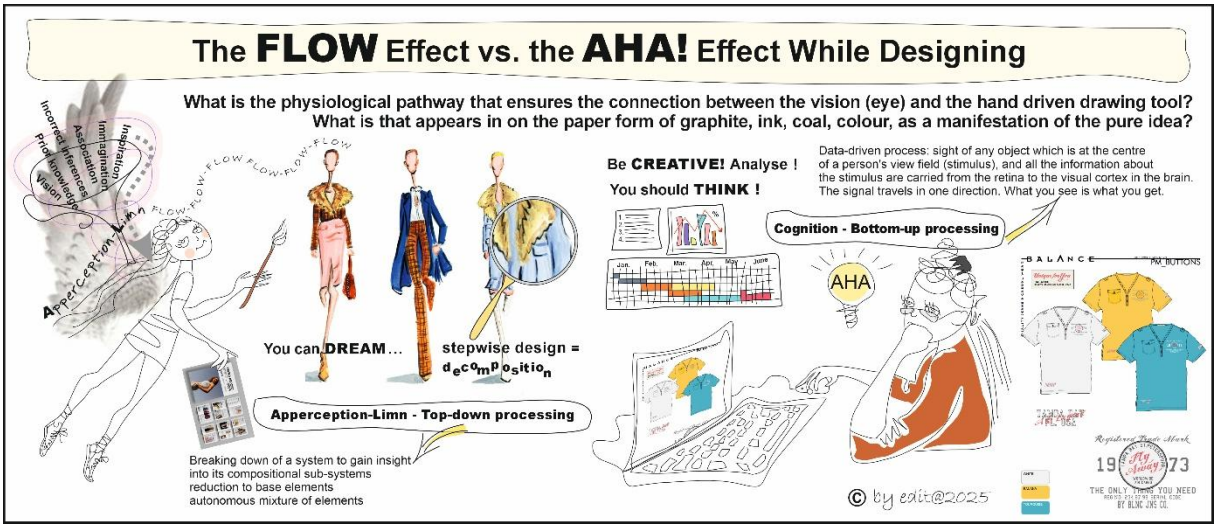

Figure 10: The FLOW vs the AHA! effects while designing

Artists and designers use specific tools while designing. Digital, and especially recently widely spread AI applications, may be usefully used in 'operative' type work, but the process of designing (creative thinking and creation) is too sensitive and irrational to be taught. Thus, FLOW can hardly be accompanied by digital tools, because their management (drawing of different objects, managing their preferences, shaping them, colouring, applying different patterns to them, combining objects to create an entire silhouette, etc.) is more cognitive in its nature. Only manual work can convey the free stream of ideas. The FLOW effect can be considered a top-down processing process, where prior knowledge related to a stimulus often reveals unexpected associations, incorrect inferences, and a decrease in attention, often led by 'errors' of perception. (Fig. 10) In manual drawing, mistakes can be considered a source of fresh ideas and renewed concepts for cuts or details.

In creative practice—particularly in fashion design—both top-down and bottom-up processes interact dynamically. The imaginative reconstruction of experience (top-down) and the analytic organisation of sensory input (bottom-up) together underpin the balance between intuition and structure that defines innovative visual design. The *top-down* mechanism supports imagination, conceptualisation, and abstract reasoning, while the *bottom-up* mechanism grounds design decisions in sensory experience and empirical observation. Effective creativity arises from the continuous interplay between these modes—between intuition and analysis, vision and perception, idea and material. Manual sketching supports cognitive states associated with spontaneous ideation, such as *insight* and *flow*, by enabling direct, unmediated interaction between perception and motor expression. In contrast, digital tools—while efficient and systematic—tend to constrain these processes through their predefined interfaces and algorithmic structures. Such an understanding contributes to the broader discourse on design cognition, offering implications for contemporary design pedagogy, the integration of creative technology, and interdisciplinary research that links art, neuroscience, and artificial intelligence. Ultimately, it redefines creativity as a hybrid cognitive phenomenon—one that evolves through the reciprocal relationship between human imagination, neural mechanisms, and technological mediation.

6. CONCLUSION

Contemporary design practice has become increasingly shaped by digital acceleration and algorithmic assistance. Designers now rely heavily on CAD systems, online mood-board platforms, and AI-based applications that generate patterns, colour harmonies, or even entire collections. These tools enable unprecedented efficiency and rapid prototyping but also encourage a surface-level, "instant creativity," where ideation often precedes reflection. The deep, iterative processes that once defined design thinking risk being replaced by automated visual synthesis and data-driven prediction.

Professional expectations mirror this transformation. Industry job profiles emphasise digital proficiency—trend forecasting, material research, and mastery of programs such as Adobe Illustrator, Photoshop, CLO3D, and emerging AI tools like Midjourney or Adobe Firefly—while manual drawing skills are rarely valued. This shift reflects both technological progress and the gradual loss of direct, tactile engagement with form and gesture. The human hand, once central to visual reasoning, has become secondary to algorithmic optimisation.

As AI-assisted creativity expands, the visual language of design risks becoming homogenised: products increasingly reflect the logic of their tools—efficient, coherent, but often predictable. The compression of development cycles under fast-fashion and AI-driven market analytics has further limited time for conceptual incubation and artistic differentiation. Yet manual artwork continues to embody the essence of creative cognition. It captures the immediacy of the idea, translating thought into form through sensory and emotional experience. Neuroscientific evidence suggests that manual and digital design processes activate distinct neural pathways and creative states—most notably the Aha! moment of insight and the Flow state of deep immersion. While AI can simulate aesthetic outcomes, it cannot replicate the embodied intuition or affective resonance inherent in human creation.

Recognising these neurocognitive distinctions underscores that creativity cannot be reduced to computational speed or technological fluency. True design innovation emerges from the interplay between intuition and analysis, sensory perception and conceptual thought, human emotion and digital intelligence. In this evolving landscape, the challenge for contemporary designers lies not in rejecting AI, but in integrating it meaningfully, balancing algorithmic assistance with the irreplaceable depth of human imagination and artistic agency.

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SOIL DRYING AND HEAT–MOISTURE DYNAMICS UNDER SIMULATED SOLAR RADIATION USING INFRARED ENERGY

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Abstract:
The soil's water and energy balance play a fundamental role in regulating the hydrological cycle and near-surface climatic conditions. Previous studies have demonstrated that coupled heat and moisture transport processes strongly affect soil evaporation and temperature dynamics. Building on this foundation, our study investigated the drying behaviour of soil columns exposed to infrared radiation simulating solar energy, with particular focus on heat and mass transfer at the soil-air interface.
Laboratory experiments were performed on soil samples of different initial moisture conditions, including natural, water-saturated, and frozen states. Each experiment involved 12 hours of infrared exposure followed by 12 hours without irradiation, forming a 48-hour day–night cycle. Temperature and moisture content were measured at three depths, while surface temperature patterns and airflow dynamics were monitored with an infrared camera.
Results showed pronounced temperature fluctuations and moisture loss in the upper soil layers. Infrared imagery clearly revealed convective airflows forming above the soil columns during heating.
The experimental setup proved effective for analysing coupled heat and moisture transport. These findings enhance understanding of soil evaporation mechanisms and contribute to the development of sustainable soil–water management strategies.

Keywords: Convective boundary layer, Environmental sustainability, Heat and mass transport, Infrared-induced soil drying, Soil–atmosphere interactions

1. INTRODUCTION

The exchange of heat and mass between the soil surface and the overlying atmosphere represents one of the most dynamic components of the land–atmosphere system. The soil–atmosphere interface controls the partitioning of net radiation among sensible heat flux, latent heat flux, and ground heat flux, thereby regulating near-surface temperature gradients and boundary-layer development [1-3]. Variations in soil thermal properties, including volumetric heat capacity and thermal conductivity, strongly influence the temporal evolution of soil temperature profiles and the diurnal propagation of thermal waves [4-6]. Recent studies have emphasised that soil temperature and soil heat flux dynamics play an increasingly important role in climate feedback processes. Global analyses reveal systematic patterns in which soil temperature may exceed air temperature under certain radiative and moisture conditions, thereby altering surface energy partitioning and near-surface atmospheric stability [7]. Similarly, multi-scale investigations demonstrate that soil thermal dynamics significantly influence the diurnal development of the atmospheric boundary layer [8-9]. Advances in observational and modelling approaches have further improved the representation of soil heat flux in land surface schemes, highlighting the importance of accurate subsurface measurements [10-12]. Convective processes emerging above heated surfaces are governed by temperature gradients and buoyancy forces, representing classical non-equilibrium thermodynamic phenomena [13]. When the Rayleigh number exceeds a critical threshold, organised convective structures may develop, ranging from small-scale cellular convection to turbulent

plumes [14]. In natural environments, surface heating during the day induces unstable stratification in the surface layer, promoting convective transport and vertical mixing [15-16]. Contemporary research demonstrates that land surface thermal heterogeneity substantially modifies convective available potential energy (CAPE) and may influence convective initiation and precipitation patterns [17-18]. Soil moisture gradients have also been shown to enhance mesoscale convection by modulating sensible and latent heat fluxes [19-20]. Soil moisture plays a central role in regulating the coupling strength between the land surface and the atmosphere. It affects evaporative fluxes, modifies the partitioning of available energy, and influences boundary layer growth [21-22]. Modern climate feedback analyses confirm that soil moisture–precipitation interactions constitute a key uncertainty in regional climate projections [23]. Remote sensing and in situ observational studies further demonstrate that variations in soil texture and moisture distribution significantly alter surface energy exchange processes [24-26]. The diurnal radiative cycle introduces periodic thermal forcing at the soil surface, generating time-dependent temperature gradients that propagate downward into the soil and upward into the atmospheric surface layer. The resulting cyclic heating and cooling strongly influence the stability regime of the near-surface air and modulate convective intensity [27-28]. Numerical investigations indicate that an accurate representation of diurnal soil temperature evolution is crucial for modelling land–atmosphere coupling and boundary-layer dynamics [29-30]. Despite substantial progress in large-scale observational and modelling studies, controlled experimental investigations of soil column systems under well-defined radiative forcing remain limited. Laboratory-scale experiments allow the isolation of key physical mechanisms governing coupled heat and moisture transport, as well as the emergence of convective air motions above the surface. Such controlled systems provide high-resolution vertical profiles of temperature and moisture, enabling quantitative assessment of energy partitioning and transient responses to periodic forcing.

In this study, we investigate bare soil columns subjected to controlled infrared irradiation in a 12 h light / 12 h dark cycle designed to simulate the diurnal solar forcing. Temperature was continuously measured in the air above the soil surface, at the surface itself, and within the soil at approximately 10 cm vertical intervals. Simultaneously, volumetric soil moisture content was monitored at corresponding depths using sensor-based measurements. This experimental setup enables the coupled analysis of subsurface thermal propagation, moisture redistribution, and near-surface atmospheric response under periodic radiative forcing. By integrating detailed vertical measurements with contemporary land–atmosphere interaction theory, our objective was to characterise the transient evolution of temperature gradients, identifying conditions conducive to convective instability, and quantify the relationship between soil drying dynamics and variability in near-surface air temperature. The results provide insight into microscale energy exchange processes and may contribute to improved parameterisation of soil heat and moisture fluxes in land-surface and boundary-layer models.

2. MATERIALS AND METHODS

2.1. Use of infrared radiation

Infrared radiation is a wavelength range of electromagnetic radiation between 0.78 μm and 1000 μm. Most of the energy from the Sun that reaches the Earth's surface is in the infrared. Infrared radiation can be divided into several ranges. These are the near-infrared (NIR, IR-A, 0.75-1.4 μm), the short-wavelength infrared (SWIR, IR-B, 1.4-3 μm), the mid-wavelength infrared (MWIR, IR-C, 3-8 μm), the far-infrared (FIR, 15-1000 μm) and the long-wavelength infrared (LWIR, IR-C, 8-15 μm). The total radiation reaching the Earth's surface consists of infrared and visible light. Optimally, 45% of the global surface radiation energy, about 450-500 W/m^2, falls in the infrared range, compared to the total of 1120 W/m^2. The wavelength of visible light falls in the range of about 380 nm to 760 nm, which represents the remaining part of the surface radiation, about 50-55%. The infrared wavelength range above 3 μm is largely absorbed by the atmosphere. Infrared energy passes through the air with almost no loss (IR-

A, IR-B). As a result, infrared rays heat up more than 80% of the body itself and less than 20% of the surrounding air. Since the effects of thermal radiation were investigated, the Sun's heating radiation was modelled using an infrared-emitting lamp (Philips Infrared R95E). The lamp's spectral energy has a maximum near 1 µm. As shown in Figure 1, the lamp emits predominantly in the near- and short-wavelength regions, whereas emission above 3 µm is negligible. The 24-hour orbit of the Sun is neglected; the lamp is emitted from a fixed point at a height of 400 mm, perpendicular to the surface of the cylindrical ground columns, from which the deeper layers of the ground are gradually heated.

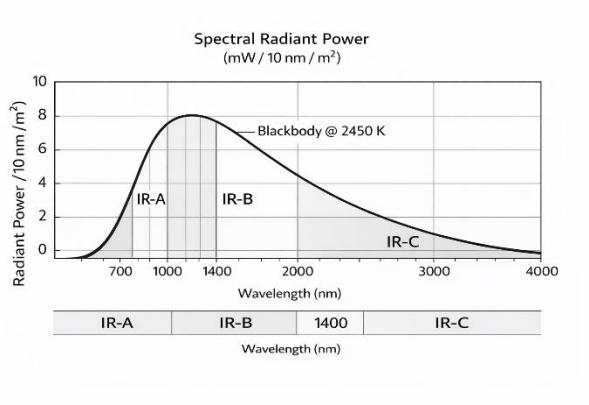

Figure 1: Spectral energy distribution of a 2450 K tungsten infrared lamp calculated from Planck's radiation law. The infrared regions (IR-A, IR-B, IR-C) are indicated according to ISO wavelength classification.

2.2. The soil columns and their saturation with water

A total of 2 quasi-undisturbed soil samples of different textures and physical properties were used in the experiments. The soil sample 1 is a sandy soil from a riverbed, and the soil sample 2 is a meadow soil. During the preparation of the soil samples, a slight degradation of the soil structure was unavoidable; therefore, the samples can be considered quasi-undisturbed. When the plastic pipe, 160 mm in diameter and 200 mm long, was buried in the soil, the structure may have been slightly damaged. At depths of 60, 120, and 180 mm below the soil surface, we made circular openings in each of the three soil columns, with a circular cross-section on each side corresponding to the width of the temperature sensors and soil tensiometers. We removed plastic elements 50 mm wide and 180 mm long from the surfaces of the two plastic columns and insulated them with plastic foil. The vertical temperature changes were subsequently monitored on this free ground surface using the infrared camera. A total of three measurements, each lasting 48 hours, were made with the aforementioned soil columns. The soils were prepared in different ways before the experiment. We present some results from two of our experiments:
First experiment: We started the experiment with soil column 1 in its original moisture state after sampling.
Second experiment: the soil column 2 was pre-saturated with water and then subjected to a 12-hour freeze immediately prior to measurement.
The saturation of the soil columns [32] with water was achieved using the principle of moving vessels to minimise changes in soil structure. We designed a closed water-saturation system in which water flows out of the vessel at a higher level than the soil column through a plastic tube attached to the vessel and to the bottom of the soil column, thereby saturating the porous soil structure. By this method, we also tried to change the soil structure as little as possible. The saturation time is about 24 hours, depending on the soil sample.

2.3. Sensors used for the measurement

Sensors were used to measure the temperature and moisture variations at three depths from the soil column surface, at the soil column surface and at a point laterally above the soil column surface during the 48-hour experiments. Temperature measurements were taken with an infrared camera at 120-second intervals in the airspace above the soil surface (160 x 160 mm^2) and on the soil surface (180 mm). The sensors were located and named as follows: One temperature sensor (TYPE K ZA-9020-FS NiCr-Ni BE NiCr °C) and one tensiometer (Ahlborn Insertion Tensiometer) were placed at a depth of 60 mm, 120 mm and 180 mm from the soil surface (Figure 2). The soil surface temperature was measured with a simple temperature plate sensor. A combined temperature-relative humidity sensor was set up on a stand on the side above the soil surface, at a point not directly exposed to the infrared light, to provide information on the air changes in the experimental enclosure. The temperature and relative humidity values were converted to vapour pressure (e) using the Magnus-Tettens [31] formula and then to absolute humidity values (a, [g/m^3]) using a simple relationship (0.217*e/T). The tensiometer used in the experiments was a plastic tube filled with water and a porous ceramic tip connected to a digital sensor, which is permeable to water but impermeable to air. The ceramic tip of the tensiometer, pre-boiled in distilled water and filled with bubble-free water, was measured at three different depths in the soil. The suction force of the soil solid phase draws water from the soil into the tip. Since no air can enter the closed interior of the tensiometer from outside, the leakage of water creates a vacuum in the interior, the extent of which is recorded by the manometer. The tensiometer actually measures the pressure, which is the 'suction' of the soil moisture, and the sensor tensiometer we use has a range of 0-900 hPa. The vacuum reading on the manometer can be converted to water column length (cm), and the moisture content corresponding to the measured tensiometer reading can be read directly from the soil's pF curve. As the soil dries, tensiometry increases in direct proportion to the continued drying [32].

2.4. Above-ground measurement surface system and infrared camera

In a previous experiment, measuring heat fluxes in the space above the soil surface was problematic because the infrared camera could only measure temperature on solid surfaces and not in air. A measurement surface system was designed to solve this problem (Figure 3). The surface system was formed from strips of paper, and the correct support and spacing were set using Styrofoam elements. The surface system consisted of 16 vertical paper surface slices, the first and third 5-5, the second 6 and 1 more horizontal at the bottom of the first layer. The paper surface slices did not overlap, allowing spatial measurement of temperature above the ground surface. The parallel layers were placed 40 mm apart. As can be seen in Figure 2, the surface system was located within a 160*160 mm^2 area, 180 mm above the ground surface. The elements of the measurement surface system could have disturbed the currents above the surface, but there was no other way to solve the problem. The thermal images were taken with a Dias Infrared System Proview 380L camera at 120-second intervals.

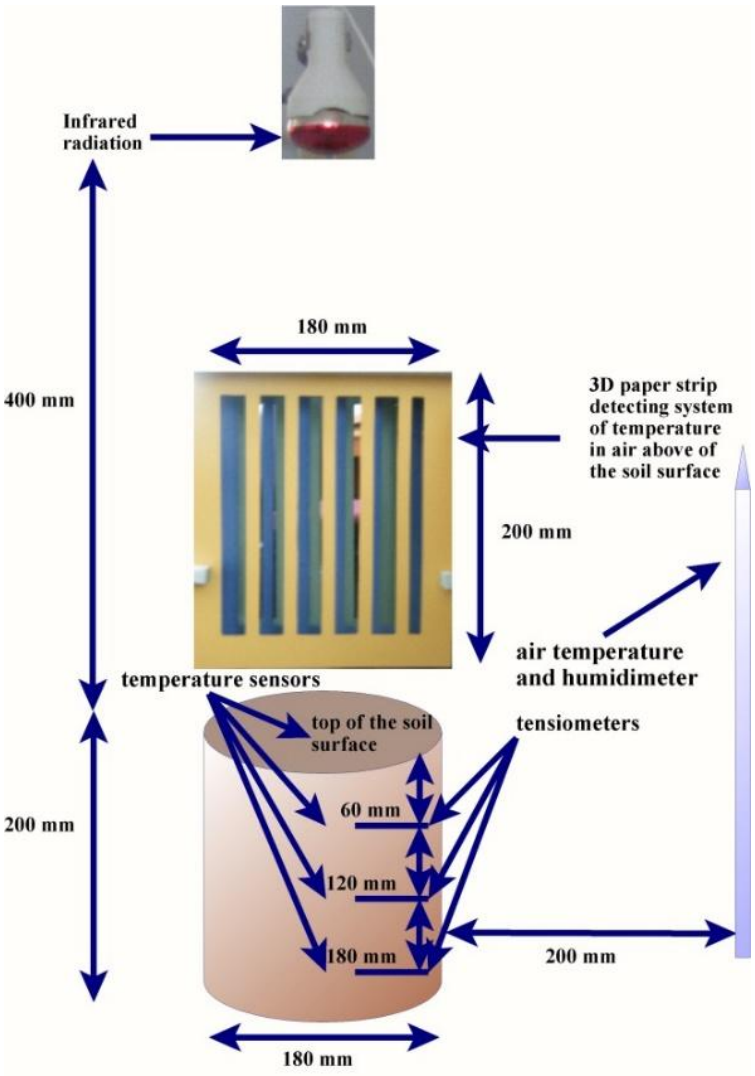

Figure 2: Schematic diagram of the experimental setup

2.4. Computer evaluation program Thermo for the infrared camera

Using a program called Thermo, we set up the lines that coincide with the line elements of the measurement surface system before starting each measurement. The temperature data are obtained from these lines. Before each measurement was started, 16 vertical lines and 1 horizontal line were set on the surface system, and 7 vertical lines were set on the 50 mm wide and 180 mm long free surface of the soil column slate. In accordance with the measurement surface arrangement, we set five measurement lines on the first and third layers, six on the second layer, and one measurement line on the first layer at the bottom, directly above the soil surface, of the same width. The measurement lines set in the Thermo program are shown in Figure 3.

2.5. Presentation of experimental conditions

The measurements were carried out in a styrofoam enclosure (Figure 4b) in order to minimise external disturbances to the drying process and the measurement results. The opening for the infrared lamp was the only one on the insulating cover. The camera, together with the soil column and the surface system,

was located in the enclosure, while the data recorder and computer were kept outside for practical reasons. The complete experimental setup is shown in Figure 4. All sensors (temperature sensors, tensiometers, and combined temperature and humidity sensors) are connected to the data logger (Almemo 2980-9). At the end of the measurements, the data logger's results were converted into Excel spreadsheets using a computer program called AMR (ALMEMO Measurement Reader). The infrared camera was connected directly to the computer, and the temperature data from the measurement line was recorded before being converted into Excel spreadsheets using a program called Thermo. The temperature and moisture content measurements were plotted using Origin Pro 8.5 software to characterise the drying of the soil and the processes that occurred during drying.

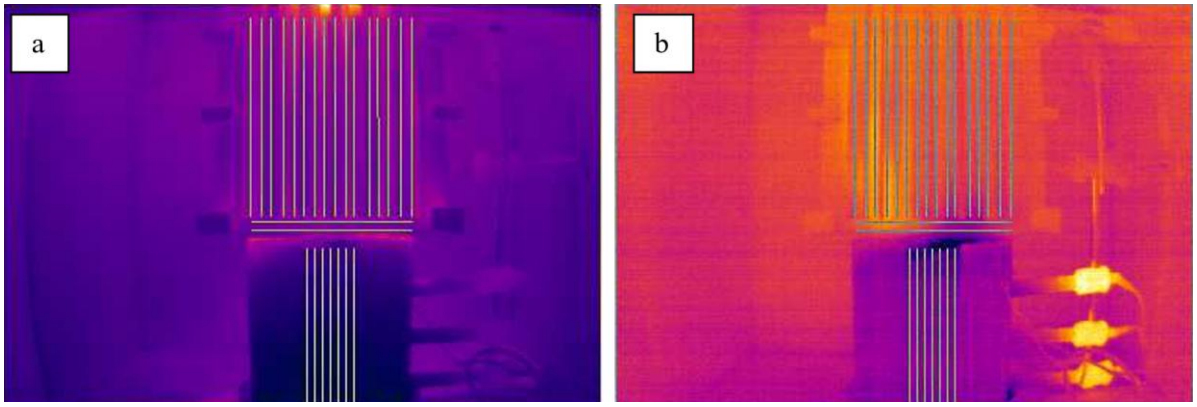

Figure 3: Measurement lines set in the Thermo program (a: illuminated 12-hour period; b: thermal images taken during the unilluminated 12-hour period) for soil column 2.

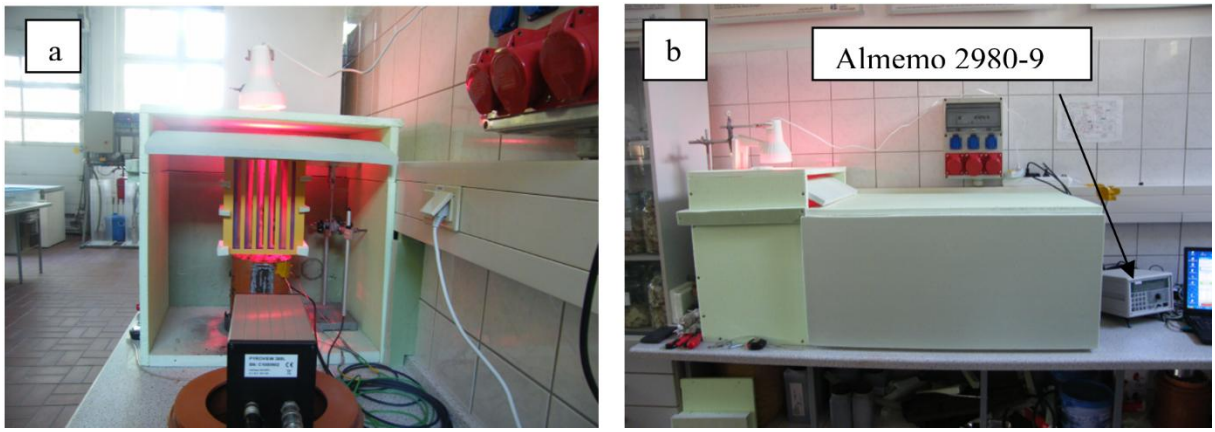

Figure 4: The complete experimental setup (a: without thermal insulation cover, viewed from the thermal camera; b: with thermal insulation cover)

3. RESULTS AND THEIR EVALUATION

When presenting the results, we selected a measurement location from among the strips of paper placed above the soil column and reported it, along with the moisture sensor results.

3.1. Soil column 1, with which we conducted the experiment using the moisture content at the time of sampling

Figure 5 shows the experimental variation in soil moisture conditions and in the moisture content of the air above the soil surface. Changes in soil moisture suction (i.e., tensiometry) are plotted at the three measurement points at depths of 60, 120, and 180 mm from the surface. The current water vapour content, independent of air temperature, provides more accurate information than the relative humidity (f, [%]) about the course of soil water content at the interface, i.e., evaporation through the soil surface, during the experiment. Therefore, the measured values from the combined temperature and relative humidity sensor placed above the soil surface were first converted to vapour pressure using the Magnus-Tettens formula [31] and then to absolute humidity values (a, [g/m^3]) using a simple relationship (0.217*e/T).

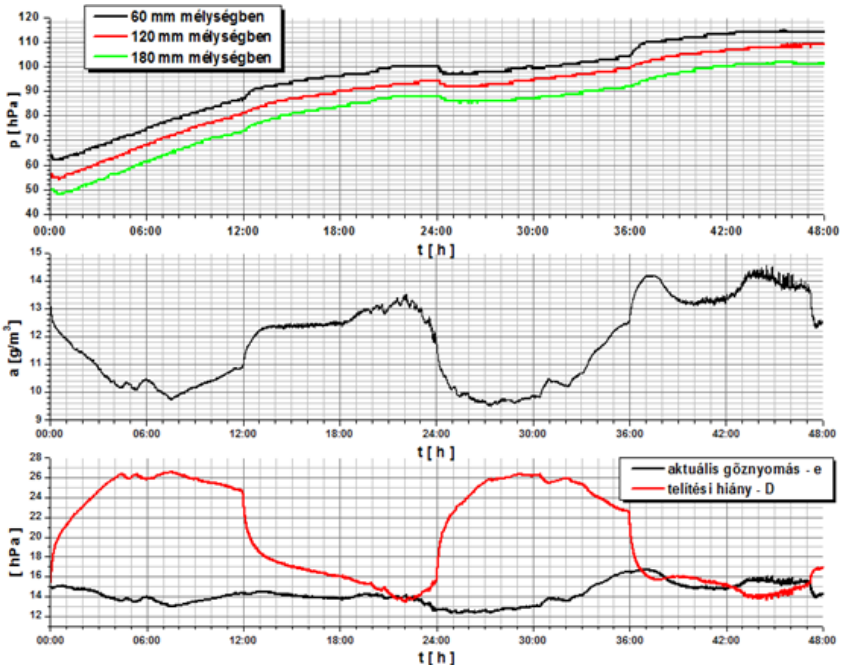

Figure 5: Moisture content changes in the soil and above the soil surface during the experiment conducted with soil column 1

Figure 5 shows that the moisture tensions of the three soil layers are lower at the beginning of the experiment and remain unchanged for about half an hour. Infrared radiation striking the soil surface heats the soil material, and the water content evaporates, so the soil dries continuously during the experiment, increasing the tensiometer reading. From the start of the experiment until 7.5 hours, the moisture content of the air decreases continuously, from an initial level of about 13 g/m^3 to about 9.8 g/m^3, then to 10.8 g/m^3 at 12 hours. Part of the heat gain of the soil material heated by irradiation is used to evaporate the soil's water content at the beginning of the non-illuminated phase. Thus, after 12 hours, the moisture tension values a and, in parallel, the moisture tensor values measured at 3 points in the soil rise steeply, indicating that more evaporation is occurring at the interface, i.e., through the soil surface. The moisture content of the air stabilises at around 12.4 g/m^3 from 13.5 h to 18.5 h, before increasing again to around 13.2 °C by 22.5 h. From 24 hours onward, with the onset of illumination, the air humidity decreases again, reaching around 9.8 g/m^3 by 30.5 hours. The moisture tension increases at 3 measured points on the soil, but with a smaller slope than 12 hours after the start of the experiment. From 30.5 hours onwards, the water vapour content in the air increases steadily, reaching 12.45 g/m^3 at 36 hours. From 36 hours onwards, at the beginning of the non-illuminated period, the a and, in line with this, the

moisture tensor values rise steeply again, with increased evaporation through the soil surface, as was the case during the first non-illuminated period. The moisture content of the air rises to 14.2 g/m^3 at 37.5 h, and then to around 13.2 g/m^3 from 32.5 h to 42 h. Thereafter, the air humidity content increases again up to 14.2 g/m^3 and then decreases continuously until the end of the experiment.

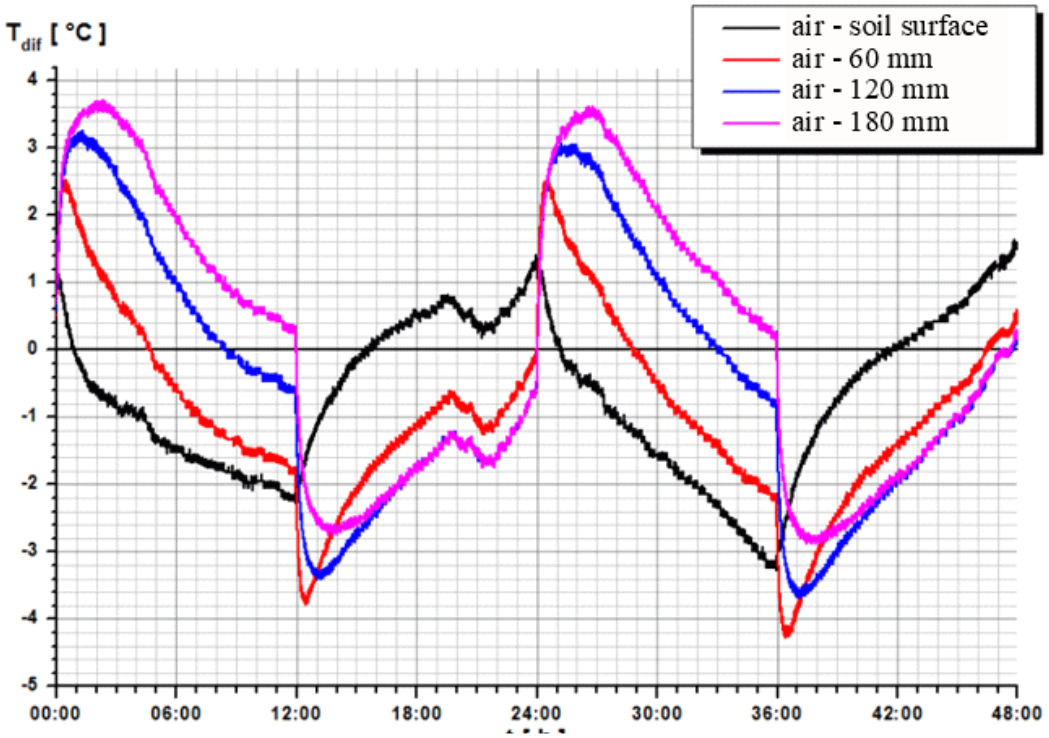

Figure 6: Temperature differences measured between the air and different soil layers

Figure 6 shows the temperature differences between the air and the indicated soil layers. At the start of the experiment, the temperature at all measured soil points was lower than in the air. Infrared rays reaching the soil surface gradually reheat the deeper soil layers due to the soil's thermal conductivity. The soil surface reaches and then exceeds the air temperature after 1 hour, the 60 mm depth after 4.5 hours and the middle level after 8.5 hours. The temperature of the lowest measured point does not reach the air temperature for the first 12 hours. Throughout the period without illumination, the temperatures at the 60 mm, 120 mm, and 180 mm ground points are higher than those in the air. The soil surface cools rapidly, falling below the air temperature after 15.5 hours, as a result of the heat-intensive process of increased evaporation through the soil surface. With the onset of illumination, the air heats up rapidly, the soil follows this process much more slowly, and therefore again the air temperatures are higher than the soil temperatures. Similar trends to those in the first half of the experiment characterise the second half, with the difference that during the last 12 hours of the experiment, without illumination, the temperature at all measured soil points is lower than in the air.

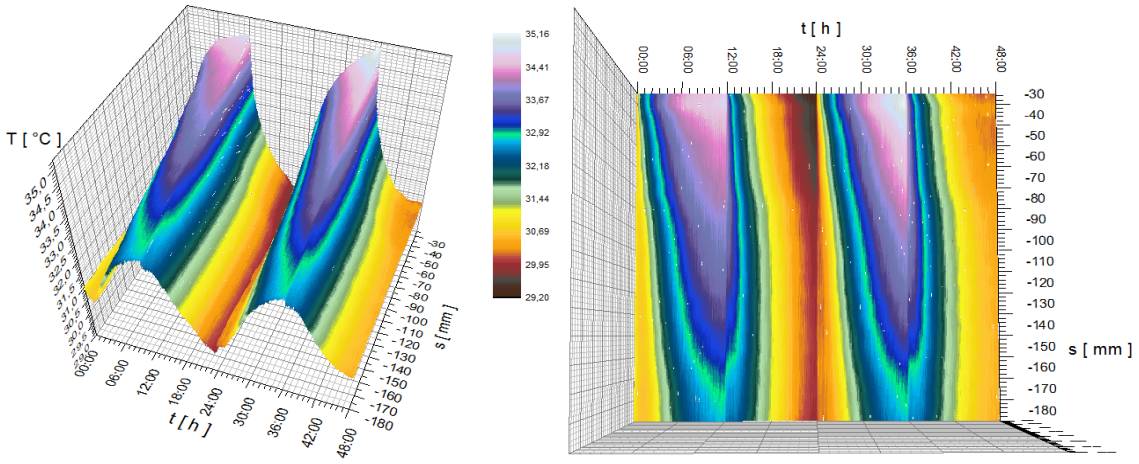

Figure 7: Temperatures measured on the surface of soil column 1 along the vertical measurement line named "Soil L4"

Figure 7 shows the variation in soil temperature, but here plotted continuously with depth from 30 mm to 180 mm below the surface. The measurement line "soil l4", set in the Thermo program for the infrared camera, is drawn vertically on the free soil surface formed on the soil column slate from 30 mm to 180 mm from the surface, with a width of 50 mm. The infrared camera captured thermal images every 2 minutes during the 48-hour experiment. Temperature was plotted as a function of time and distance from the surface. The colour map provides an additional tool for monitoring temperature changes. Overall, temperatures at the surface of the slate are much higher than those within the column along its vertical axis, due to the thin film of air between the soil and the surrounding air in this area, which allows significant heat exchange. At the start of the experiment, temperatures at all measured soil points are nearly identical, around 31 °C. The infrared rays absorbed by the soil surface heat the surface and adjacent layers rapidly, and the soil's thermal conductivity causes the deeper layers' temperatures to rise over time. This change starts at lower levels after 3 to 3.5 hours, with values around 30 °C. By the end of the first 12 hours, distinct temperature ranges with depth have developed. The effect of the vertical heat conduction of the soil is less pronounced on the free surface of the soil column mantle than on the inner soil areas, so that, compared to the sensor measurements, temperature maxima occur shortly after the beginning of the non-illuminated period, followed by a rapid drop in temperature. It can be seen that, well separated from the deeper layers, the soil loses heat more rapidly towards the surface, from a depth of 80 mm, presumably due to increased evaporation in the near-surface layers or convective processes. The deeper areas show a much more uniform pattern of temperature decrease, with slower, more uniform heat loss. The upper 80 mm layer cools to the lowest measured temperatures during the experiment, with uniform values around 29 °C. The lower 140 mm soil layer has a higher temperature of around 30 °C. In the second half of the experiment, similar temperature changes were observed as in the first 24 hours, but with higher values at all points, as already mentioned in the sensor measurement results.

We present here the results for one strip of the data collected by the paper-measuring system above the soil column. In Figure 8, the temperature values of the measurement line "L13" set in the Thermo program are shown as a function of time and distance from the top of the surface element on the third vertical surface element of the first layer of the measurement surface system. The measurement line is 220 mm long; the starting point is the uppermost point of the surface element towards the infrared lamp, and the end point, i.e., point 0, is the ground surface. The temperature of the upper 100 mm of the measurement line is directly influenced by the infrared lamp's radiation, not by the temperature of the surrounding air. It follows that between 0 and -100 mm, both illuminated sections have much higher

temperatures. The temperature between -100 and -220 mm is independent of the direct radiation. These problems do not occur during the 12-hour periods without illumination. Part of the infrared radiation is absorbed by the ground surface, but as heat flows into the ground, the ground surface re-radiates about 80% of the long-wavelength infrared back towards the air. The effect of this is clearly visible in the temperature values of the lower 20 mm of the measurement line in both illumination stages, where higher values are observed in the air layers between -200 and -100 mm. At the start of the non-illuminated periods, the temperature drops steeply to about 32°C along the entire length of the measurement line ("L13"). The effect of the intense convective mass and heat flux associated with increased evaporation, especially during these periods, is reflected in the temperature changes, which are clearly visible in the colour map along the entire length of the measured line.

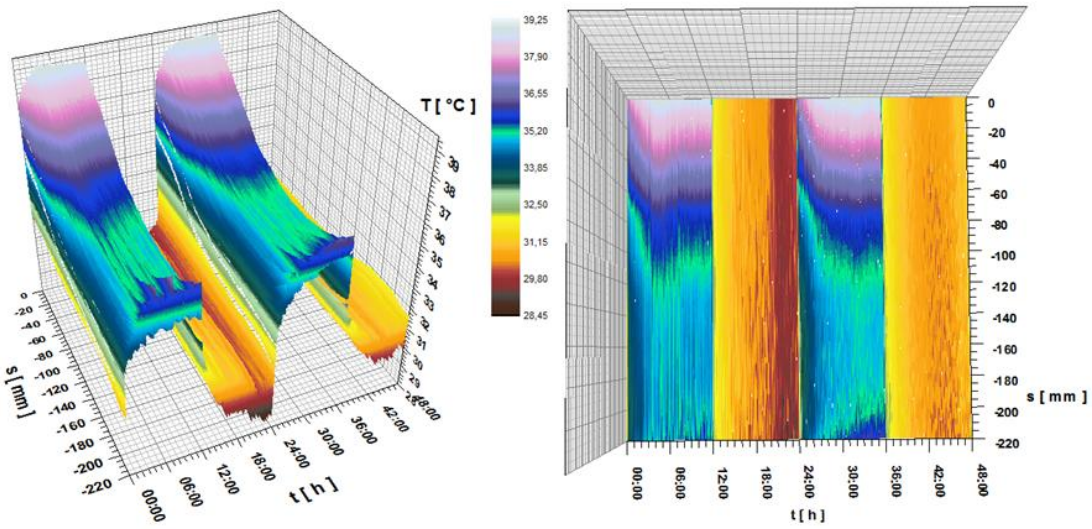

Figure 8: Temperature values of the measurement line named "L13" set on the third vertical surface element of the first layer of the measurement surface system

3.2. Results and evaluation of soil column 2 saturated with water and frozen

Prior to the experiment, the column containing meadow soil was saturated with water through its porous structure using a closed water-distillation system. The saturation process took approximately 24 hours. We exposed the soil sample to 12 hours of freezing before starting the experiment. The markings in Figure 9 are the same as in the previous experiments. It can be seen that at the beginning of the experiment, the temperature at all measured soil points is around the freezing point. At a depth of 60 mm, the temperature is slightly higher than at the soil surface. At the lower two depths, it is slightly lower. While the soil surface warms rapidly and reaches and exceeds the air temperature about 7.5 hours after the start of the experiment, the deeper layers remain frozen, with no increase in temperature. Melting starts after 1 hour 40 minutes at 60 mm from the surface, 120 and 180 mm at about the same time, after 3 hours. At the beginning of the 12-hour non-irradiated phase, the surface and air temperatures fall steeply. Afterwards, the surface temperature remains higher than the air temperature for 3 hours, then falls below it. The high moisture content at this time implies that evaporation is intense, mainly leading to decreases in the near-surface layers and surface temperature. The heat flux into the soil during the experiment decreases with depth, and a phase shift is observed in the deeper layers, due to the soil's thermal conductivity. Thus, the deeper layers reach their maximum temperature after 12 hours without irradiation, i.e., after the cessation of further energy input, after about half an hour at the 60 mm level, 1 hour at the 120 mm level, and 1.5 hours at the 180 mm depth. After 13 hours, the temperatures at

depths of 60 mm and 120 mm are approximately the same until the start of the next illumination phase at 24 hours. Compared with the lowest depth of 180 mm, the higher depths heat up less. The temperature characteristics of the next 24 hours are similar to those observed in the same half of the previous experiments. Figure 10 shows variations in moisture content across the different soil layers and in the air above the soil surface. The readings of the tensiometers placed in the soil are given in hPa. It can be seen that at the beginning of the experiment, the moisture absorption in all three soil layers stagnates and then decreases. This means that the liquid water content of the thawing frozen soil remains unchanged until thawing, after which it increases, and the amount of solid water decreases accordingly. The tensiometer can only measure the suction force of the liquid water in the soil, not the solid water. Therefore, after the initial stagnation, the values decrease in parallel with the melting. In all 3 layers, the values begin to increase at about the same time, after 6 hours, as the soil water content begins to evaporate. This process can be clearly followed by the change in absolute humidity(a), which shows a continuous increase. At the beginning of the non-illuminated phase, from 12 h, the humidity of the air increases suddenly with a steep slope, and continues to increase until 20 h, when it reaches 14.5 g/cm^3, compared with the value at the end of the illuminated phase at 12 h, which was around 11.7 g/cm^3. This sudden increase is accompanied by a steep rise in soil moisture content, which decreases due to intense evaporation. From about 20 hours onward, the air humidity begins to decrease, as reflected in the stagnation of the tensiometer readings. From 24 hours onwards, the air humidity drops steeply, and with it the soil moisture tensiometry. After 26 hours, there is a steady increase in the air humidity and a steady decrease in the soil moisture. From 36 hours onwards, similar changes in soil and air moisture content are observed as in the 12 hours to 24 hours interval, but with significantly lower values, as the soil has dried out substantially since the beginning of the experiment and its moisture content has decreased.

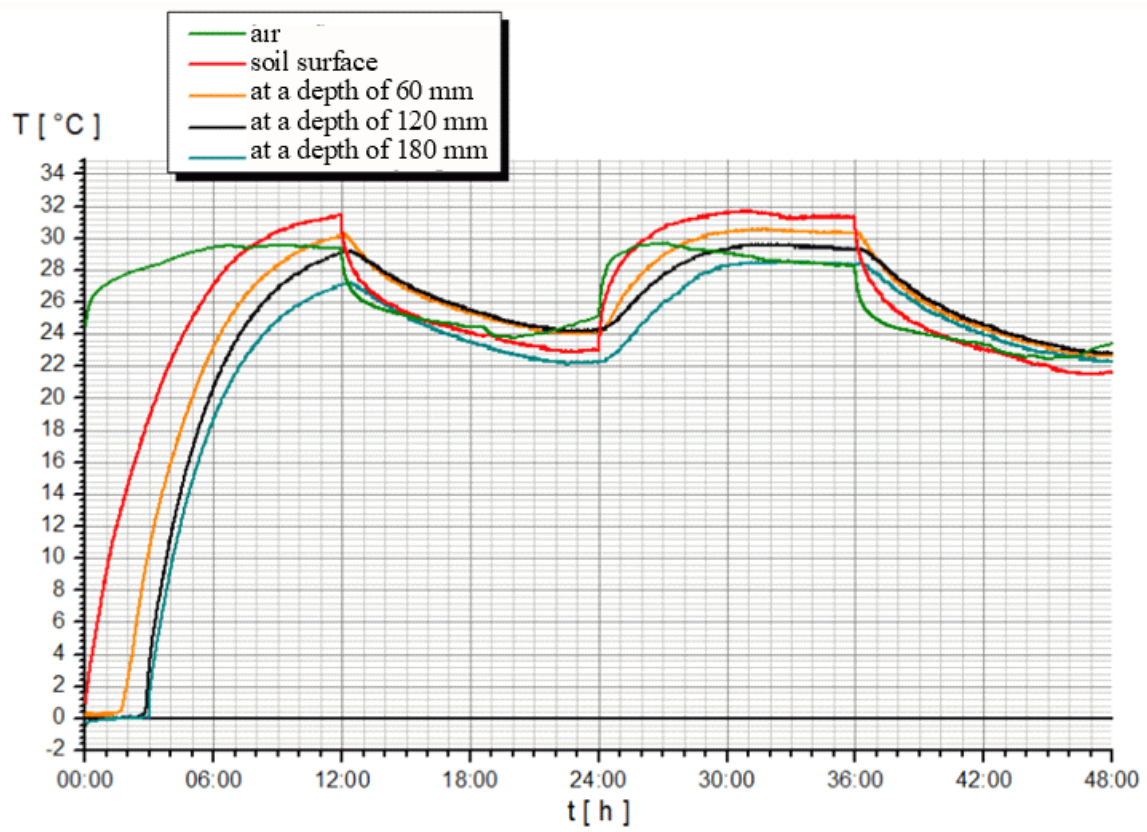

Figure 9: Temperature changes in the soil and above the soil surface during the experiment with soil column 2

Figure 10 shows variations in moisture content across the different soil layers and in the air above the soil surface. The readings from the tensiometers placed in the soil are given in hPa. It can be seen that at the beginning of the experiment, the moisture absorption in all three soil layers stagnates and then decreases. This means that the liquid water content of the thawing frozen soil remains unchanged until thawing, after which it increases, and the amount of solid water decreases accordingly. A tensiometer measures only the suction of water in the liquid phase in soil and does not measure the forces associated with water bound to the solid phase. Therefore, after the initial stagnation, the values decrease in parallel with the melting. In all 3 layers, the values begin to increase at about the same time, after 6 hours, as the soil water content begins to evaporate. This process can be clearly followed by the change in absolute humidity(a), which shows a continuous increase. At the beginning of the non-illuminated phase, from 12 o'clock, the humidity of the air increases suddenly with a steep slope, and continues to increase until 20 o'clock, when it reaches 14.5 g/cm^3, compared with the value at the end of the illuminated phase at 12 o'clock, which was around 11.7 g/cm^3. This sudden increase is accompanied by a steep rise in soil moisture content, which decreases due to intense evaporation. From about 20 h onward, the air humidity begins to decrease, as reflected in the stagnation of the tensiometer readings. From 24 h onwards, the air humidity drops steeply, and with it the soil moisture tension. After 26 hours, there is a steady increase in the air humidity and a steady decrease in the soil moisture. From 36 hours onwards, similar changes in soil and air moisture content are observed as in the 12 h to 24 h interval, but with significantly lower values, as the soil has dried out substantially since the beginning of the experiment and its moisture content has decreased.

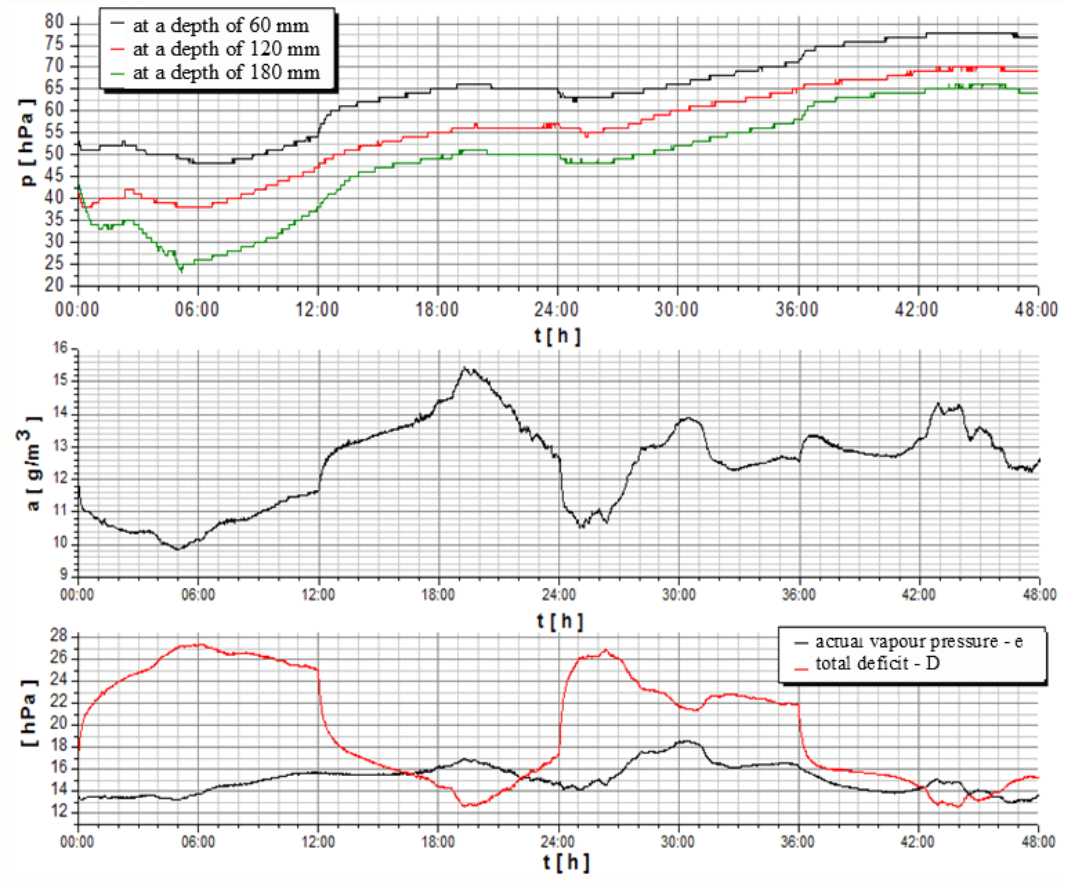

Figure 10: Moisture content changes in the soil and above the soil surface during the experiment with soil column 2

Figure 11 also shows the variation in soil temperature with depth up to 180 mm below the soil surface. The measurement line "soil l4", set in the Thermo program for the infrared camera, is drawn vertically along the free soil surface of the soil column slate to a depth of 180 mm, with a width of 50 mm. The camera took thermal images every 2 minutes during the 48-hour experiment. Temperature was plotted as a function of time and distance from the surface. The colour map further helps to interpret the temperature variation. Understandably, the surface of the slate reaches much higher temperatures than the interior of the column along its vertical axis, due to contact with the surrounding air. The lowest temperatures are around 10°C, compared to the interior of the soil column along the longitudinal axis, where temperatures were near freezing at the start of the experiment and remained so throughout. The heat flux to the shale surface decreases less with depth during the experiment, and heat conduction is lower than in the soil interior, due to continuous energy transfer between the air and the soil. The colour map clearly shows that the layers near the soil surface lose much more heat than the lower layers during the non-illuminated period, partly due to continuous contact between the soil surface and the air and the energy-intensive evaporation of soil water.

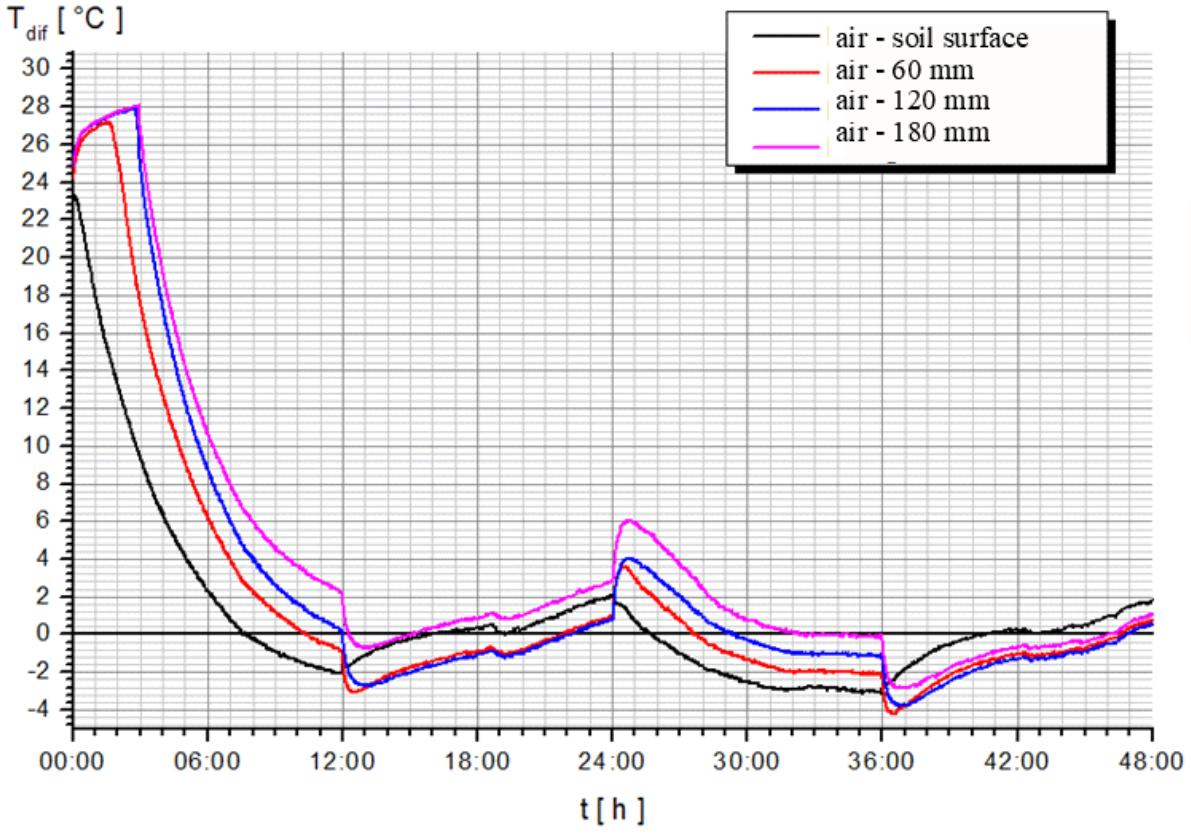

Figure 11: Temperature differences measured between the air and different soil layers

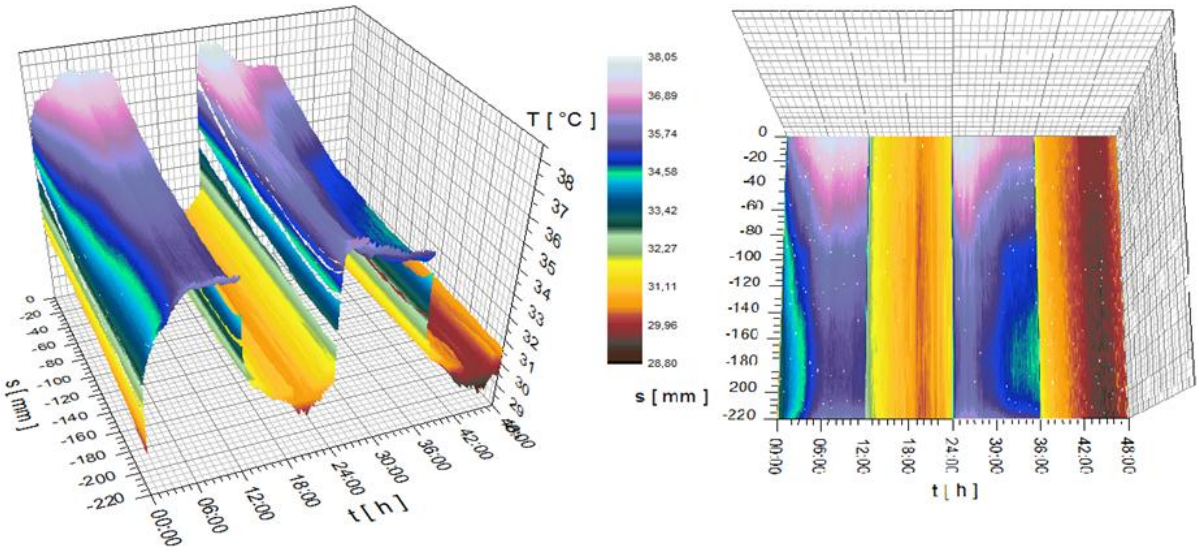

Figure 12: Temperature change on the surface of soil column 2 along the vertical measurement line named "Soil L4"

Figure 12 shows the temperature differences between the air and the other measurement points. It can be seen that the soil surface temperature increases continuously from the beginning of the experiment, faster than the air temperature, and reaches and exceeds the air temperature after 7.5 hours. Initially, the temperature difference between the other measurement points increases compared to the air. The ground is still frozen, but the air temperature is increasing. Here again, as shown in Figure 9, thawing starts after 1.5 hours at a depth of 60 mm and almost simultaneously at the bottom two measuring points after 3 hours. At 60 mm from the surface, the temperature reaches and exceeds the surface air temperature after 10 and a half hours, and at 120 mm just after 12 hours, at the beginning of the 12-hour period without irradiation. The lowest measuring point reaches and exceeds the air temperature only at the beginning of the non-irradiation period, when the air temperature decreases in the absence of irradiation. At a depth of 180 mm, the temperature is higher for 15 hours, and at the ground surface for 15 hours and 50 minutes compared to the surrounding air. The soil surface loses heat due to the heat-absorbing effect of intense evaporation and, presumably, convection, whereas the lowest point of measurement after freezing is not warmed by the 12-hour irradiation like the upper layers and therefore has lower temperatures than the surrounding air. At 60 mm and 120 mm from the surface, the soil continues to cool relative to the air, almost simultaneously, after 22 hours. With the onset of illumination, the temperature differences at all points increase relative to the air, due to the different heat capacities of soil and air. With depth, the temperature difference increases due to thermal conduction, and then the values at different depths decrease over time and exceed the air temperature. The values at the lowest measurement point and the air temperature are approximately the same from 32h to 36 h; the other measurement points continue to warm relative to the air temperature. For the last period without illumination, ground temperatures remain uniformly above air temperatures for 46 hours and fall below air temperatures only in the 2 hours before the end of the experiment.

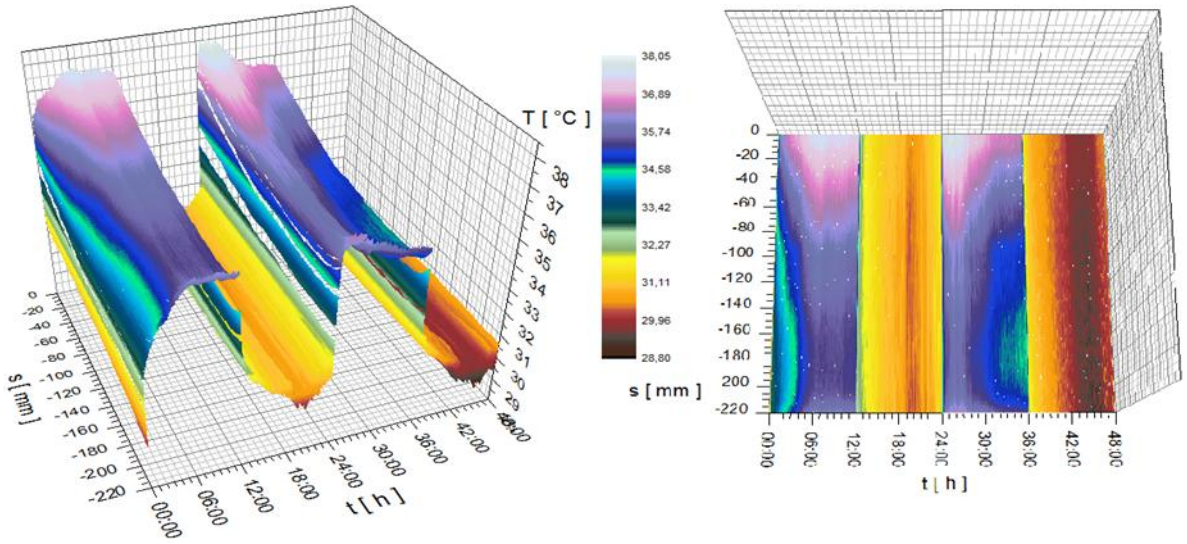

Figure 13: Temperature values of the measurement line named "L23" set on the third vertical surface element of the second layer of the measurement surface system above soil column 2.

In Figure 13, the temperature values of the measurement line "L23" set in the Thermo program are shown as a function of time and distance from the top of the surface element on the third vertical surface element of the second layer of the measurement surface system. The measurement line was 220 mm long; the starting point is the uppermost point of the surface element toward the infrared lamp, and the end point is the point toward the ground surface. It can be seen that the temperature evolution in the air above the ground shows a different pattern from that in previous experiments. The colour map clearly shows that from the beginning of the experiment until about 5 hours after the start, the temperature is significantly lower in the air layer between -130 mm above the top of the measurement line and the last measurement point towards the ground surface. The air layers above -130 mm reach increasingly higher temperatures (as they are directly heated by infrared radiation). The initially frozen ground surface is in constant contact with the air and exposed to continuous infrared radiation, and these two effects combine to accelerate soil thawing. By 3 hours, the entire soil has thawed, as evidenced by the accelerating rate of increase in surface air temperature from this time. The melting of the soil, because it draws heat away from its surroundings, results in significantly lower values in the above-ground air at temperatures below -130 mm. From 5 am to 12 noon, the temperature trend is uniform. From 12 noon, the temperature in the air drops sharply because infrared radiation does not heat the air, and the ground surface is cooler, so the surface radiation is lower. From 24 h onwards, at the start of the second illumination phase, the air warms rapidly to around 35.5 °C in the air layer between -80 mm and -220 mm, then drops from 29 h onwards due to the heat-absorbing effect of increasing evaporation. The moisture content of the air increases markedly at this time, reaching a maximum of 14 g/m^3. Over the last 12 hours without illumination, the temperature trend is similar to that of the first period, but with lower values overall.

4. CONCLUSIONS AND SUGGESTIONS

In this paper, the drying of soil columns under infrared radiation was investigated. Using an infrared lamp to simulate the sun, we measured temperature and moisture changes in the soil and in the air layer above the soil surface using sensor and infrared camera measurements to describe the water and energy balance of the soil, similar to the work of Gao et al. [33]. The instrumentation and setup of the experimental system developed enabled a coordinated measurement process. I have interpreted and

described the changes by plotting the sensor and infrared camera measurements. The measurement system designed to monitor flow conditions above the ground surface during the experiment can be considered a result of the experimental work. Despite its many shortcomings, the experiment can provide a good starting point for future work on soil water and energy balance. Some suggestions are therefore made on how and by what methods the efficiency of the experiment could be improved and how a more accurate picture of temperature, moisture and flow conditions could be obtained:

- The use of temperature sensors at several points in the soil could provide a more accurate picture of soil temperature variations.
- More accurate measurements of soil thermal conductivity require the use of a sensor capable of measuring the heat flux into the soil.
- In order to determine the pF curve (The pF curve is a curve describing the water retention capacity of soil, showing the relationship between soil water content and soil water suction (matrix potential)), it is necessary to measure the moisture content of the soil, in addition to measuring the moisture tensiometry values, where possible.
- Measurement of the intensity of infrared radiation reaching the soil surface is recommended.
- Monitoring the variation in soil surface moisture content could be achieved by installing an additional tensiometer.
- Further development of the above-ground measurement surface system is needed to improve accuracy.
- Where possible, thermal images should be taken at a higher frequency, both at the surface of the soil column and in the air layer above the soil surface.
- A plastic tube containing the soil sample should be replaced with a material with better thermal insulation properties.

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ECONOMIC AND ECOLOGICAL CONDITIONS CONCERNING SOME EXPERIENCES OF UPPER MISSISSIPPI RIVER VALLEY IN US

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Abstract:
Study analyses correlations among main economic and ecological variables of the United States of America for researched period of 2010-2021. Correlations of different variables connects with conditions of Upper Mississippi River Valley. Study within correlations of economic and ecological conditions focuses on agricultural gross value added produced by irrigated agriculture, growing rate of GDP with annual growth and per capita, gross fixed capital formation in share of GDP and its annual growing rate, value added of total manufacturing in share of GDP with annual growing rate. Study emphasizes CO2 emissions in economic sectors, as on-farm energy use, agrifood systems waste disposal, food processing, food household consumption, energy. Study uses Statistical Program for Social Sciences, which provides possibilities to analyse correlations among different economic and ecological conditions of US concerning issues of Mississippi River. In 2021 annual GDP growth, value-added total manufacturing and gross fixed capital formation increased by more than 5%, and CO2 emissions less decreased by 5% in food processing and by 12% in energy CO2 emissions. Emissions CO2 of food household consumption decreased by 19% and emissions CO2 of on-farm energy use decreased 16% comparable to last years. More increase of economic growth connects with less CO2 emissions.

Keywords: *Agricultural value added, Correlations, Food consumption, Gas emissions, Household, Variables*

1. INTRODUCTION

This study would like to analyse correlations among main economic and ecological variables of the United States of America for the period of 2010-2021. The correlations of different variables have wide-side connections with conditions of the Upper Mississippi River Valley (UMRV) at the same time. The US plays significant economic role in the global economy; therefore, the US has important influences on the processes and development trend of the world market. The whole watershed of Mississippi River Valley – together Upper and Lower River Valleys – has about 3.2 million km2, which means that this is one third of US area. The Mississippi river collects water from this wide side area and brings this water to the Mexico gulf. Naturally these natural conditions emerge some important questions that how the large amount of water and soil as sediment can be kept back in US. This case study focuses on the main economic-ecological correlations accompanying with some water issues of the Upper Mississippi River Valley, because all of this river issue can be so bigger one within this case-study.
The study within correlations of economic and ecological conditions focuses on agricultural gross value added (GVA) produced by irrigated agriculture, growing rate of GDP with annual growth and per capita, gross fixed capital formation (GFCF) in share of GDP and its annual growing rate, value added of total manufacturing in share of GDP with annual growing rate. Additionally, to the above-mentioned objectives, the study emphasizes the CO2 emissions in some main economic sectors, as on-farm energy use with emissions CO2 totals, the agrifood systems waste disposal with emissions CO2 totals, food processing with emissions CO2 totals, food household consumption with emissions CO2 totals and energy, emissions CO2 totals during period of 20210 and 2021 (Table 1; Table 2; Table 3; FAO-AQUASTAT 2023). These correlations among mentioned economic and ecological variables can make

some influences on some examples for management in field of Upper Mississippi River Valley. Importance of this river as the sustainable water use of Mississippi river is to support agricultural production, industrial, manufacture and energy sectors by advanced modern innovative technology based on productive, efficient and effective methods (efficiently, effectively, productivity). There are some difficulties of the river as large water reservoirs behind dams makes difficulties for seasonal pattern of river-water discharge and interrupts sediment going into Mississippi river (Floodplain Management 2010). Some main reports concerning the Upper Mississippi River Valley can provide important experiences for water management of this river (AWI Steering Committee 2015). Also, some experts declared that by the start of the 21st century it was clear that regulation alone was not enough, and people began taking additional steps to restore the lost functioning of natural ecosystems (Allan – Palmer 2006). This argument is satisfactory for the main goals for Mississippi river as providing reliable flood control and risk reduction.

The wide-side analyses of this study for the economic-ecological correlations are based on the statistical data coming from FAO AQUASTAT Dissemination System, FAOSTAT 2023 Macro Indicators and FAOSTAT 2023 Emissions Total concerning the original national scientific and statistical sources of the US. Some experts emphasized importance of green climate policy to mitigate gas emissions and ensure clean policy for natural environment, which are strongly connecting with sustainability of Mississippi river valley basin.

The Los Angeles fires alone will cost insurers $30 billion (Zahn 2025). Over the last 45 years, climate-related disasters have cost the U.S. more than $2.9 trillion (Office of Management and Budget 2005).

In addition, the U.S. Climate Alliance, representing over half the national economy, is committed to cutting emissions by at least 50% by 2030 (U.S. Climate Alliance 2025). Meanwhile, at least 3,000 U.S. companies that conduct business globally are expected to have to comply with climate reporting requirements under international frameworks like the EU's Corporate Sustainability Reporting Directive (CSRD) (Abramson 2024). Climate finance also remains compelling on the opportunities side. *Clean energy investment in the U.S. hit a record $248 billion in 2023—triple the 2018* (Climate Central 2024). Political shifts won't change the fact that climate risks are real and accelerating. Despite regulatory rollbacks, wildfires, floods, and extreme weather continue to cause billions in financial losses, making it be essential for investors to focus on long-term risks and opportunities (Lorenzo 2025). Naturally the environmental conservation policy also focuses on decreasing flood risk of Mississippi river and remaining the river habitat in the ecosystem.

The analyse focuses on *some main hypotheses*, which are as follows:

The analyse wants to provide proof that GDPpCap2 has any correlations with GrowGDP3 and GFCFAnn5, VaAdMAnn7.

The study provides proof the any correlations of GrowGDP3 with GFCFAnn5 and VaAdMAnn7.

The study provides proof that any correlations of GFCFinGDP4 with VaAdManu6, HousEmis11 and EnEmisTo12.

Also, it should be important to get proof that VaAdManu6 has such correlations with HousEmis11 and EnEmisTo12.

The study provides proof that VaAdMAnn7 has important correlations with FoodPrCO10.

The study provides proof that HousEmis11 has any correlations with EnEmisTo12.

The AGVA1 variable has any correlations with GFCFinGDP4, FarmEnCO8, FoodPrCO10 and HousEmis11.

Naturally the correlations can be among other economic-ecological variables in the researched period in case of the US, which can also make somehow any influences on each-others, but these correlations among variables can probably be less important than the above-mentioned variables.

Also, there some important economic and ecological data, which have not considerably been changing in the US for period of 2010-2021, but these provide important actual conditions of US. These data, which concern fields of irrigation by surface water, for irrigation by groundwater, cultivated area equipped for irrigation, area equipped for irrigation total in hectare, total country area cultivated,

agriculture valued added in GDP, irrigated cultivated area (arable land + permanent crops) and human development index.
The SPSS statistical system (Field 2020; Horváth-Mitev 2023) can calculate such any data, which are really changing, as variables, otherwise the statistical system cannot include non-changing data.
The study focuses on the analysing some connects among economic -ecological variables and *several features of Upper Mississippi River Valley in the latest decade*. These connects can emphasize the successful enforces of local and federal American authorities to strengthen the *sustainability of the Mississippi River Valley* for interests of extending flood risk control, clean water supply, navigation for transport, sedimentation and restore ecosystems within the Mississippi River Watershed to support natural habitats.
The following chapters overview the research methods of the case study based on the statistical analyse and then provide summaries of tables and figures used in the research.

2. RESULTS AND DICUSSION

In the United States there were considerable changes in the fields of CO2 gas emissions responsible for the global warming based on the economic growth. Each given year is characterized by economic variables as its features. The *Figure 1* shows different years of the researched period with their economic features based on the *correlations between*
.- at principal line "X" *Component 1* including share of the gross fixed capital formation in GDP (*GFCFinGDP4*), share of value-added total manufacturing in GDP (*VaAdManu6*), on-farm energy use emissions CO2 totals (*FarmEnCO8),* food processing emissions CO2 totals (*FoodPrCO10*), emissions CO2 total of food household consumption (*HousEmis11)* and energy emissions CO2 totals (*EnEmisTo12*) and
.- at principal line "Y" *Component 2* including annual growth of GDP per capita (*GDPpCap2*), annual growing rate of GDP (*GrowGDP3*), annual growth of gross fixed capital formation (*GFCFAnn5*) and annual growth of value-added total manufacturing (*VaAdMAnn7*) economic variables.
The *first quarter* up-right side as positive session of the coordinate system shows that the CO2 gas emissions little increased in 2010 and then little decreased in 2015 comparably to other further years between 2019-2021 (also Tables 2-3). But in the *fourth quarter,* down-left side as negative session of the coordinate system in 2019 and 2020 the CO2 gas emissions more considerably decreased, while the economic growth little increased in 2019, but considerably decreased in 2020 because of corona virus extending globally. The annual growth of value-added total manufacturing increased by 5.7% in 2010, and little increased only by 0.5% in 2019, while this sharply decreased by 4.3% in 2020. This means that the CO2 gas emissions considerably decreased in 2020 for example by 20% in fields of emissions CO2 total of food household consumption against its decrease by 13% in 2015 and by 19% in 2019. While energy emissions CO2 totals against considerably decreased by 17% in 2020 comparably to its decrease by 5% in 2015 and by 7% in 2019. This shows that when in 2020 the economic growth decreased in fields of GDP growth per capita, annual GDP growth, annual growth of value-added total manufacturing and annual growth of gross fixed capital formation considerable decreased, while CO2 gas emissions remaining more considerably decreased, but only in field of food processing CO2 emissions comparably little decreased by 18% in 2020 to its result by 22% in 2019. In 2020 there was a health crisis as corona virus in global economy, which resulted some economic decreases either in US or in most of countries of the world.
In the *second quarter* up-left side of the coordinate system in 2021, when the annual GDP growth, GDP growth per capita, annual growth of value-added total manufacturing and annual growth of gross fixed capital formation increased by more than 5% in all of their cases, CO2 gas emissions only less decreased by 5% in fields of food processing CO2 gas emissions and by 12% in energy CO2 gas emissions. While the emissions CO2 total of food household consumption could decrease by 19%. Emissions CO2 total of on-farm energy use also considerably decreased 16% comparable to last years by 9% in 2020 and 8% in 2015. Based on economic results it can be mentioned that more increase of economic growth connects

with less CO2 emissions, which can be resulted by more environmental-friendly technologies used in US during the period of 2021-2021.
These Figure 1 very clearly show the contradictive correlations between the increasing economic growth and decreasing CO2 gas emissions for the little more than one decade. In case of the US this contradictive trend is a favourable economic condition, but this one alone cannot solve the global warming, while the US growth can be seen as good initiative steps for the future economic growth. These overviews emphasize importance of increasing attention for decreasing gas emission.
Reply for hypotheses. Based on researches concerning main results and data base of the *Table 4* in the US during researched period of 2010—2021, it is proofed that annual growth of GDP per capita (***GDPpCap2***) has *very strong* correlations by 0.997 (99.7%) with annual growing rate of GDP (*GrowGDP3*) and by 0.950 (95.0%) with annual growth of gross fixed capital formation (*GFCFAnn5*) and by 0.858 (85.8%) with annual growth of value-added total manufacturing (*VaAdMAnn7*).
Results of the research provide proof that annual growing rate of GDP (***GrowGDP3***) has very strong correlations by 0.954 (95.4%) with annual growth of gross fixed capital formation (*GFCFAnn5*) and by 0.878 (87.8%) with annual growth of value-added total manufacturing (*VaAdMAnn7*).
Results of the study strengthen that share of the gross fixed capital formation in GDP (***GFCFinGDP4***) has *negative very strong* correlations by (minus) 0.905 (-90.5%) with of share of value-added total manufacturing in GDP (*VaAdManu6*), by (minus) 0.982 (-98.2%) with emissions CO2 total of food household consumption (*HousEmis11)* and by (minus) 0.830 (-83.0%) with energy emissions CO2 totals (*EnEmisTo12*).
In the US there are special contradictive correlations between two variables namely the share of the gross fixed capital formation in GDP (*GFCFinGDP4*) and share of value-added total manufacturing in GDP (*VaAdManu6*). In spite that the share of the gross fixed capital formation in GDP has sharply increased for this period and the share of value-added total manufacturing in GDP has decreased for the same time. This shows that the fixed capital formation extended in other sectors out of the manufacturing, for example in service sectors and infrastructure or logistic network.
Also, share of the gross fixed capital formation in GDP (*GFCFinGDP4*) considerably increased and its share in GDP originally remained as a large one, while the emissions CO2 totals could considerably decrease in fields of food household consumption, energy sector, on-farm energy use and food processing. This signs, that the US implemented considerable forces to decrease emissions CO2 totals, while the fixed capital formations were realised in order to increase prosperity of economic development (Table 2, Table 4). The considerable decrease of emissions CO2 totals was considerable, but this one did not decrease level of CO2 gas emissions determined by the Paris Agreement in 2015. Therefore, also, these data strengthen reasons, why the US refused to accept the demands of Paris Agreement in 2015.
Also, it should be important that share of value-added total manufacturing in GDP (***VaAdManu6***) has very strong correlations by 0.959 (95.9%) with emissions CO2 total of food household consumption (*HousEmis11)* and by 0.905 (90.5%) with energy emissions CO2 totals (*EnEmisTo12*).
For the environmental conservation of the US the emissions CO2 totals *agri-food systems* waste disposal has extended by little not considerable rate for the researched period, therefore, this variable cold not enough considerable impact on the other economic-ecological variables of this study. This can be proofed from the Table 2 and Table 4 (FAO AQUASTAT 2023) but this does not mean that this variable cannot be important, only in this researched period is not considerable. *FAO defines agri-food systems* as all the interconnected activities and actors involved in getting food from field to fork. This broad definition encompasses everything from agricultural production and processing to distribution, consumption, and waste management. It also highlights the critical role of economic, social, and environmental factors in shaping how food reaches our plates (FAO 2025).
Also, there some important economic other data base out of the SPSS as statistical analyses, which show that *cultivated area* as arable land with permanent crops is 160 million hectares of which 16.7% is irrigated. This share of *irrigated areas* internationally comparably is considerable against 10-12% globally. 65% of area equipped for irrigation by *groundwater* is realised, which can lead to less water

transpiration from reserved water stock based on the climate change and longer drouth period. This is better more favourable condition of water use than use of *surface water* as remaining 35%. Because of the *agricultural value added* is at highly level in value of production, but its share of GDP has little part, namely between 0.89%- 0.96%, because other sectors are mostly heavy industries, mining sectors and service sectors are considerable. Additionally, to these data the *human development index* (HDI) is at very highly level as 0.9% closed to 1.0 as maximum level. This data shows how much the educated level, purchase power parity and healthy level of the population of US during the researched period (FAO AQUASTAT 2023).

Upper Mississippi River Valley for the service of environmental conservation

According to the above mentioned economic and ecological features of US the American economic and ecological strategy would like to manage successfully the water issue concerning the surface water supply from Upper Mississippi River Valley. The all-Mississippi River Valley has watershed equally to mostly one-third of the continent area of US between two Atlantic and Pacific oceans, from which area the Mississippi river collects water. There some main goals for the Mississippi River Watershed included in *support and enhance healthy and productive ecosystems* within the Mississippi River Watershed to support natural habitats and the fish and wildlife resources. *Provide reliable flood control and risk reduction* through well managed and maintained infrastructure, including appropriate floodplain connections for water conveyance and ecosystem benefits, and management of surface. *Serve as the nation's most valuable river transportation corridor* to ensure a competitive advantage for national goods in global markets. *Maintain supply of abundant clean water* ensuring the quality and quantity of water in the Mississippi River Basin. *Support local, state and national economies* to sustain a water use system to efficiently and effectively support agricultural, industrial and energy productivity. Provide world-class recreation opportunities ensure the quality of life for people and recreation-based economies by maintaining and enhancing riverine, lake and wetland (AWI Steering Committee 2015).

About the *Upper Mississippi River Basin Association* – (UMRBA) is a five-state interstate organization formed by the Governors of Illinois, Iowa, Minnesota, Missouri, and Wisconsin to coordinate the states' river-related programs and policies and work with federal agencies that have river responsibilities. The UMRBA is structured as a 501(c) non-profit association, with the Board of Directors composed of all duly Governor-appointed representatives and alternatives. Through UMRBA, the Governors' joint interstate collaborative, the above-mentioned states are bringing together those who live and work in the floodplain to improve disaster preparedness, economic growth and resilience, and ecological health. The Governors declared purposes concerning this Upper River Regions, as 1) increase the economic, ecological, and social resilience of the Upper Mississippi River to major flood events, prolonged drought, and excessive sediment; 2) Foster dynamic, balanced, objective, and adaptive approaches to flood, drought, and sediment management in a multi-purpose management context. In detailed the Governors describe objectives in detailed as 1) develop an integrated, comprehensive, and systems-based approach to minimize the threat to health and safety resulting from flooding by using structural and non-structural floodplain management measures; 2) Develop new, or renew existing, comprehensive long-term channel management strategies that are sustainable, cost-effective, and ecologically sensitive; 3) develop mitigation strategies for multi-year drought events that would increase the resilience of communities and economies adjacent to, or dependent on, the river; 4) seek opportunities to support environmental sustainability, restoration, and water quality goals for the Upper Mississippi and Illinois Rivers; 5) accelerate efforts in the watershed that reduce the volume and rate of runoff to the Mississippi River. (Ecosystems of Upper Mississippi River Basin Association 2015).

Main results of the activities of Upper Mississippi River Basin by the middle of 2010s are as economic sectors in the UMR corridor generate more than $345 billion annually, supporting over 1 million jobs. *Manufacturing, tourism and agriculture* account for over 90 percent of the total UMR corridor revenue within the 133-county corridor, supporting 92 percent of total employment. Tourism and outdoor recreation support more than 420,000 jobs. The detailed results are based on the

REVENUE: Manufacturing 81.70%, Agriculture 7.21%, Tourism 5.96%, Energy Production 2.3%, Mineral Resources 1.38%, Outdoor Recreation 1.16%, Commercial Navigation 0.19%, Water Supply 0.09% and Natural Resources Commercial Harvest 0.006%.
JOBS: Manufacturing 49.14%, Agriculture 11.91%, Tourism 31.29%, Energy Production 0.71%, Mineral Resources 1.15%, Outdoor Recreation 5.56%, Commercial Navigation 0.08%, Water Supply 0.11% and Natural Resources Commercial Harvest 0.04%. *Economic sectors in the UMR corridor generate more than $345 billion annually*, supporting over 1 million jobs. *Manufacturing, tourism and agriculture* account for over 90 percent of the total UMR corridor revenue within the 133-county corridor, supporting 92 percent of total employment. Tourism and outdoor recreation support more than 420,000 jobs. (Ecosystems of Upper Mississippi River Basin Association 2015; Mississippi River Watershed Report Card 2020).
The above-mentioned data shows that the *manufacturing sectors were more profitable* because the 81.70% of all revenues were given by this sector, while its share of all jobs was only half of all jobs in Upper Mississippi River Basen. Also, these sectors included from food processing to petroleum and chemical manufacturing, from transporting raw materials to processing facilities, supplying water for processing, washing, and cooling, and safely at cost-effective level. The second efficient sector was the agriculture by 7.21% after manufacturing in fields of revenues, but its share of jobs was higher by 11.91%, which shows less profitable sector than manufactures. This can be resulted by somehow *little farming measures*, therefore, less profitable and income possibility. The farmers have financial difficulties to obtain fertilizers and water-supply. Also, production of farmers is mostly pressed by drought weather and water-flood crisis of Mississippi river and extending diseases in animal stocks. Sometimes the large scale small, retailed networks can press purchasing prices against income-interests of farmers. The other important sector is tourism, which also needs more supports from local authorities to keep level of their survival income accompanying supports for farmers.

Conclusions and Recommendations

The main results of research focus on the increasing importance of the environmental conservation, because CO2 emissions less decreasing is not enough to avoid more natural damages resulted by human activity and social economic conditions. Based on economic results it can be mentioned that more increase of economic growth connects with less CO2 emissions, which can be resulted by more environmental-friendly technologies used in US during the period of 2021-2021. Also, when the economic developing trend declined in 2020 because of corona virus extending as health crisis, the CO2 gas emissions considerably decreased based on the new innovative green technologies used. Naturally the economic decline also can contribute to less CO2 emissions.
The economic growth naturally is accompanying with increasing trends in fields of growth of value-added total manufacturing, annual growth of gross fixed capital formation and increasing use of natural resources as groundwater and surface water coming from the Mississippi River Valley Basen. This last one also demands an adequate water management and minimizes the threat to health and safety resulting from flooding.
Also, it is important to realise and adequate harmonizations between economic activities by profit maximize and *support and enhance healthy and productive ecosystems* within the Mississippi River Watershed. Additionally, to the international cooperation the national cooperation should develop even at level of common force of different American states.
For the future economic development trends, it is important to increase the innovative investment for increasing benefit for the society and natural background as base of our survival life

3. FIGURES, TABLES AND EQUATIONS

This chapter provides main tables and figures, which demonstrate changing trends of economic and ecological variables in researched period in US.

Table 1. Abbreviation of economic variables in case of United States

Economic variables	Means of economic variables	Years	Source
AGVA1	in % of agricultural GVA produced by irrigated agriculture	2010-2021	FAO-AQUASTAT 2023 Dissemination System
GDPpCap2	GDP per capita in US dollar in %, Annual growth US$ per capita, 2015 prices	2010-2021	Macro Indicators FAOSTAT, 2023
GrowGDP3	Growing rate of GDP in %, Annual growth US$, 2015 prices	2010-2021	Macro Indicators FAOSTAT, 2023
GFCFinGDP4	Gross Fixed Capital Formation, Share of GDP US$, 2015 prices in %	2010-2021	Macro Indicators FAOSTAT, 2023
GFCFAnn5	Gross Fixed Capital Formation, Annual growth US$, 2015 prices in %,	2010-2021	Macro Indicators FAOSTAT, 2023
VaAdManu6	Value Added (Total Manufacturing), Share of GDP US$, 2015 prices	2010-2021	Macro Indicators FAOSTAT, 2023
VaAdMAnn7	Value Added (Total Manufacturing), Annual growth US$, 2015 prices	2010-2021	Macro Indicators FAOSTAT, 2023
FarmEnCO8	On-farm energy use, Emissions totals, Emissions CO2, in %, 2010 = 100	2010-2021	Emissions Total FAOSTAT, 2023
AgrFooCO9	Agrifood Systems Waste Disposal, Emissions totals, Emissions CO2, in %, 2010 = 100	2010-2021	Emissions Total FAOSTAT, 2023
FoodPrCO10	Food Processing, Emissions totals, Emissions CO2, in %, 2010 = 100	2010-2021	Emissions Total FAOSTAT, 2023
HousEmis11	Food Household Consumption, Emissions totals, Emissions CO2, in %, 2010 = 100	2010-2021	Emissions Total FAOSTAT, 2023
EnEmisTo12	Energy, Emissions totals, Emissions CO2, in %, 2010 = 100	2010-2021	Emissions Total FAOSTAT, 2023

Table 2: Main several ecological and economic data of the United States of America based on the CO2 gas emissions in percent between 2010-2021

Economic variables	2010	2015	2019	2020	2021
X line					
GFCFinGDP4	14	20.6	21.18	22	21.9
VaAdManu6	12.3	11.7	11	10.8	10.8
FarmEnCO8	0.1	-8	-4	-9	-16
FoodPrCO10	0.1	-13	-22	-18	-5
HousEmis11	0.1	-13	-19	-20	-19
EnEmisTo12	0.1	-5	-7	-17	-12
Y line					
GDPpCap2	1.8	2.1	1.8	-2.7	5.5
GrowGDP3	2.7	2.9	2.5	-2.2	5.8
GFCFAnn5	2.2	4.4	2.9	-1	5.4
VaAdMAnn7	5.7	1.3	0.5	-4.3	5.7
AGVA1	20.85	20.59	20.70	20.70	20.70
AgrFooCO9	0.1	0.6	1.2	1.0	1.4

Source: FAO AQUASTAT Dissemination System, FAOSTAT, 2023 Macro Indicators, FAOSTAT, 2023 Emissions Total

Table 3: Gas emissions in different economic sectors in USA in 2020-2021

Title of sectors	Year	Unit	CO2 emissions	Decrease*
On-farm energy use	2021	kt	60814.3	-16
Agrifood Systems Waste Disposal	2021	kt	1951.6	1.4
Food Processing	2021	kt	98918.9	-5
Food Household Consumption	2021	kt	87792.3	-19
Energy	2021	kt	4744624.3	-12

Source: FAOSTAT, 2023 Emissions Total

. * = CO2 emission has decreased for period of 2010-2021 in US in percent, 2010= 100

. kt = Unit

Table 4: Correlation Matrix[a]

		AGVA1	GDPpCap2	GrowGDP3	GFCFinGDP4	GFCFAnn5	VaAdManu6	VaAdMAnn7	FarmEnCO8	AgrFooCO9	FoodPrCO10	HousEmis11	EnEmisTo12
Correlation	**AGVA1**	1.000	-.027	-.007	**-.773**	-.292	.430	.415	**.565**	.386	**.585**	**.654**	.402
	GDPpCap2		1.000	**.997**	-.046	**.950**	.069	**.858**	-.336	.399	.483	.085	.333
	GrowGDP3			1.000	-.107	**.954**	.142	**.878**	-.266	.349	**.500**	.149	.407
	GFCFinGDP4				1.000	.061	**-.905**	**-.535**	**-.780**	.192	**-.703**	**-.982**	**-.830**
	GFCFAnn5					1.000	.094	**.733**	-.354	.145	.332	.022	.346
	VaAdManu6						1.000	.471	**.733**	**-.541**	**.605**	**.959**	**.905**
	VaAdMAnn7							1.000	.046	.304	**.818**	**.554**	**.626**
	FarmEnCO8								1.000	-.342	.104	**.723**	**.729**
	AgrFooCO9									1.000	.097	-.324	-.320
	FoodPrCO10										1.000	**.738**	**.504**
	HousEmis11											1.000	**.855**
	EnEmisTo12												1.000

a. This matrix is not positive definite.

Source: SPSS analyse based on data base from FAO AQUASTAT Dissemination System, FAOSTAT 2023 Macro Indicators, FAOSTAT 2023 Emissions Total

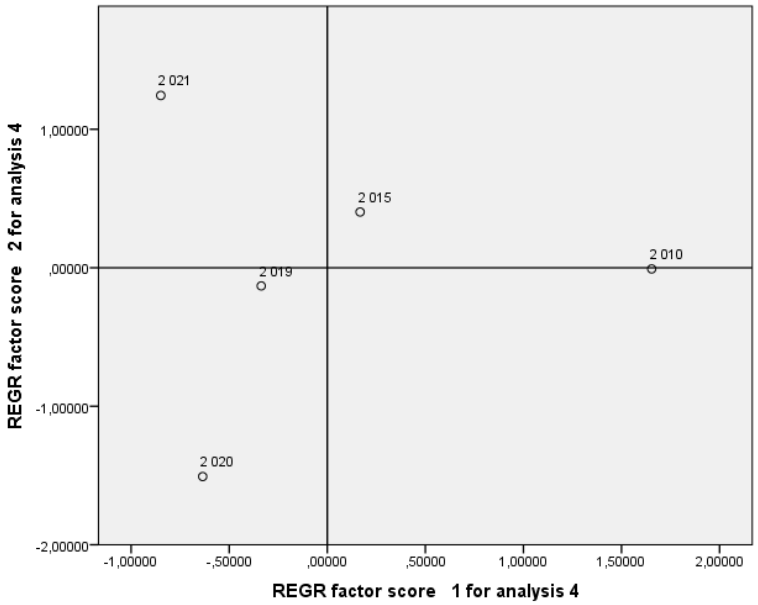

Figure 1: Correlations between Component-1 including HousEmis11, GFCFinGDP4, VaAdManu6, EnEmisTo12, FarmEnCO8, FoodPrCO10 economic variables at principal line "X" and Component-2 including GDPpCap2, GrowGDP3, GFCFAnn5, VaAdMAnn7 economic variables at principal line "Y" *Source*: SPSS analyse based on data base from FAO AQUASTAT Dissemination System, FAOSTAT 2023 Macro Indicators and FAOSTAT 2023 Emissions Total

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https://www.fao.org/faostat/en/#data/MK; https://www.fao.org/faostat/en/#data/GT

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ENERGY EFFECTIVENESS AND EMPLOYMENT ISSUES IN EU-27 IN 2020s

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Abstract

Recently energy effectivity globally became in centre of international attention, by which economic competitiveness can be strengthened based on securing adequate or more income conditions for future economic prosperity. The study analyses correlations of energy effectiveness with employment conditions in EU-27. The study focuses on correlations and significance among real GDP per capita, investment share of GDP, employment issues, tertiary educational attainment, energy effectivity in euro per kilogram of oil equivalent, final energy consumption, final energy consumption in households and share of renewable energy in gross final energy consumption. Statistical analyses are essence of research method, as statistical package for social sciences in study. Increasing euro per kg of oil equivalent energy opposite to efficient energy effectivity did not stimulate to increase the investment share of GDP and by little increase of investment to increase to real GDP per capita in period of 2010-2023. Share of renewable energy in gross final energy consumption ensured the EU to realize its main goal to decrease carbon-dioxide gas emissions. For future economic growth of EU-27 there is important, that more efficient energy effectivity should be followed by economic policy to transfer into more green development by using more educated and skilled human resources.

Keywords: *Correlations, Employment, Investment, Real GDP, Significance, Tertiary educational attainment*

1. INTRODUCTION

Recently the energy effectivity globally became in the centre of the international attention and in European Union, by which the economic competitiveness can be strengthened based on securing the adequate or more income conditions for the future economic prosperity. The energy effectivity is based on the first cost of unified energy calculated by kilogram of oil equivalent, which is accompanying with employment issues. Globally and at national levels the energy effectivity also includes the energy consumption at the level of households. For the latest decades because of the stronger global warming the role of the renewable energy resources became more important roles of the energy use strategy to mitigate of negative influences according to human activities on the natural environment as natural background of the human society.

The employment issues are concerning the employment effectivity based on the skilled human resources coming from the educated level of employed workers. Therefore, the study overviews the main different educated levels, aged, selected employment and unemployment ratios. The energy effectivity can be successfully realised by the productive educated and skilled human resources by wide-side employment. The study aims at analysing correlations among energy effectivity and employment conditions; different educational level to increase the skilled human resources to strengthen the competitiveness of national economies in EU member states. The study analyses the correlations of energy effectivity with the employment conditions in EU-27 member states as Belgium, Denmark, France, Cyprus, Luxembourg,

Netherlands, Austria, Finland, Sweden, Bulgaria, Malta, Portugal, Romania, Czechia, Germany, Croatia, Hungary, Poland, Slovenia, Slovakia, Estonia, Ireland, Latvia, Lithuania, Greece, Spain and Italy during the period of 2010 – 2023. The main statistical data base comes from the Eurostat data based on the national statistical reports of the EU member states.

The EU declared some main analyses concerning the energy effectivity(sdg_07_30**)**. Energy effectivity is measured as the amount of economic output per unit of energy consumed (Eurostat, 19/12/2024), (sdg_07_30). The EU (2024) declared an important aim, which is to improve energy effectivity by increasing economic output while reducing energy consumption through measures like renewable energy and energy efficiency. The EU is known as net energy importer and even though the EU's need for energy was not going to increase as much as the same of China, the community is dependent on oil imports. And even if numbers have not been growing that rapidly, they are still high. At the beginning of the 1990's, major oil consumer countries in the Community (Germany, France, Italy, the United Kingdom, Spain, Belgium, the Netherlands) used about 10.5 million barrels per day (Markus 2018). The EU's *final energy consumption* has seen reductions since 2005, with 23 member states decreasing their final energy consumption. While the *primary energy consumption* has also decreased, with 25 member states reducing their consumption since 2005 (EEA, European Environment Agency, 2024). Also, the EU emphasized importance of employment in the energy sector (EEA, 26 June 2024), namely the *environmental goods and services sector employed 5.2 million people* (in FTEs) in the EU, accounting for about 2.5% of total EU employment by the end of 2021. The increase in green employment between 2010 and 2021 was largely driven by an increase of 525,000 FTEs in the number of jobs related to the management of energy resources. The Full-Time Equivalent (FTE) measures the total number of hours worked by employees in relation to a full-time work schedule The EU also declared importance of different kind of jobs in the different sectors, which are as follows: producing renewable energy; manufacturing equipment needed to generate renewable energy, such as wind turbines and photovoltaic cells; manufacturing energy-efficient equipment; research and development (R&D) activities; installation, consultancy and management services. According to these sectors also, the European Environment Agency of the EU declared (EEA, 26 June 2024): that the employment in the environmental goods and services sector has been growing faster than overall EU employment. This growth is largely due to the creation of jobs in renewable energy, energy efficiency, and waste management. Specifically, employment in renewable energy and energy efficiency has increased significantly, with over 2 million full-time equivalent jobs created between 2000 and 2022 (Eurostat April 2025). Waste management also contributes significantly to environmental employment, with an increase from 0.8 million to 2.0 million full-time equivalent jobs between 2000 and 2022 (Eurostat 26 June 2024). The renewable energy sector is expected to continue growing, potentially creating more jobs in the EU (EEA 26 June 2024). Moreover, Baranyai et al. (2022) pointed out that "greening" large customers can serve as a model for other segments and players and suggested the partial solar energy supply for further consideration for the energy needs of Liszt Ferenc International Airport (Budapest) with a PVGIS system ("Photovoltaic Geographical Information System"), which could prevent 1,300 tons of CO_2 emissions. The construction sector, which is crucial for energy efficiency renovations, employs almost 25 million people in the EU (EC 2024). Small and medium-sized enterprises (SMEs) in the construction sector benefit from the increased renovations market (EC 2024).

In the European manufacturing industry, effectivity growth has been slower compared to the US, and a gap has widened since the mid-1990s and again after the Covid pandemic. This gap is evident in both overall effectivity and in the manufacturing sector specifically. Albulescu (2024) examined the asymmetric relationship between corporate tax avoidance and total factor effectivity (TFP) using firm-level data for 141 European oil and gas companies, covering the period 2007 to 2015. While some countries like Denmark and Belgium show high productivity, others, particularly in Central and Eastern Europe, have lower effectivity levels with slower improvement (da Silva et al 2024). The model accounts for key aspects of the US experience with only changes in aggregate technology. It attributes half the variation in mean and dispersion of firm size across countries to technical change. Huisman and van Nijen (2024) analysed a sample of more than 9.000 municipal bonds issued by the counties wherein

lie the 22 American coastal cities that are physically exposed to climate risk between 2015 and 2020. Distortions also affect the size distribution. To summarize, both data sources show a clear, strong, positive relationship between average firm size and income per worker, no matter whether all data is used or whether the samples are truncated. The small effect on total employment is explained because most jobs in the EU are in so-called 'white' sectors, generating few CO_2 emissions. Activities such as electricity production, transport, manufacturing, agriculture and mining sectors together produce about 90% of all CO_2 emissions in the EU, but account for less than 25% of employment (EC, EC 2019). Chen (et al 2022) similarly finds that the net effect of EPS (environmental policy stringency) tightening on total employment has been small and temporary, with a peak after two years, and a coinciding reallocation of employment from high- to low-emission firms and sectors. Timilsina and Malla (2023) mentioned that nowadays more than half a trillion USD has been invested annually in clean technologies. Based on their bibliographic analysis their findings were, mixed as most ex-post studies showed positive relationship between clean investments and energy-intensive manufacturing firms' productivity. Clements et al. (2023) found climate debt (estimated for 131 countries) was extremely large, equalling around USD 59 trillion over the period of 1959-2018. They stated climate debt was also substantially like other government liabilities which equalled G-20 about 81 percent of GDP. Also, the promoting labour market flexibility can strengthen the successful energy effectivity accompanying with employment effectivity to decrease costs of damages resulted by pollutions. The other chapters analyse correlations among energy effectivity and employment effectivity in the EU-27 for the period of 2010-2023.

2. MATERIAL AND METHODS

The statistical analyses are the essence of the research method in the case-study. The statistical package for social sciences was in detailed worked out by Field (2020) and Horváth and Mitev (2023). Aims of study are to overview changing trends of real GDP per capita (*ReaGDPCap1*); investment share of GDP (*InvGDP2*); employment rate from 20 to 64 aged year employed people in 2010 (*Empl20103*) and in 2023 (*Empl20234*); long-term unemployment rate from 15 to 74 aged in 2010 (*UnEmp20105*) and in 2023 (*UnEmp20236*); early leavers from education and training population from 18 to 24 years total in 2010 (*LevEd20107*); early leavers from education and training population from 18 to 24 years total in 2023 (*LevEd20238*); tertiary educational attainment total from 25 to 34 years based on the International Standard Classification of Education (ISCED 2011) tertiary education (levels 5-8) in 2010 (*TerEd20109*); tertiary educational attainment total from 25 to 34 years based on the International Standard Classification of Education (ISCED 2011) tertiary education (levels 5-8) in 2023 (*TerEd202310*); population unable to keep home adequately warm by poverty status in 2023 (*PopUnab11*); energy effectivity in euro per kilogram of oil equivalent (KGOE) between 2010-2023 (*EnProdKg12*); final energy consumption 2023, in million tonnes of oil equivalent, between 2010-2023 and (*EnCons13*); final energy consumption in households per capita in kilogram of oil equivalent (KGOE), between 2010-2023 *(EnConCap14*); and share of renewable energy in gross final energy consumption by sector, renewable energy sources annual, in 2023 (*RenEn15*) (Table-1, Eurostat 2024). There are ***some hypotheses***, which are focusing on main essences of researched objectives, which are as follows: The study analyses ***correlations*** between real GDP per capita [sdg_08_10], annually at market prices euro per capita between 2010 -2023 (*ReaGDPCap1*) and energy effectivity in euro per kilogram of oil equivalent (KGOE) between 2010-2023 (*EnProdKg12*). The study focuses on the correlations of employment rate from 20 to 64 aged year employed people in 2010 (*Empl20103*) and in 2023 (*Empl20234*) with long-term unemployment rate from 15 to 74 aged in 2010 (*UnEmp20105*). Analyse correlations of employment rate from 20 to 64 aged year employed people in 2023 (*Empl20234*) with long-term unemployment rate from 15 to 74 aged in 2023 (*UnEmp20236*). Study analyses correlations of early leavers from education and training population from 18 to 24 years total in 2010 (*LevEd20107*) with early leavers from education and training population from 18 to 24 years total in 2023 (*LevEd20238*) and population unable to keep home adequately warm by poverty status in 2023

(*PopUnab11*). Analyse correlations of tertiary educational attainment total from 25 to 34 years based on the International Standard Classification of Education (ISCED 2011) tertiary education (levels 5-8) in 2010 (*TerEd20109*) with tertiary educational attainment total from 25 to 34 years based on the International Standard Classification of Education (ISCED 2011) tertiary education (levels 5-8) in 2023 (*TerEd202310*). Study analyses correlations of final energy consumption 2023, in million tonnes of oil equivalent, between 2010-2023 (*EnCons13*) with final energy consumption in households per capita in kilogram of oil equivalent (KGOE), between 2010-2023 *(EnConCap14*). Also, the study analyses ***significance*** of energy effectivity in euro per kilogram of oil equivalent (KGOE) between 2010-2023 (*EnProdKg12*) with real GDP per capita (*ReaGDPCap1*), investment share of GDP (*InvGDP2*), employment rate from 20 to 64 aged year employed people in 2023 (*Empl20234*), long-term unemployment rate from 15 to 74 aged in 2023 (*UnEmp20236*), tertiary educational attainment total from 25 to 34 years in 2010 (*TerEd20109*) and population unable to keep home adequately warm by poverty status in 2023 (*PopUnab11*).

The study focuses on the ***significance*** of final energy consumption in households per capita in kilogram of oil equivalent (KGOE), between 2010-2023 *(EnConCap14*) with investment share of GDP (*InvGDP2*), employment rate from 20 to 64 aged year employed people in 2010 (*Empl20103*), early leavers from education and training population from 18 to 24 years total in 2010 (*LevEd20107*); tertiary educational attainment total from 25 to 34 years in 2010 (*TerEd20109*); tertiary educational attainment total from 25 to 34 years in 2023 (*TerEd202310*); population unable to keep home adequately warm by poverty status in 2023 (*PopUnab11*); final energy consumption 2023, in million tonnes of oil equivalent, between 2010-2023 (*EnCons13*). Naturally the economic variable as share of renewable energy in gross final energy consumption by sector, renewable energy sources in 2023 (*RenEn15*), but its share in final energy consumption is not so considerable as 27% averagely in all of EU-27 in the international compare in the researched period. Therefore, this variable can only be mentioned. The values of the economic variables in cases of correlations can be important if these are more than 0.500 or 50%. If these values of correlations are between 0.800 (80%) and 1.000 (100%), correlations of economic variables are very important, and between 0.500 (50%) and 0.800 (80%), correlations are important, but under 0.500 (50%) the correlations among variables are not important. In cases of *negative values* of correlations of economic variables, the correlations are *inversely proportional to the positive* valued correlations and *direct proportional* to other negative valued correlations of variables. In cases of the significance of economic variables this means that the values of economic variables are very closed to each-others. Namely when differences between these values of variables are 0.000 (0%) or less than 0.100 values closed to 0.000, the significance is for economic variables.

The *correlation* among economic variables means that values of correlations are bigger than 0.500 (50%) and more closed to 1.000 (100%), therefore the corelations over 0.800 (80%) are *very strong*. The *significance* among economic variables means, when the values of correlations are *0.000 (as zero*) or probably very closed to 0.000 (zero), namely within 0.100 values (10%). The values of significance of economic variables are neither negative or positive values, because these are mostly zero or very closed to zero.

3. FIGURES, TABLES AND EQUATIONS

Table 1: Energy and employment conditions in EU-27 between 2010 and 2023 in percent

Variables / EU-27	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Belgium	12	2	68	72	4	2	12	6	44	50	6	47	-15	-33	15
Bulgaria	55	-5	64	76	5	2	13	9	27	36	21	38	9	5	22
Czechia	22	1	70	82	3	1	5	6	23	34	6	49	-7	-17	19
Denmark	20	4	75	80	1	0.5	11	10	38	49	7	2	-14	-23	44
Germany	11	2	74	81	3	1	12	13	26	38	8	54	-14	-19	22
Estonia	38	7	68	82	7	1	11	10	38	43	4	93	-10.	-12	41
Ireland	95	6	65	80	7	1	12	4	50	63	7	138	-1	-40	15
Greece	-3	-2	63	67	5	6	13	4	30	44	19	24	-18	-14	25
Spain	11	-2	63	70	7	4	28	14	40	52	21	28	-9	-21	25
France	10	2	70	74	2	2	13	8	43	52	12	39	-14	-24	22
Croatia	40	1	62	71	7	2	5	2.0	26	39	6	38	-1	-10	28
Italy	7	2	60	66	4	4	19	10	21	31	9	31	-14	-21	20
Cyprus	20	-1	75	80	1	2	13	10	48	62	17	43	-1	-13	20
Latvia	60	5	64	78	10	2	13	8	35	45	7	57	-5	-13	43
Lithuania	72	6	64	78	7	2	8	6	46	57	20	57	10	4	32
Luxembourg	98	-1	71	75	1	2	7	7	44	60	2	65	-19	-32	14
Hungary	45	5	62	81	5	1	11	12	26	30	7	52	-12	-16	17
Malta	58	-3	61	80	4	1	21	10	24	46	7	57	40	23	15
Netherlands	15	1	77	83	1	1	10	6	40	54	7	63	-24	-43	17
Austria	8	3	74	77	1	1	8	9	21	43	4	30	-9	-15	41
Poland	13	-2	62	78	3	1	5	4	37	46	5	61	6	-6	17
Portugal	15	-1	67	78	6	2	28	8	25	41	21	24	-5	1	35
Romania	62	-1	56	69	3	2	19	17	21	22	12	73	5	-1	26
Slovenia	26	0.2	70	77	3	1	5	5	31	41	4	56	-12	-26	25
Slovakia	33	-1	66	77	11	4	5	6	24	40	8	47	-18	-20	17
Finland	4	-1	72	78	3	2	10	10	39	39	3	20	-13	-8	51
Sweden	11	-3	78	83	2	2	6	7	42	54	6	42	-9	-24	66
Average	***32***	***0.9***	***67***	***77***	***4***	***2***	***12***	***8***	***34***	***45***	***9.5***	***49***	***-6***	***-16***	***27***

Source: Eurostat, [sdg_08_10], [sdg_08_11], [sdg_08_30], [sdg_08_40], [sdg_04_10], [sdg_04_20], [sdg_07_11], [sdg_07_20], [sdg_07_30], [sdg_07_40], [sdg_07_60], 2024

ReaGDPCap1 =Real GDP per capita [sdg_08_10], Annual Gross domestic product at market prices euro per capita between 2010 -2023 in percent 2010= 100

InvGDP2 = Investment share of GDP by institutional sectors [sdg_08_11], annual total investment, in percent in 2023 minus 2010, difference between two years

Empl20103 = Employment rate by sex [sdg_08_30], Total employment (resident population concept – LFS), From 20 to 64 years, Percentage of total population, in 2010

Empl20234 = Employment rate by sex [sdg_08_30], Total employment (resident population concept – LFS), From 20 to 64 years, Percentage of total population, in 2023

UnEmp20105 =Long-term unemployment rate by sex [sdg_08_40], Annual total Long-term unemployment, From 15 to 74 years Percentage of population in the labour force, in 2010

UnEmp20236 =Long-term unemployment rate by sex [sdg_08_40], Annual total Long-term unemployment, From 15 to 74 years Percentage of population in the labour force, in 2023

LevEd20107 = Early leavers from education and training by sex [sdg_04_10] Annual Percentage

Population From 18 to 24 years total in 2010

LevEd20238 = Early leavers from education and training by sex [sdg_04_10] Annual Percentage Population From 18 to 24 years total in 2023

TerEd20109 = Tertiary educational attainment by sex [sdg_04_20], Annual Total From 25 to 34 years Percentage, International Standard Classification of Education (ISCED 2011) Tertiary education (levels 5-8) in 2010

TerEd202310 = Tertiary educational attainment by sex [sdg_04_20], Annual Total From 25 to 34 years Percentage, International Standard Classification of Education (ISCED 2011) Tertiary education (levels 5-8) in 2023

PopUnab11 = Population unable to keep home adequately warm by poverty status [sdg_07_60], in 2023, Annual Percentage Total

EnProdKg12 = Energy effectivity[sdg_07_30], Euro per kilogram of oil equivalent (KGOE), Annual between 2010-2023 in percent

EnCons13 = [sdg_07_11] page_spreadsheet_Final energy consumption 2023, Annual, Million tonnes of oil equivalent, between 2010-2023, in percent

EnConCap14 = Final energy consumption in households per capita [sdg_07_20], Annual, Kilogram of oil equivalent (KGOE), between 2010-2023, in percent

RenEn15 = [sdg_07_40] page_spreadsheet_Share of renewable energy in gross final energy consumption by sector, Renewable energy sources annual, in 2023, in percent

Table 2: Correlation Matrix

		ReaGDPCap1	**InvGDP2**	**Empl20103**	**Empl20234**	**UnEmp20105**	**UnEmp20236**	**LevEd20107**	**LevEd20238**	**TerEd20109**	**TerEd202310**	**PopUnab11**	**EnProdKg12**	**EnCons13**	**EnConCap14**	**RenEn15**
Correlation	**ReaGDPCap1**	1.000	.238	-.341	.119	.290	-.250	-.079	-.040	.184	.195	-.071	**.649**	.393	.106	-.253
	InvGDP2		1.000	.036	.233	.228	-.345	-.177	-.037	.215	.104	-.276	.379	-.214	-.296	.083
	Empl20103			1.000	**.583**	**-.542**	-.347	-.363	-.115	.377	.457	-.281	-.188	-.465	-.476	.374
	Empl20234				1.000	-.141	**-.719**	-.338	-.066	.232	.274	-.320	.276	.093	-.044	.225
	UnEmp20105					1.000	.362	.136	-.156	-.119	-.127	.231	.229	.126	.194	-.030
	UnEmp20236						1.000	.280	-.052	-.108	-.068	.491	-.330	-.242	.005	-.072
	LevEd20107							1.000	**.567**	-.144	-.106	**.582**	-.159	.246	.302	-.076
	LevEd20238								1.000	-.242	-.383	.186	-.134	.099	.252	.105

	TerEd20109									1.000	**.859**	.019	.288	-.148	-.427	.085
	TerEd202310										1.000	.059	.227	-.035	-.371	-.003
	PopUnab11											1.000	-.268	.208	.363	-.095
	EnProdKg12												1.000	.192	-.214	-.321
	EnCons13													1.000	**.791**	-.102
	EnConCap14														1.000	.113
	RenEn15															1.000

Source: Eurostat, [sdg_08_10], [sdg_08_11], [sdg_08_30], [sdg_08_40], [sdg_04_10], [sdg_04_20], [sdg_07_11], [sdg_07_20], [sdg_07_30], [sdg_07_40], [sdg_07_60], 2024

Table 3: Correlation Matrix: Significant

		ReaGDPCap	**InvGDP2**	**Empl20103**	**Empl20234**	**UnEmp20105**	**UnEmp20236**	**LevEd20107**	**LevEd20238**	**TerEd20109**	**TerEd202310**	**PopUnab11**	**EnProdKg12**	**EnCons13**	**EnConCap14**	**RenEn15**
Sig. (1-tailed)	**ReaGDPCap1**		.116	**.041**	.277	**.071**	.104	.348	.421	.180	.165	.363	**.000**	**.021**	.299	**.101**
	InvGDP2			.429	.121	.126	**.039**	.188	.428	.141	.303	**.082**	**.026**	.142	**.067**	.341
	Empl20103				.001	**.002**	**.038**	**.031**	.284	**.026**	**.008**	**.078**	.173	**.007**	**.006**	**.027**
	Empl20234					.241	**.000**	**.042**	.372	.122	**.083**	**.052**	**.081**	.322	.414	.130
	UnEmp20105						**.032**	.249	.219	.278	.263	.123	.125	.266	.166	.441
	UnEmp20236							**.078**	.398	.296	.367	**.005**	**.046**	.112	.490	.360
	LevEd20107								**.001**	.237	.300	**.001**	.215	.108	**.063**	.354
	LevEd20238									.112	**.024**	.177	.252	.311	.102	.301
	TerEd20109										**.000**	.463	**.073**	.231	**.013**	.337
	TerEd202310											.385	.128	.432	**.028**	.494
	PopUnab11												**.088**	.148	**.031**	.319
	EnProdKg12													.169	.142	**.052**
	EnCons13														**.000**	.306

	EnConCap 14															.288
	RenEn15															

Source: Eurostat, [sdg_08_10], [sdg_08_11], [sdg_08_30], [sdg_08_40], [sdg_04_10], [sdg_04_20], [sdg_07_11], [sdg_07_20], [sdg_07_30], [sdg_07_40], [sdg_07_60], 2024

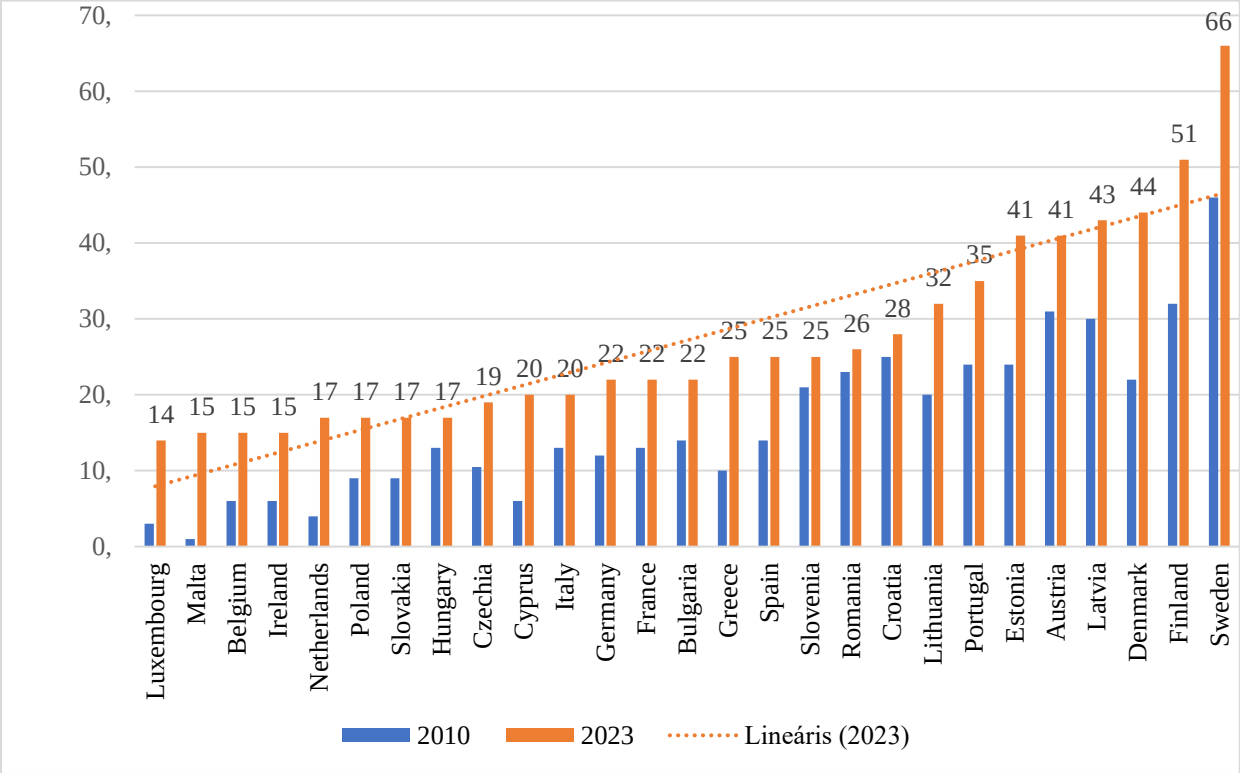

Figure 1: Share of renewable energy in gross final energy consumption by sector in EU-27 in 2010 and 2023 in percent, Source: Eurostat, [sdg_07_40], 2024

4. RESULTS AND DISCUSSIONS

The study analyses the main correlations and significance of economic variables in cases of EU-27 member states within the researched period of 2010 and 2023. The Table-2 for correlation matrix (Eurostat 2024) widely and cleanly shows the exact correlation values among different economic variables. Based on the results of the research it can be declared that value of ***correlations*** of real GDP per capita [sdg_08_10] with annually at market prices euro per capita between 2010 -2023 (*ReaGDPCap1*) by 0.649 (64.9%), as *strong with* energy effectivity in euro per kilogram of oil equivalent (KGOE) between 2010-2023 (*EnProdKg12*).

The correlations of employment rate from 20 to 64 aged year employed people in 2010 (*Empl20103*) are *strong* by 0.583 (58.3%) *with* employment rate from 20 to 64 aged in 2023 (*Empl20234*) and by contradictive strong minus 0.542 (-54.2%) *with* long-term unemployment rate from 15 to 74 aged in 2010 (*UnEmp20105*). Manly this last one means that when the employment has averagely considerably increased by 67% in 2010, the long-term unemployment increased only little by 4% in EU-27 in the same year. The correlations of employment rate from 20 to 64 aged year employed people in 2023

(*Empl20234*) are minus 0.719 (-71.9%) contradictive negative valued with long-term unemployment rate from 15 to 74 aged in 2023 (*UnEmp20236*). The employment averagely increased by 77%, but the long-term unemployment increased only very little by 2% in EU-27 in 2023 (Table-2; Eurostat 2024). Finds of research declared that correlations of early leavers from education and training population from 18 to 24 years total in 2010 (*LevEd20107*) are *strong* by 0.567 (56.7%) *with* early leavers from education and training population from 18 to 24 years total in 2023 (*LevEd20238*) and *strong* by 0.582 *with* population unable to keep home adequately warm by poverty status in 2023 (*PopUnab11*). Additionally, to above mentioned results correlations of tertiary educational attainment total from 25 to 34 years based on the International Standard Classification of Education (ISCED 2011) tertiary education (levels 5-8) in 2010 (*TerEd20109*) are *very strong* by 0.859 *with* tertiary educational attainment total from 25 to 34 years based on the International Standard Classification of Education (ISCED 2011) tertiary education (levels 5-8) in 2023 (*TerEd202310*). This trend shows very consequence increase in fields of tertiary educational attainment during the researched period. This trend provides proof that more participants or students continued their study at highly level education system, which can lead to increase level of labour forces in EU. This trend also can strengthen the innovative technological development at firm level. Correlations of final energy consumption in million tonnes of oil equivalent, between 2010-2023 (*EnCons13*) are *mostly very strong* by 0.791 *with* final energy consumption in households per capita in kilogram of oil equivalent (KGOE), between 2010-2023 *(EnConCap14*). This trend shows that the *decrease of final energy consumption* by 6% at the level of EU-27 can stimulate final energy consumption per capita per 16% to decrease during the period of 2010-2023. Naturally decrease of this final energy consumption per capita can also strengthen the decrease of final energy consumption at national and EU-27 levels.

It can be declared that the ***significance*** of energy effectivity in euro per kilogram of oil equivalent (KGOE) between 2010-2023 (*EnProdKg12*) is 0.000 *with* real GDP per capita (*ReaGDPCap1*), 0.026 investment share of GDP (*InvGDP2*), 0.081 *with* employment rate from 20 to 64 aged year employed people in 2023 (*Empl20234*), 0.046 *with* long-term unemployment rate from 15 to 74 aged in 2023 (*UnEmp20236*), 0.073 *with* tertiary educational attainment total from 25 to 34 years in 2010 (*TerEd20109*) and 0.088 *with* population unable to keep home adequately warm by poverty status in 2023 (*PopUnab11*) (Table-3, Eurostat 2024). Also, the ***significance*** of final energy consumption in households per capita in kilogram of oil equivalent (KGOE), between 2010-2023 *(EnConCap14*) 0.067 *with* investment share of GDP (*InvGDP2*), 0.006 *with* employment rate from 20 to 64 aged year employed people in 2010 (*Empl20103*), 0.063 *with* early leavers from education and training population from 18 to 24 years total in 2010 (*LevEd20107*); 0.013 *with* tertiary educational attainment total from 25 to 34 years in 2010 (*TerEd20109*); 0.028 *with* tertiary educational attainment total from 25 to 34 years in 2023 (*TerEd202310*); 0.031 *with* population unable to keep home adequately warm by poverty status in 2023 (*PopUnab11*); 0.013 *with* final energy consumption 2023, in million tonnes of oil equivalent, between 2010-2023 (*EnCons13*) (Table-3, Eurostat 2024). Naturally significance values of economic variables are somehow similar with correlation values, but some other values of significance are more exact data than general values of correlations. For example, data of energy effectivity in euro per kilogram of oil equivalent in fields of investment share of GDP, employment rate from 20 to 64 aged year, long-term unemployment rate from 15 to 74 aged in 2023, tertiary educational attainment total from 25 to 34 years in 2010, population unable to keep home adequately warm by poverty status in 2023. In case of final energy consumption in households per capita compares were exact with investment share of GDP, employment rate from 20 to 64 aged year employed people in 2010, early leavers from education and training population from 18 to 24 years total in 2010 tertiary educational attainment total from 25 to 34 years in 2010 and in 2023 and population unable to keep home adequately warm by poverty status in 2023.

5. CONCLUSIONS AND SUGGESTIONS

Based on the significance two economic variables can be emphasized, namely energy effectivity between 2010-2023 and final energy consumption in households per capita in 2010-2023. The energy effectivity has very strong correlation with real GDP growth per capita, because both variables have sharply increased. The energy effectivity has unfavourable conditions for the researched period, because the euro per kilogram of oil equivalent energy averagely increased by 49% in EU-27, because of strong increasing trend of crude oil price at global market, while the real GDP per capita [sdg_08_10] at market prices euro increased by 32% in the same period. The sharply increasing crude oil price made press for decreasing final energy consumption [sdg_07_11] in EU-27, which decreased by 6%, but final energy consumption in households per capita [sdg_07_20] in kilogram of oil equivalent (KGOE) decreased by 16% between 2010-2023 (Table-1). Therefore, decrease of the final energy consumption and the energy effectivity resulted by global oil price increase and not the real productive energy consumption.
In case of energy effectivity during the researched period in EU-27 *not the energy effectivity increase, but this decrease was based on the increase in euro per kilogram of oil equivalent energy*. The investment share of GDP by institutional sectors [sdg_08_11] decreased by 0.9% in EU-27 in 2023 comparably the level of investment share in 2010. This did not result so considerable final energy consumption decrease. In case of Hungary investment share of GDP by institutional sectors increased by 5%, more intensively increased than in cases of EU-27, while the final energy consumption at national level decreased by 12% and the final energy consumption per capita by the same rate 16% as well as in EU-27. In Hungary the energy effectivity was unfavourable as in case of EU-27, because as the euro per kilogram of oil equivalent increased by 52%, more than level of EU-27. The energy effectivity could have been better if the euro per kg of oil equivalent had decreased (Table-1, Eurostat 2024). According to employment the GDP per capita has averagely increased by 32% in EU-27 for the period of 2010-2023, while the energy effectivity was less favourable because of the euro per kilogram of oil equivalent increased by 49% in the same period. This means that the GDP per capita increased less than increase of price of energy resources. Mostly the world price of crude oil increased pressed the increasing growing rate of GDP based on increasing production cost leading to decreasing competitiveness of the EU-27 at the global market (Table-1, Eurostat 2024). Pollitt (2024) examined the 2021–2023 energy crisis in Europe exacerbated by the energy consequences of the full-scale Russia-Ukraine war and the European Union's attempts to co-ordinate EU-27 responses to the crisis. Naturally the real GDP growth per capita and energy cost as kilogram of oil equivalent can sharply be different in cases of EU member states. The *oil equivalent energy price* mostly increased by 138% but the real *GDP per capita* increased by 95% in *Ireland*, which last one was the second largely after Luxembourg by 98%. In Ireland the costly energy prices built into the final market price of products, which resulted considerable increase of real GDP per capita, while the *investment share of GDP* considerably increased by 6% in 2023 comparably to investment in 2010 after increasing by 7% in Estonia and by 6% in Lithuania and averagely by 0.9% in EU-27. The energy price increased by 93% in *Estonia* as second after Ireland, but real GDP per capita increased by 38% over the average level of EU-27. The third biggest increase of oil equivalent energy price has increased by 73% in *Romania* but the real GDP per capita could increase by 62% for the same period, in spite that investment share of GDP decreased by 1%. But in case of *Poland* the biggest fifth increase of oil equivalent energy price was 61% and the real GDP growth rate per capita increased very little by 13%, which was little more than by 4% in Finland by 8% in Austria and by 11% in Sweden, Spain and Germany. Also, similarly the result of Netherlands was 63% in field of energy price increase and by 15% little more than in Poland in field of real GDP growth increase per capita (Table-1, Eurostat 2024).
In case of *Germany* the oil equivalent energy price increased by 54% more than average level of EU-27, as 49%, but also real GDP per capita growing rate increased only by 11% less than in Poland, while investment share of GDP increased by 2% in 2023 comparably level of 2010. Therefor the little increase of investment could not stimulate to increase real GDP per capita. In case of *France* in sipe that the oil equivalent energy price increased by 39% less than in Germany and EU average level, but the 2%

increase of investment share of GDP from 2010, the real GDP per capita increase was only by 10%. This also shows less favourable economic conditions of France than EU average level. In case of *Italy*, as the other considerable big EU member state the energy price increased by 31% with increasing 2% in investment share, but GDP per capita increase was only by 7% in the researched period. This result was better than by decreasing 3% in Greece and 4% in Finland, but the economic conditions of Italy were unfavourable. The energy price increased by 20% in *Finland* and by 42% in *Sweden* as less than EU average level, but the investment share of GDP in Finland was decreasing 1% and decreasing 3% in Sweden as much as in Greece in the same period. But their real GDP per capita increase was 4% in Finland and 11% in Sweden. This less GDP per capita increase mostly resulted by decreasing line of investment share of GDP (Table-1, Eurostat 2024). In case of *Denmark*, This EU member state has the less increase price of energy by 2% for the same period and its investment share of GDP was by 4%, more than three biggest EU member states, as Germany, France and Italy. But this investment share was not enough to increase rate of real GDP growth per capita, which was 20% under the EU average level of 0.9%. In case of *Hungary* there was highly level of per kilogram of oil equivalent energy by 52% accompanying with higher level investment share of GDP by 5% and both ensured by 45% increase in field of real GDP per capita increase, considerably over the EU average level. In order that EU-27 can ensure more green economy and economic development the EU extended the share of renewable energy in gross final energy consumption. Therefore, this share became averagely 27% by the end of 2023. From this point of view the top green economic Sweden in EU by 66% with Finland by 51% and Denmark by 44% (Eurostat [sdg_07_40] 2024. The three largest EU economies have little less share than the EU average level, because Germany and France by 22% and Italy by 20. The green energy mostly comes from solar, water and wind energy sources. The EU can help member states additionally to the national supports and self-financing resources of firms and companies. The *Figure-1* shows that the share of renewable energy has sharply increased from 16% in 2010 to 27% in 2023, of which increase was more than half during this period in EU-27 (Table-1, Eurostat 2024). In the study there are not strong correlations of employment issues with energy effectivity in EU-27 within the researched period from point of view of the statistical approach. But the employment rate from 20 to 64 years, in percentage of total population, in 2010 and in 2023 (Eurostat, [sdg_08_40] 2024) shows considerable increase from 67% to 77% and the long-term unemployment rate from 15 to 74 years in percentage of population in the labour force in 2010 and in 2023 show important decrease from 4% to 2% (Eurostat, [sdg_08_40] 2024). These development trend can also ensure considerable increase in field of real GDP per capita in the researched period. The modern innovative technology should follow the *strategy of new green technology*, which needs for the highly developed, educated and skilled human resources. This green innovative technology demands for more educational period for human resources, which can be proofed by less *earlier leavers from education and training* (Eurostat [sdg_04_10] 2024) in annual percentage of population from 18 to 24 years total in 2010 and in 2023, which decreased from 12% in 2010 to 8% in 2023 at the average level of EU-27. This shows considerable one-third decrease. Also, *tertiary educational attainment* (Eurostat [sdg_04_20] 2024), annually total from 25 to 34 years percentage based the International Standard Classification of Education (ISCED 2011) was 34% in 2010, which increased to 45% at the average level of EU-27. This increase was considerable about one-third. Also, the economic growth resulted low level of population unable to keep home adequately warm by poverty status [sdg_07_60] from 12% in 2010 to 9.5% in 2023 as average level of EU.

6. CONCLUSIONS

The study overviews the correlations and significance among different economic-ecological variables for EU-27 during the researched period 2010-2023. The main issue is to realise such economic innovative green development to implement energy effectivity by using educated and skilled human resources. Naturally, the increasing euro per kg of oil equivalent energy *opposite* to the efficient energy effectivity did not stimulate to increase the investment share of GDP and by little increase of investment to increase to the real GDP per capita in the researched period. Also, the increasing trend in investment

share of GDP can contribute to the increase of real GDP per capita. Some Central-East European EU member states as Bulgaria, Croatia, Latvia, Lithuania, Hungary, Romania and Slovakia and over this region Ireland considerably contributed to increase average level of real GDP per capita in EU-27. The increasing highly level of employment, decreasing level of long-term unemployment, less early leavers from education and training from 18 to 24 aged years and increasing tertiary education attainment from 25 to 34 aged years stimulated increase of real GDP per capita. The share of renewable energy in gross final energy consumption has considerably increased for the researched period, which ensured the EU to realize its main goal to decrease carbon-dioxide gas emissions by 20% in the 2020 years. The population unable to keep home adequately warm by poverty status considerably increased between 2010 and 2023 as average level of EU, which shows increase of living standard in EU-27. For the future economic growth of the EU-27 there is important, that more efficient energy effectivity should be followed by the economic policy to transfer into more green development by using more educated and skilled human resources in wide-side sectors. Also, the investment share of GDP in the EU member states should increase by decreasing unemployment rate, extending the tertiary educational attainment and increasing the share of renewable energy in gross final energy consumption accompanying with less final energy consumption at the national economic level and in fields of households per capita.

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SOME EXPERIENCES CONCERNING LOWER MISSISSIPPI RIVER VALLEY IN US

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Abstract:
The study focuses on main features of Lower Mississippi River Valley accompanying with some economic and ecological conditions. The study overviews these economic and ecological conditions for the period of 2010 and 2021. From point of view the study analyses annual freshwater resources, nitrous oxide emissions from different sectors, as agriculture, power industry energy, transport energy, foreign direct investment, forest areas, high-technology export in manufactured exports, imports of goods and services in percent of GDP, industry including construction in value added in percent of GDP, inflation, merchandise trade in percent of GDP, population density and urban population growth. The study analyses correlations of different economic and ecological variables based on statistical package for social sciences. The research analyses correlations of annual freshwater withdrawals, which are declared as very strong valued by -82.8% with nitrous oxide emissions from power industry energy, by 89.8% with forest area in km2, by -80.8% with industry including construction in value added in GDP and by 80.1% with population density per km2 of land area. The high-technology export can globally provide more increasing competitiveness for the US economy. Develop more favourable conditions of Lower-Mississippi River – even with Upper Mississippi River – for interest of the American society.

***Keywords:* Annual freshwater resources, Competitiveness, Correlations, High-technology export, Imports of goods, Nitrous oxide emissions**

1. INTRODUCTION

The article overviews the Lower Mississippi River Valley, which comes from the meeting point, where Missouri River goes to the Upper Missouri River and from here the Lower Mississippi River goes to the delta of the Mississippi river in the Mexico-gulf. The Mississippi river collects all of amount of water from the watershed of this river, which is about 3.2 million km2, as the biggest watershed of the world. The study emphasizes importance of the Mississippi river valley in fields of large sized watershed, irrigation system, water supply and inside ship-navigation system at national level. The study focuses on some main features of the Lower Mississippi River Valley as economic and ecological conditions. The study overviews these economic and ecological conditions for the period of 2010 and 2021.
From point of view the study analyses annual freshwater resources, nitrous oxide emissions from different sectors, as agriculture, power industry energy, transport energy, foreign direct investment, forest areas, high-technology export in manufactured exports, imports of goods and services in percent of GDP, industry including construction in value added in percent of GDP, inflation, merchandise trade in percent of GDP, population density and urban population growth. The analyses are based on the database of World Development Indicators, which can obtain data from national resources of the US. *America's Watershed Initiative* (AWI 2015; AWI 2018) aims at sustaining a water use system to support efficient and effective agricultural, industrial and energy productivity. Access to high-quality water in sufficient, reliable quantities is critical for many economic sectors in local, state and national economies. The Mississippi River Watershed's water resources are used in power generation, agricultural irrigation, animal husbandry and industrial production (AWI 2018; USEPA 2022).

Ward (et al 2023) declared that Resist–Accept–Direct (RAD) framework may enhance large-river management by promoting coordinated and deliberate responses to social-ecological trajectories of change. RAD-informed basin-, reach-, and site-scale decisions could: (1) provide cross-spatial scale framing; (2) open the entire decision space of potential management approaches; and (3) enhance coordinated inter-jurisdictional management in response to the trajectory of the Upper Mississippi River hydrograph (Ward et al 2023; see more in Wang et al 2023; Wang-He 2022).
The research emerged some main *hypotheses* concerning main correlations among different economic and ecological variables for the Lower Mississippi River Valley in the US, which are as follows (Table 1-2-3; World Development Indicators 2010 – 2021, US Environmental Protection Agency 2022)
The research analyses correlations of annual freshwater withdrawals (***AnnFreshW1***) by any value ***with*** nitrous oxide (N2O) emissions from power industry energy (NitEPoIn3), forest area in km2 (ForestAre6), industry including construction value added in GDP (IndConGDP9) and population density as people per km2 of land area (PopDens12).
Analyse the correlations of nitrous oxide (N2O) emissions from agriculture in million tons CO2 equivalent (Mt CO2e) (***NitEPoAgr2***) by any values ***with*** high-technology exports in percent of manufactured exports (HTechEx7).
Research correlations of nitrous oxide (N2O) emissions from power industry energy in Mt CO2e (***NitEPoIn3)*** by any values ***with*** nitrous oxide (N2O) emissions from transport energy in Mt CO2e (NitEPoTra4) and high-technology exports in percent of manufactured exports (HTechEx7), imports of goods and services in percent of GDP (Import8) and industry including construction in value added in percent of GDP (IndConGDP9), merchandise trade in percent of GDP (MeTraGDP11) and population density of people per km2 of land area (PopDens12).
The research focuses on correlations of nitrous oxide (N2O) emissions from transport energy in Mt CO2e (***NitEPoTra4***) by any values ***with*** high-technology exports in percent of manufactured exports (HTechEx7), imports of goods and services in percent of GDP (Import8), industry including construction, as value added in percent of GDP (IndConGDP9), merchandise trade in percent of GDP (MeTraGDP11) and population density of people per km2 of land area (PopDens12).
As it is mentioned above, the *first four economic* variables as annual freshwater withdrawals, nitrous oxide (N2O) emissions from agriculture (Mt CO2e), nitrous oxide (N2O) emissions from power industry energy (Mt CO2e) and nitrous oxide (N2O) emissions from transport energy (Mt CO2e) have important role for analysing correlations among the variables. The following chapter analyses researching methods of the study. The study analyses correlations of the different economic and ecological variables based on *the statistical package for social sciences (SPSS),* which provides wide-side possibility for overviews of research for different variables and their connections for the Lower Mississippi River Valley Basen in the US (Field 2020 and Horváth – Mitev 2023). The principal component analysis can be followed in the *Figure 1* where the principal line "X" gets the component-1 and the principal line "Y" get component-2 in the Figure 1.

2. RESULTS AND DISCUSSION

The study overviews the basic correlations among economic and ecological variables based on data of Table 2 and Table 3 concerning the Lower Mississippi River Valley (World Development Indicators 2010 – 2021, US Environmental Protection Agency). The values of variables show the strengthen of correlations among variables. This means if the values are between 0.800 and 1.000 (80% - 100%) the correlations among variables are ***very strong***. But if the values are between 0.500 and 0.800 (50%-80%) the correlations are only ***strong***. If the values are under 0.500 (50%), which means that the correlations are weak, therefore these correlations are not important for the researching. Naturally the values of correlations among variables can also be written in percentage. There are also the other issues, namely that if the values are negative, this means the correlations are inversely proportional to other positive valued variables, but direct proportional to the same negative valued variables. Naturally the positive valued variables are also direct proportional to other positive valued variables. In this case

of the study the negative or positive valued of variables means opposite changing direction and not more or less values. The positive values of variables are increasing trends, and the negative values of variables are decreasing developing trends (Table 3).
From point of view the very strong correlations mostly are emphasized in this study (Table 3).
The research analyses correlations of annual freshwater withdrawals total in percent of internal resources (***AnnFreshW1***) can be declared as *very strong* valued by -82.8% ***with*** nitrous oxide (N2O) emissions from power industry energy (NitEPoIn3), by 89.8% with forest area in km2 (ForestAre6), by -80.8% with industry including construction value added in percent of GDP (IndConGDP9) and by 80.1% with population density as people per km2 of land area (PopDens12). This hypothesis can be accepted.
In cases of above-mentioned correlations, the correlations of annual freshwater withdrawals total in percent of internal resources are opposite with nitrous oxide (N2O) emissions from power industry energy (NitEPoIn3), because the green policy for protecting natural resources resulted in *decreased pollutions* by considerable decreasing nitrous oxide (N2O) emissions. At the same time freshwater withdrawals use increased.
Correlations of nitrous oxide (N2O) emissions from agriculture in million tons CO2 equivalent (***NitEPoAgr2***) are contradictive *very strong* valued by -85.1% ***with*** high-technology exports in percent of manufactured exports (HTechEx7). In any way the high-technology exports can increase by decreasing trend of nitrous oxide (N2O) emissions from agriculture, because the production process provided by used high-technology can ensure modern technology for agriculture with less nitrous oxide (N2O) emissions from agriculture based on developed *agro-business*.
Also it can be declared that correlations of nitrous oxide (N2O) emissions from power industry energy in Mt CO2e (***NitEPoIn3)*** are *very strong* valued by 97.2% ***with*** nitrous oxide (N2O) emissions from transport energy in Mt CO2e (NitEPoTra4) and by 92.6% with high-technology exports in percent of manufactured exports (HTechEx7), by 88.4% with imports of goods and services in percent of GDP (Import8) and by 95.4% with industry including construction as value added in percent of GDP (IndConGDP9), by 88.3% with merchandise trade in percent of GDP (MeTraGDP11) and by -99.1% with population density of people per km2 of land area (PopDens12). Naturally considerable decreasing nitrous oxide (N2O) emissions from power industry energy in Mt CO2e can make positive effects on the decreasing gas emission of other sectors and some other variables could less decrease as high-technology exports in percent of manufactured exports, imports of goods and services in percent of GDP, merchandise trade in percent of GDP, when population density of people per km2 could increase during the researched period.
It can also be declared that wide-side correlations of nitrous oxide (N2O) emissions from transport energy in Mt CO2e (***NitEPoTra4***) are *very strong* valued by 83.3% ***with*** high-technology exports in percent of manufactured exports (HTechEx7), by 94.2% with imports of goods and services in percent of GDP (Import8), by 99.2% with industry including construction, as value added in percent of GDP (IndConGDP9), by 92.4% with merchandise trade in percent of GDP (MeTraGDP11) and by -95.2% with population density of people per km2 of land area (PopDens12).
According to results of the study correlations of high-technology exports in percent of manufactured exports (***HTechEx7***) are very strong valued by 80.9% ***with*** merchandise trade in percent of GDP (MeTraGDP11) and by -91.2% with population density of people per km2 of land area (PopDens12).
Based on the funds of the study it can be declared that correlations of imports of goods and services in percent of GDP (***Import8***) are *very strong* valued by 93.5% ***with*** industry including construction, as value added in percent of GDP (IndConGDP9), by 99.3% with merchandise trade in percent of GDP (MeTraGDP11) and by -82.1% with population density of people per km2 of land area (PopDens12). The little decrease of high-technology exports in percent of manufactured exports does not make negative effects on the other economic variables.
The research emphasizes that correlations of industry including construction as value added in percent of GDP (***IndConGDP9***) are *very strong* valued by 90.5 % ***with*** merchandise trade in percent of GDP (MeTraGDP11) and by -93.5% with population density of people per km2 of land area (PopDens12).

The development of industry including construction can affect the increase of merchandise trade in percent of GDP, in spite that both variables have less share of the GDP by more increase of other sectors.
Based on the research it can be stated that correlations of inflation GDP deflator by annual changes in percent (***Inflation10***) are contradictive *very strong* valued by -84.4% ***with*** urban population growth annually in percent (UrbPopG13). The inflation could increase by 4.6% in 2021 because of influences of health crisis in 2020.
In this case-study based on the results of research we can declare that correlations of merchandise trade in percent of GDP (MeTraGDP11) are *very strong* by -81.6% ***with*** population density of people per km2 of land area (PopDens12). *All these correlations are very strong and accepted in cases of the above- mentioned correlations. Correlations among economic variables are based on the features of each year* (Table 2 and Table 3).
In the ***Figure 1*** correlations of componet-1 including MeTraGDP11, Import8, NitEPoTra4, NitEPoIn3, HTechEx7, IndConGDP9, PopDens12 and NitEPoAgr2 comparing with component-2 including UrbPopG13 and Inflation10 (WDI 2010 – 2021; US EPA 2022). This Figure 1 shows that how correlations of component-1 can be comparing with component-2. In *second quarter* of the coordinate system, - *up-left-side* – where the economic features of 2021 and 2019 are at principal line "X" in the negative position, the economic variables of component-1 generally either decrease or little increase; and at principal line "Y" economic variables of component-2 either increase or little decrease in positive position.
The data of Table 2 are relevant of the second quarter of the coordinate system in the Figure 1 in the US. Because in 2010 and 2015 in positive position of *third quarter* in *under-right-side*, the merchandise trade in percent of GDP, imports of goods and services in percent of GDP, nitrous oxide (N2O) emissions from transport energy in Mt CO2e**,** nitrous oxide (N2O) emissions from power industry energy in Mt CO2e, high-technology exports in percent of manufactured exports, industry including construction, value added in percent of GDP, population density in number of people per km2 of land area, and nitrous oxide (N2O) emissions from agriculture in Mt CO2e *considerably increased or little decreased* than these were in 2019 and 2021 in second quarter.
In 2010 and 2015 the increase clearly was higher for example by 21.6% and by 21.0% in merchandise trade in GDP and by 22.6% and by 21.4% in high-technology exports in percent of manufactured exports more than in 2019 and 2021.
The nitrous oxide (N2O) emissions from agriculture (NitEPoAgr2) little increased in 2015 and little decreased in 2010, while in 2019 and 2021 this more increased by 2.4% and by 0.6%.
In 2010 and 2015 the imports of goods and services in percent of GDP increased by 15.9% and by 15.3% more than in period of 2019-2021.
In 2019 and 2021 two sectors namely emissions from power industry energy (NitEPoIn3) achieved considerable decrease by 44% and by 46%; the nitrous oxide (N2O), emissions from transport energy (NitEPoTra4) achieved considerable decrease by 19% and 25%. Naturally the nitrous oxide (N2O) emissions of two sectors are favourable, when this gas emission decreased in these years.
In the *third quarter* of the coordinate system, - *down-right-side* – where the economic features of 2015 and 2010 at principal line "X" in the positive position, the economic variables of component-1 generally increase or little decrease, but at principal line "Y" in the negative position economic variables of component-2 either decrease or little increase.
In the *fourth negative quarter* of the coordinate system, - *down-left-side* – where the economic features of 2020 at principal line "X" and at principal line "Y" in the negative position, the economic variables of component-1 generally decrease or little increase, and in the negative position economic variables of component-2 either decrease or little increase.

Some main features of Lower Mississippi River Valley concerning Mexico Gulf

Formed in 2010, *America's Watershed Initiative (AWI)* is a collaborative organization working with hundreds of businesses, government, academic and civil organizations to find solutions for the challenges of managing the Mississippi River stretching across 31 US states and 2 Canadian provinces, and the more than 250 rivers that flow into it.

The Mississippi River Delta Basin is defined as all the land and shallow estuarine area between the two northernmost passes of the Mississippi River and the Gulf of Mexico. The basin is in Plaquemines Parish, Louisiana, south of the city of Venice. Baptiste Collette Bayou, on the east side of the river, and Red Pass, on the west side, form the basin's northern boundary. This area is also referred to as the Plaquemines-Balize or *"bird's foot" delta*. The Mississippi River has had a profound effect on the landforms of coastal of Louisiana. The entire area is the product of sediment deposition following the latest rise in sea level about 5,000 years ago. This deltaic process has, *over the past 5,000 years, caused the coastline of south Louisiana* to advance gulfward from 15 to 50 miles (24 km to 80 km), forming the present-day coastal plain. Mississippi River Delta Basin comprises approximately 521,000 acres (2108,41 km2) of land and shallow estuarine water area in the active Mississippi River delta. Approximately 83 percent of this area, or 420,000 acres (1700 km2), is open water. The 101,100 acres (410 km2) of land in the basin are characterized by low relief, with the most prominent features being natural channel banks and dredged material disposal areas along the Mississippi River, its passes, and man-made channels. Coastal marshes make up approximately 61,650 acres (250 km2) or about 61 percent of the total land area in the Mississippi River Delta Basin. Eighty-one percent of this marsh is fresh, 17 percent is intermediate, and 2 percent is brackish saline (AWI 2018).

Originally in *Iowa* in Upper Mississippi River Valley, where it is estimated that over 1 billion pounds of ***nitrogen*** (cc. 0.45 million tons= cc. half million tons) has been delivered to the Mississippi River and its tributaries in two of the last four years, resulting in a *doubling of the nitrogen* load leaving the state for the last 20 years. Crop production, even on well-managed fields, invariably results in nutrient losses through surface runoff and tile drainage.

According to the *United States Geological Survey (USGS) within AWI*, which reports that *annually* about *half million tons of nitrogen* are delivered to Upper Mississippi River Valley and then originally from all of Mississippi River Valley Watershed *1.5 million tons of nitrogen* goes to the *Mississippi River Delta* and then to *Mexico-Gulf*, of which a large proportion is from agriculture. This natural damage caused ***dead zone***, which has annually become averaged 5,408 square miles (14,000 square km) for the last 5 years based on the Hypoxia Task on the coast of the *Luisiana* seacoast in Gulf of Mexico. From point of view of *highly level of nitrogen* coming from wastewater as fertilizer and livestock manure, which needs for creating water treatment because of causing growth of *harmful algae* that eventually reduces dissolved oxygen in the *dead zone* in Gulf of Mexico. These efforts have restored over 10,000 acres (40 km2) of wetlands between *Venice* and the *Gulf of Mexico* since 2009 and have been vital in rebuilding coastal Louisiana. As part of the ongoing beneficial use of dredged material program, the *US Army Corps of Engineers* (USACE) also recycles dredged material from the Mississippi River to build small islands that create obstacle against further additional deposition of sediment and mitigate erosion. Some efforts, such as Gunn Island, have been intentionally designed to provide habitat for migratory and nesting birds (America's Watershed Initiative Steering Committee 2015; America's Watershed Initiative 2018).

Long-term suspended sediment loads in the river average 436,000 tons per day; they have ranged from an average of 1,576,000 tons per day in 1951 to a still considerable average of 219,000 tons per day in 1988. Between 1974 and 1990 the *land loss* rate in the Mississippi River Delta Basin averaged 1,072

acres (4 km2) per year, or 1.69 percent of existing land area (Dunbar et al 1992; Kendall et al 2021; Slocum et al 2005). This loss is the result of compaction, subsidence, hurricanes, tidal erosion, sea level rise, and human activities. The total land area lost in this basin over the last 60 years has been approximately 113,300 acres (458 km2). *In recent decades, the delta front has been building laterally into the Gulf of Mexico at a rate of 300 to 400 feet/year (122 m). Currently, the delta front is located at the edge of Mexico-Gulf's continental shelf. As a result, large volumes of sediment are now being lost to the continental slope or ocean floor, where water depths are up to 1,000 feet (304 m) and, therefore, not conducive for land-building* (AWI 2018; AWI 2015; AWI2 20015; Guo 2023).

The other difficulty concerning the Mississippi River Valley is that for the last decades the exceed ***flood discharge thresholds*** have been increasing from result of changes in precipitation and landscape conditions. Therefore, extreme flooding occurred in the watershed in 5 of the last 10 years. The opening of the spillway *reduces flood risk* in New Orleans, but also has ecological consequences, namely the massive influx of fresh water into *Lake Pontchartrain* not only affects the fish and shellfish there but also brings *high doses of nutrients* into the lake, that can cause certain types of *algae to grow*, which can be toxic.

The Mississippi River Watershed is vital to economic development of the US. It provides drinking water for population of the country, water for agriculture and industry, and the ***world's largest inland navigation system***. These ports are vital to US exports and imports, and maintaining access for deep draft shipping is critically important. The watershed is a recreational and environmental treasure. It is also facing growing challenges. Therefore, the vital to the Lower Mississippi *deep draft navigation* has substantially increased since 2015. Therefore, the maintenance and operations of the ship channel in Mississippi River are needed, because average age of transportation infrastructure along the Mississippi River is far beyond their designed life expectancy of 50 years.

According to the natural issues the national economy needs for more investment for supporting and financing economic prosperity in direction to diversity structure. From point of view this development trends, the employment has relatively remained at highly level compared to other regions and states of the US, owing in part to the regions' incredible economic diversity, which includes agriculture, energy, industry, transportation, and recreation, among many other sectors. However, as important as the Mississippi River Watershed is to the national economy, national investment to support that the watershed has not kept pace (AWI 2018; Abramson 2024).

Fields of economic prosperity, which are follows:

INVEST**:** $2 Billion in annual funding through private and government sources to address critical needs in inland navigation, regenerative agriculture, ecosystem function, and flood and water management.

LEARN**:** Establish a science agenda, improve data information systems, and report progress against goals to inform decisions and ensure wise use of funds.

EDUCATE**:** An informed citizenry—coupled with transparent and data-informed decision-making by basin leaders—will facilitate progress toward goals.

ACT**:** Greater collaboration among complementary and competing interests will improve ability to manage in a way that values all uses of this tremendous resource.

This 2020 Mississippi River Watershed Report Card describes *progress toward achieving the goals established in the 2015,* highlights some of the important work that partners across the watershed are doing to make positive change, and documents the additional work that remains.

The *Mississippi River Valley Watershed provides some main economic favourable conditions:*

$50 billion in agricultural products, flood mitigation and resilience, habitat for diverse and important living resources, recreational opportunities and public land access and 25% of America's total hydropower. *Additionally, to the favourable conditions, there are some facts which are threatened:*

more frequent and extreme floods and droughts, lagging habitat and coastal restoration funding, continued urbanization and agricultural intensification and persistent nutrient and chemical pollution.

Nutrient runoff that contributes to the "Dead Zone" in the Gulf of Mexico.

The *outdoor recreational activities* are valued at $4 billion per year, supporting 420,000 jobs. Likewise, the Mississippi River Delta, with its unique assemblage of species, is known for fishing and hunting.

The Mississippi River Watershed provides *energy from hydropower* (25% of the nation's hydropower is produced in the Mississippi River Watershed) and renewable sources like wind, solar, and biofuel, and there is capacity for more (AWI 2018; Allan-Palmer 2006).

Restored *networks of floodplains*, wetlands, and uplands that work together to provide benefits such as flood damage reduction, water storage, and habitat conservation. The floodplains can be "reconnected" to river channels, so that rivers can safely expand beyond their banks as floodwaters rise.
Providing *critical habitat for aquatic and bird species*, combating land loss caused by subsidence and erosion, and reducing nutrient load.
Along the coast, wetlands provide critical storm surge protection to vulnerable communities during hurricanes and tropical storms. The floodwater storage to minimize flood damage to infrastructure and property and prevent overall loss of critical wetland habitat (America's Watershed Initiative Steering Committee 2015; America's Watershed Initiative 2018).
The lack of growth in the Mississippi River delta, on a large scale, is as much a coast-wide problem as a basin problem. This source of ample fresh water and sediment, which shaped the Louisiana coast as we know it, is no longer producing a net gain in coastal wetlands, placing the entire Louisiana coast at risk. To achieve the goal of maintaining the current level of wetland functions and offset the high rates of wetland loss, measures which net large gains in coastal wetlands must be pursued. *Any major reduction in the flow of the Mississippi River will result in a reduction of the naturally maintained channel. This would in turn result in increased dredging requirements* (AWI2 2015; AWI 2018).

The correlations of economic and ecological variables show considerable *decreasing trends* of the *nitrous oxide (N2O)* emissions in million-ton CO2 equivalent first from power industry energy and then transport energy in 2019 and 2021. But *in 2020* two sector more decreased their nitrous oxide (N2O) emissions based on their less intensive activities, which can be resulted by corona virus caused health crisis. There is also a difficulty for economy of the US, that the nitrous oxide (N2O) emissions in million-ton CO2 equivalent *from agriculture* has been *continuously only little increasing* for the period of 2010-2021. But in 2020 the nitrous oxide (N2O) emissions of agricultural sector have been at top increase by 2.4% since 2010. Also, the agricultural sector *should decrease pollutions into the Mississippi river* to defence natural environment even at seacoast of Louisiana state accompanying with decreasing high

risk of nitrogen contamination in the river. The high-technology exports have had considerable share in percent of manufactured exports for researching period, but only a little decrease was in 2019 and 2020, which was partly accused by corona virus difficulty in 2020. The high-technology export can globally provide more increasing competitiveness for US economy. The wide-side national cooperation should be increasing to develop more favourable conditions of Mississippi River.

3. FIGURES, TABLES AND EQUATIONS

The tables, figures and maps of this chapter can show the correlations of economic and ecological variables with each-others. Also, these can help to understand more trends of changes of the variables.

Table 1. *Means of economic variables for researched period of 2010-2021*

Economic variables	Means of economic variables	Years	Source
AnnFreshW1	Annual freshwater withdrawals, total (% of internal resources)	2010-2021	World Development Indicators
NitEPoAgr2	Nitrous oxide (N2O) emissions from Agriculture (Mt CO2e)	2010-2021	World Development Indicators
NitEPoIn3	Nitrous oxide (N2O) emissions from Power Industry (Energy) (Mt CO2e)	2010-2021	World Development Indicators
NitEPoTra4	Nitrous oxide (N2O) emissions from Transport (Energy) (Mt CO2e)	2010-2021	World Development Indicators
FDINetIf5	Foreign direct investment, net inflows (BoP, current US$)	2010-2021	World Development Indicators
ForestAre6	Forest area (sq. km)	2010-2021	World Development Indicators
HTechEx7	High-technology exports (% of manufactured exports)	2010-2021	World Development Indicators
Import8	Imports of goods and services (% of GDP)	2010-2021	World Development Indicators
IndCoGDP9	Industry (including construction), value added (% of GDP)	2010-2021	World Development Indicators
Inflation10	Inflation, GDP deflator (annual %)	2010-2021	World Development Indicators
MeTraGDP11	Merchandise trade (% of GDP)	2010-2021	World Development Indicators
PopDens12	Population density (people per sq. km of land area)	2010-2021	World Development Indicators
UrbPopG13	Urban population growth (annual %)	2010-2021	World Development Indicators

Source: World Development Indicators, 2023

***Table 2**. Main economic indicators of the US between 2010-2021 in percent*

Economic variables	2010	2015	2019	2020	2021
Component-1, Principal line "X"					
MeTraGDP11	21.6	21.0	19.6	18.0	20.0
Import8	15.9	15.3	14.5	13.0	14.5
NitEPoTra4	0.1	-10	-19	-31	-25
NitEPoIn3	0.1	-23	-44	-52	-46
HTechEx7	22.6	21.4	18.7	19.5	20.0
IndConGDP9	19.3	18.5	18.2	17.3	17.7
PopDens12 (Number of people)	33.8	35	36	36.2	36.3
NitEPoAgr2	0.1	-0.1	2.4	1.0	0.6
Component-2, Principal line "Y"					
UrbPopG13	1.0	0.9	0.7	1.2	0.4
Inflation10	1.2	1.0	1.7	1.3	4.6
Component-3, Principal line "Y"					
ForestAre6	0.1	0.5	0.3	0.4	0.3
AnnFreshW1	14.8	15.8	15.7	15.9	15.6
FDINetIf5	0.1	94.0	19.7	-48	55

Source: World Development Indicators 2010 – 2021, US Environmental Protection Agency

***Table 3**. Correlation Matrix[a] among main economic indicators of the US between 2010-2021*

		AnnFresW1	NitEPoAgr2	NitEPoIn3	NitEPoTra4	FDINetIf5	ForestAre6	HTechEx7	Import8	IndConGDP9	Inflation10	MeTraGDP11	PopDens12	UrbPopG13
Correlation	**AnnFresW1**	1.000	.344	**-.828**	-.771	.117	**.898**	-.728	-.722	**-.808**	.073	-.702	**.810**	-.041
	NitEPoAgr2		1.000	-.598	-.464	-.344	-.034	**-.851**	-.462	-.367	.054	-.555	.574	-.190
	NitEPoIn3			1.000	**.972**	.199	-.512	**.926**	**.884**	**.954**	-.417	**.883**	**-.991**	.241
	NitEPoTra4				1.000	.320	-.469	**.833**	**.942**	**.992**	-.422	**.924**	**-.952**	.128
	FDINetIf5					1.000	.361	.230	.555	.266	.252	.592	-.096	-.586
	ForestAre6						1.000	-.362	-.439	-.549	-.119	-.393	.498	.088
	HTechEx7							1.000	.767	.780	-.284	**.809**	**-.912**	.264
	Import8								1.000	**.935**	-.129	**.993**	**-.821**	-.202
	IndConGDP9									1.000	-.402	**.905**	**-.935**	.096
	Inflation10										1.000	-.090	.517	**-.844**
	MeTraGDP11											1.000	**-.816**	-.205
	PopDens12												1.000	-.364
	UrbPopG13													1.000

a. This matrix is not positive definite.

Source: World Development Indicators 2010 – 2021, US Environmental Protection Agency

Based on the SPSS analyse

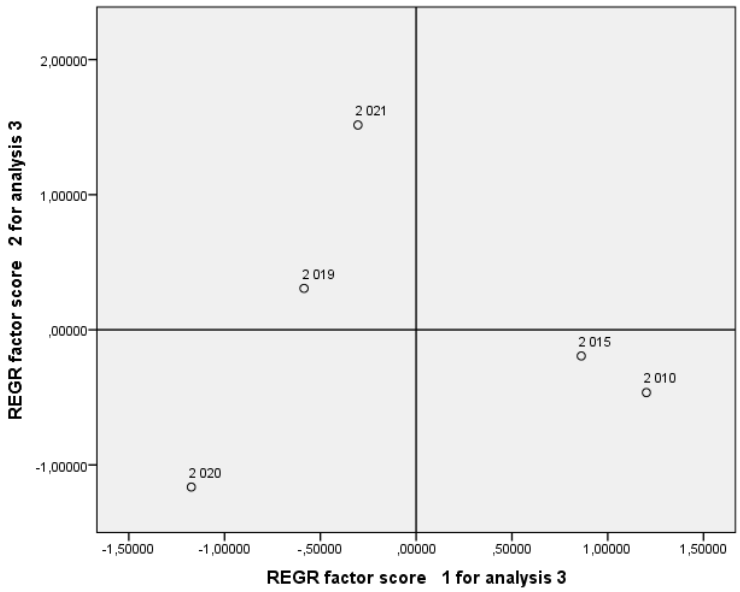

Figure 1.
Source: World Development Indicators 2010 – 2021, US Environmental Protection Agency
Based on the SPSS analyse
Correlations of componet-1 including MeTraGDP11, Import8, NitEPoTra4, NitEPoIn3, HTechEx7, IndConGDP9, PopDens12 and NitEPoAgr2 at the principal line "X" with component-2 including UrbPopG13 and Inflation10 at the principal line "Y"

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EFFECT OF WASTE EGGSHELL PARTICLES ADDITION ON THE OPTICAL PROPERTIES OF PAPER

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Abstract:
*For this study, eggshells were collected during household food processing, and their protein membrane was manually separated from each eggshell. Membrane-removed eggshell waste was subjected to washing, drying, grinding, and sieving processes. The size of the prepared eggshell powder was less than 45 μm and was used, as an alternative to industrially precipitated calcium carbonate, in the production of laboratory paper. Filter paper was used as the basis for the paper pulp, while the filler content was varied from 5 to 20%. To determine the effect of adding eggshell powder on the optical properties of the paper, papers with the same $CaCO_3$ content were produced in parallel as a control. It was observed that adding both types of fillers, eggshell powder and calcium carbonate, to laboratory-produced paper increases its reflectance. However, the impact on L*a*b* values of paper is different for these fillers. Calcium carbonate increases its lightness (L* value) more than eggshell powder, and reduce the a* and b* value unlike eggshell powder that increases them.*

Keywords: *eggshell waste, filler, optical properties, paper*

1. INTRODUCTION

Dominantly used fillers in papermaking industry are mineral ones divided in two main classes, natural and synthetic. Worldwide, commonly used fillers in papermaking are ground calcium carbonate (GCC), talc and clay as natural inorganic, particulate materials and precipitated calcium carbonate (PCC) and titanium dioxide as synthetic ones [1]. They have an important role in reducing cost in papermaking industry [2,3,4] as their usage can replace up to 40% of fibrous material in a paper pulp [5]. Beside the fact that their usage is leading to direct cost savings, they also improve various properties of the manufactured paper. Fillers normally help in paper dimensional stability, appearance, opacity, brightness (if the filler is brighter than the pulp), surface smoothness and gloss, improve the reduction in printing strike through and uniformity in printing ink receptivity on paper [6,7]. However, due to excessive use of fillers, the abrasive properties of mineral fillers are manifested in increased wear of the wire on the paper machine and the printing plates in the printing press. Excessive amounts of filler reduce the bonding in the paper, thereby increasing the tendency to dust [1]. An alternative to most used calcium carbonate can be waste biomaterials such as chicken eggshells or marine shellfish (marine molluscs, mussels, clams, oysters, scallops and cockles) as they contain high calcium carbonate content [8]. FT-IR analysis of eggshell waste indicated an almost identical chemical composition to precipitated calcium carbonate or PCC, a synthetic calcium carbonate product that is used in large quantities in paper production [9]. Namely, chemical composition of eggshells is calcium carbonate in the form of calcite ranging from 94–97% and 3–4.5% organic matter. While other elements such as MgO (0.83%), SO_3 (0.66%), P_2O_5 (0.43%), Al_2O_3 (0.15%), K_2O (0.08%), SiO_2 (0.07%), Cl_2O_3 (0.06%) and SrO (0.04%) have been detected in minor traces [8]. The composition of the eggshell may vary slightly depending on the feed the chickens are fed. [10]. The colour of the shell does not dictate the amount of calcium carbonate. Although the eggshell can be brown- or white-coloured, the colour does not affect the amount of calcium carbonate [8]. Eggshell is a globally available waste material, and in year 2020 chicken egg

production was reached up to 86.7 million tonnes [11]. This abundant and discarded by-product can serve as a potential replacement for calcium carbonate derived from sedimentary rocks. Reuse of all kinds of waste is a closely connected with the awareness of environmental pollution and a lack of certain materials. Therefore, it is of great importance to examine the possibilities of alternative raw materials usage for the paper industry. So far there were some studies about eggshell usage as a paper filler [12,13,14,15,16] and paper coating [17].

2. EXPERIMENTAL

Materials in this study were household waste eggshell, calcium carbonate precipitated, p.a. (Kemika d.d., Croatia) and round filter paper, blue ribbon (Whatman, Germany). As the filter paper made from high-purity cellulose fibres, specifically cotton linters, was used as a source of cellulose fibres in Table 1 some of its basic characteristics are given.

Table 1: Characteristics of filter paper

Filter paper	Weight (g/m^2)	Thickness (mm)	Ash Content (%)
Blue ribbon	85	0.15	≤ 0.01

2.1 Waste eggshell powder (ESP) preparation

Processes of preparing waste eggshell powder (ESP) included: separating protein membrane from eggshell, washing in tap water, drying in a Memmert drying oven at a temperature of 40 °C, grinding in an IKA laboratory grinder and sieving to the desired particle size of < 45 μm by Retsch AS 200 vibratory sieve shakers. In Figure 1 the final product, waste eggshell powder, gained from waste eggshell is presented.

Figure 1: Eggshell waste and waste eggshell powder (ESP)

2.2 Laboratory paper production

For laboratory paper production as a source of fibres ashless/blue ribbon filter paper was used (Whatman, Germany). 80 g of absolutely dry filter paper was disintegrated in tap water (T = 40°C; t = 20 min) to a consistency of 5% in an Enrico Toniolo disintegrator. During the homogenization process in the homogenizer Frank, PTI (t = 5 min), tap water was added so that a total of 10 L of pulp was prepared, which was divided into batches in which fillers (calcium carbonate precipitated, p.a. (Kemika d.d., Croatia) or prepared ESP) were added in a defined proportion given in Table 2.

Table 2: Samples of laboratory paper

Paper sample	w ($CaCO_3$), %	w (ESP), %
FP (control)	-	-
FP_5%$CaCO_3$	5	-
FP_10%$CaCO_3$	10	-
FP_15%$CaCO_3$	15	-
FP_20%$CaCO_3$	20	-
FP_5%ESP	-	5
FP_10%ESP	-	10
FP_15%ESP	-	15
FP_20%ESP	-	20

Laboratory papers of 150 mm diameter and defined composition were made on a Buchner funnel with a vacuum pump and were dried by laboratory sheet dryer Rapid Kothen.

2.3 Optical properties analysis

The colorimetric values (CIE L*a*b* system) and reflectance in a visible spectrum for all laboratory paper samples were measured by spectrophotometer X-Rite SpectroEye under a D50 illuminant and 2° standard observer. All presented results are mean value of 20 measurements.

3. RESULTS AND DISCUSSION

From Figure 2 it is evident it is visible how the addition of any type and amount of filler increases reflectance value of the laboratory paper throughout the visible part of the spectrum.

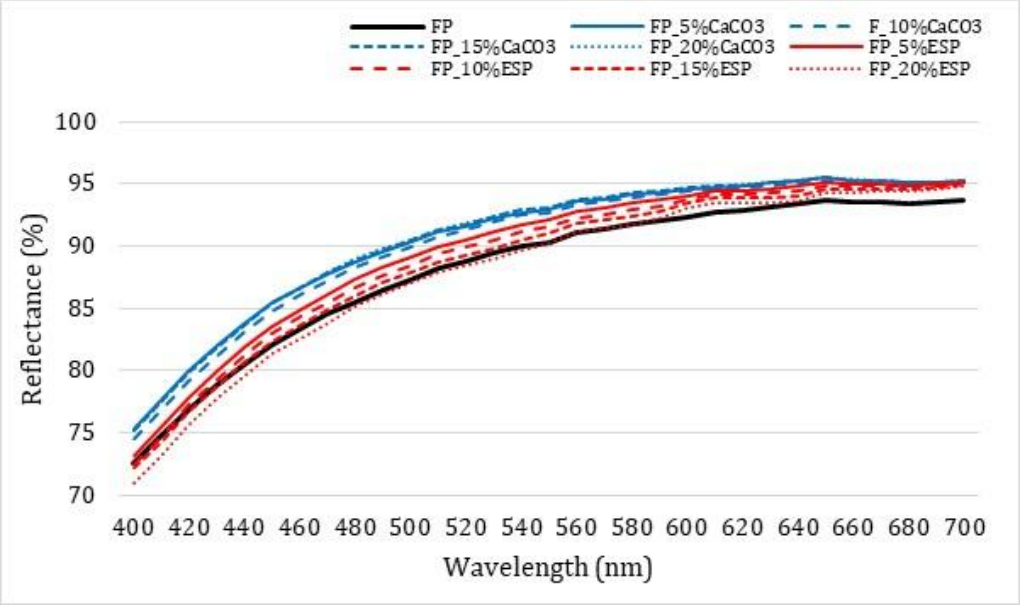

Figure 2: Reflectance of laboratory papers with addition of fillers

The optical properties of each paper are determined by the types of cellulose fibres and any added materials. Filter papers due to their application, are made from high-purity cellulose fibres (often bleached to achieve a white, pure colour and remove impurities) and is ashless (do not have fillers). By adding any type of filler ($CaCO_3$ or ESP) in paper pulp, the reflectance of the paper will be increased by increasing the scattering and reflection of light (Fig. 2). Namely, these fillers break the bonds between the fibres, creating more surfaces from which light is reflected [1].

Table 3: Colorimetric values of laboratory papers with addition of fillers

Paper sample	L^*	a^*	b^*
FP (control)	96.02 ± 0.14	0.19 ± 0.07	6.57 ± 0.26
FP_5%$CaCO_3$	97.08 ± 0.12	-0.10 ± 0.05	5.96 ± 0.21
FP_10%$CaCO_3$	97.02 ± 0.11	-0.13 ± 0.06	6.28 ± 0.30
FP_15%$CaCO_3$	97.14 ± 0.12	-0.20 ± 0.07	6.09 ± 0.29
FP_20%$CaCO_3$	97.17 ± 0.13	-0.21 ± 0.05	6.11 ± 0.24
FP_5%ESP	96.73 ± 0.12	0.02 ± 0.09	6.73 ± 0.29
FP_10%ESP	96.52 ± 0.15	0.15 ± 0.08	6.83 ± 0.20
FP_15%ESP	96.29 ± 0.18	0.30 ± 0.10	6.89 ± 0.22
FP_20%ESP	96.03 ± 0.18	0.45 ± 0.07	7.17 ± 0.10

Fillers such as calcium carbonate ($CaCO_3$) have high refractive indices and small particle sizes, which causes light to be reflected more within the paper structure, which also leads to greater perceived whiteness and brightness of paper. Since in this study, filter paper with R457 blue light whiteness of 80.01 was used as the basis for making laboratory paper, the addition of calcium carbonate and ESP did not significantly increase the CIE L* value of the laboratory papers (Tab. 3). Elementary colour component a* of laboratory paper is changed by filler addition. Namely, the presence of $CaCO_3$ reduces this value by shifting it to green area, while presence of ESP increases this value in red area. Adding filler to the paper does not have a significant effect on the b* colour component value, as it is approximately the same for all laboratory papers and is in the yellow range.

It should be emphasized that the effects of filler on the optical properties of paper in this study are not drastic, given that filter paper was used as the basis. But if recycled fibres had been used as the basis in the paper pulp, the addition of selected fillers would have had a much greater impact on the optical values. Since the basis of ESP is calcium carbonate, it is evident from this study that ESP can be a potential alternative to industrially precipitated calcium carbonate.

4. CONCLUSION

Reusing all types of waste is becoming an environmental imperative today. This research shows that eggshell powder, which is almost identical to the chemical composition of precipitated calcium carbonate, can improve the optical properties of papers when used as a filler. Of course, improvements of optical properties would be more significant if this filler would be added to a pulp of recycled fibres or unbleached fibres.

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ECO-FRIENDLY PRINTING WITH AGRO-INDUSTRIAL WASTE: REVIEW OF ADVANCES IN FUNCTIONAL TEXTILES

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Abstract:
The growing demand for sustainable and eco-friendly solutions in the textile and graphic industries highlights the urgent need to replace conventional synthetic dyes with natural alternatives. This review aims to provide an overview of recent advances in the use of agro-industrial waste as a valuable source of bio-based pigments and binders for printing applications. The main objective is to demonstrate how natural colorants such as anthocyanins or carbon-based pigments like biochar and activated carbon can serve as options for achieving both aesthetic and functional properties in textiles. Furthermore, the review discusses the role of eco-friendly binders in formulating stable printing pastes. Special attention is given to functional outcomes such as antimicrobial activity, antioxidant capacity, and dielectric properties. By summarizing current progress and challenges, the paper emphasizes the potential of natural pigments and agro-industrial by-products to drive innovation in textile printing. The review also identifies existing limitations, including colour stability and scalability of production, and highlights future perspectives for integrating natural pigments into advanced functional materials. In this way, the study contributes to building a foundation for sustainable, innovative, and environmentally responsible printing technologies.

Keywords: *agro-industrial waste, natural pigments, eco-friendly printing, functional textiles.*

1. INTRODUCTION

Modern graphic and textile industries face increasing sustainability and environmental pressures, largely due to the extensive use of synthetic dyes and pigments. Although highly durable, their complex chemistry limits degradation, and their by-products may be toxic, allergenic, or carcinogenic, posing risks to human health and ecosystems [1]. Consequently, research is increasingly directed toward natural dyes and pigments, particularly plant- and mineral-based colourants incorporated into printing pastes. Extracts from agro-industrial waste (e.g., grape pomace and blackberry) are especially attractive because they combine colouring ability with antioxidant and antimicrobial potential, enabling value-added functional textiles while supporting waste valorisation [2].

2. NATURAL INKS

Natural inks and dyes are organic or mineral colourants applied to various substrates, including textiles. While synthetic dyes dominate industry because of their colour range and permanence, natural dyes are gaining renewed interest due to biodegradability, low toxicity, and bioactive potential, reflecting their long-standing use before the advent of synthetic colourants [3]. **Plant dyes** constitute the most numerous groups and include pigments such as anthocyanins, flavonoids, tannins, curcumin, and chlorophyll, which are extracted from flowers, leaves, roots, fruits, or bark [4]. This group of dyes often possesses additional functionalities (antimicrobial and antioxidative properties), making them suitable for obtaining functional textiles [5]. **Animal dyes**, although less frequently used in contemporary research, had historical significance. The most well-known example is carmine, a red colour obtained from the cochineal insect, which was used to dye luxury fabrics [6]. Also, in ancient times, Tyrian purple from

sea snails of the genus *Murex* was used, which was a symbol of status and power [7]. **Mineral dyes** include pigments such as ochre, hematite, and ultramarine, which are distinguished by exceptional stability and resistance to light and washing. Their application in the textile industry is limited, but in combination with natural binders, they can contribute to specific functionalities, as UV resistance [4].
Contemporary research is focused on plant dyes due to their availability, low cost, and possibility of extraction from agro-industrial waste [5]. In this way, the ecological footprint of waste is simultaneously reduced and a new source of dyes for textile applications is obtained. The most common printing with natural dyes involves obtaining colour by grinding part of the plant into a powder sample and adding various thickening agents (alginates) which are subsequently treated as conventional screen dyes. Various researchers have investigated the intensity of colour (K/S) from alkanet [8][9][10], rhubarb [8][9], turmeric [9][11], marigold [11], madder [12], walnut bark [12][13], tamarisk, acacia [14], pomegranate bark [13][14], walnut shells, orange tree leaves, chamomile [13], henna [10][14][15], Japanese knotweed rhizome [16][17], sour dock [18][19], grape [5], or white pine [20][21]. Özgüney et al. investigated the applicability of Indian madder in printing, examining the effects of dye concentration and urea, type of fixing, temperature and duration of fixing, type of mordant and method of adding mordants [22]. El-Hennawi and colleagues (2012) used laccase enzymes instead of harmful mordants for fixing natural dyes [23]. Klančnik demonstrated the applicability of Japanese knotweed rhizome extract for screen printing on paper and textiles using synthetic thickeners [17]. In another investigation, Klančnik reported that methanolic extracts of *Impatiens glandulifera* flowers exhibit pronounced pH-dependent colour changes but also cause reduced paste viscosity at higher concentrations, limiting printability and leading to brownish colour shifts after drying due to non-anthocyanin phenolics [19].
Visual and spectrophotometric measurements of prints on various materials showed variations in colour depending on dye concentration and the basic colour of the substrate. Prints on virgin fibre paper (white) had a purple-blue tint, whilst on recycled paper (brown) they had a greenish-yellow tint. Alkaline printing paste gave greenish prints, whilst in the case of acidic printing paste, the prints were lighter and less chromatic [19]. Thakker, Sun and Bucknall used aqueous extracts of plant indigo *Indigofera tinctoria*, red quebracho *Schinopsis lorentzii* and plant flower forest flame *Butea monosperma*, which give blue, red and yellow colours, respectively. Black plant colour was obtained by mixing these primary colours. These colours were used in a cartridge ink-jet printer and properties of absorption and colour durability were investigated [24]. Savvidis et al. also used ink-jet printing dyes on a water basis prepared with natural pigments from henna Bixa orellana, acacia Acacia Catechu, pomegranate bark Punica granatum and yellow dock Rumex crispus. The physical and rheological properties of the prepared dyes—pH, conductivity, surface tension and viscosity—were measured over a period of 90 days to assess the stability of the dyes [15].

Red Shades

Anthocyanins are flavonoid pigments whose colour and stability depend on molecular structure and environmental factors such as pH and light [25]. In addition to colouration, anthocyanin-rich extracts exhibit antioxidative and antimicrobial properties [5] and are therefore widely explored as pH-responsive indicators in intelligent systems for food freshness monitoring [26]. Some examples relate to the production of agar/potato starch filled with anthocyanin [27]; cellulose nanofibril film for packaging based on anthocyanin from purple sweet potato and oregano essential oil [28]; purple sweet potato starch and pH indicator films based on peel connected with anthocyanin [29]; *Echium amoenum* anthocyanins incorporated into bacterial cellulose film [30]; gelatine films with anthocyanin [31]; and nanocomplexes of ovalbumin-propylene glycol alginate filled with anthocyanin [32]. However, stabilisation and delivery of these molecules is challenging because they are unstable under certain environmental conditions, leading to low bioavailability [33]. Ameri et al. developed a food-safe film for pH-indicator sensors on fish packaging using anthocyanin. Thanks to simple printing procedure, the solution is easily applicable to food packaging [34]. Betalain and betanin extracted from the peel of red pitaya and combined with anthocyanin extracted from the peel of Kyoho grape have been developed as dyes for piezoelectric inkjet printing and then printed as colorimetric indicators [35]. Sun and colleagues

developed a printing dye based on natural pigment from purple cabbage and successfully applied it in fish packaging for monitoring freshness [36]. Liu and colleagues combined anthocyanins from black goji berries with xanthan gum, they used screen printing for applying these applications [37]. Alshammari et al. screen printed a thermochromic dye from red cabbage anthocyanins on paper, the experiment showed reddish-purple tones in the acidic domain and pH-dependent colour changes [38]. A common combination of anthocyanins is with chitosan [39] or sodium alginate [5].

Blue Shades

Blue hues from nature are rare because only a few classes of natural pigments stably give blue colour and this is usually under specific environmental conditions. The main sources of blue hues are indigo compounds – indigotin from *Indigofera/Isatis tinctoria* – which in oxidised form give stable blue and are a classic choice for textiles [40]. These plants have been used for centuries in art for obtaining blue pigment. Phycobilins such as phycocyanin from *Spirulina*, a blue-green alga that grows in both salt and fresh water, give an intensely blue pigment but is extremely sensitive to light and heat [41]. Genipin-derived pigments such as *gardenia blue* arise from the reaction of genipin with amines/proteins [42]. There are anthocyanin systems also in which blue is achieved by changing the pH value to a neutral or alkaline medium. For strong blue hues, stable formulas combined from gardenia blue pigment and gelatine gels have been shown, which are suitable for food colours [43], and there are also blue edible ink-jet dyes from this pigment [44]. For textiles, the latest review and experimental work examine natural indigo *Indigofera tinctoria* and proposes direct pigment printing with bio-based binders, thereby preserving blue hues [45].

Yellow Shades

Yellow hues in nature most often come from curcuminoids from turmeric, carotenoids – β-carotene, lutein – flavonols such as quercetin or crocin. These pigments differ in solubility and stability: carotenoids and curcumin are hydrophobic and sensitive to light/oxygen, whilst crocins are water-soluble, but also sensitive to light [46]. Eco-friendly pastes with acrylic or polysaccharide binders such as PVA, alginate, chitosan, combined with dye from turmeric, are successfully combined in screen-printing dyes and give pure yellow. The quality of the print and viscosity parameters have been described in detail by Khankaew and Panichayupakaranant [47]. Similarly, Sharma and colleagues developed an acrylic, functional water-based dye with curcumin for packaging, with antimicrobial effect and rapid drying time/adhesion to substrate [48]. For ink-jet dyes, Wang and colleagues used crocin (*Gardenia jasminoides)* and successfully printed on wool using ink-jet printing. The dye showed high stability, they added tannin after printing, which significantly improved colour durability, and the prints had antibacterial effect against *S. aureus* and *E. coli*. They obtained pure yellow hues [49]. Additionally, natural extracts rich in flavonoids/carotenoids such as Japanese knotweed rhizome gave sufficiently durable yellow hues for screen printing [16] as well as for inkjet printing [17].

Black Shades

Black pigments are crucial for contrast in textile and graphic printing; however, the extensive use of carbon black raises health and environmental concerns. Biochar produced by biomass pyrolysis and activated carbon represent promising alternatives, providing dark coloration while supporting waste valorisation. Activated carbon is widely used due to its high surface area, porosity, and surface functional groups that enable adsorption and purification functions [50][51]. Pigment obtained from pyrolysis of certified wood waste is used in aqueous dispersion for printing on various materials. The particles are smaller than 400 nm and irregular shaped, with black shade in print [52], while bamboo-derived activated carbon showed shades from light grey to dark grey and black, with excellent durability against washing, light and friction [53]. Coal and activated carbon from biomass have been extensively investigated for use in the textile industry. Particles of bamboo charcoal were added to spinning solutions during the production of polymer fibres [54][55], and the biomass wood coal was applied into fabrics

by coating or printing techniques [39]. In one study, polyester non-woven fabric was treated with bamboo charcoal and acrylic resin to provide protection from infrared radiation and negative ions, as well as deodorisation [56]. In another study, activated carbon powder from coconut and palm kernel shells was applied by coating and pigment printing to cotton and polyester fabrics to provide deodorising properties against onion odour [57]. Çay and colleagues investigated the potential of using biochar from textile waste for improving the properties of textile materials. The addition of biochar improved moisture transport lowered drying time and increased water vapour permeability [58].

3. BINDERS AND MODIFIERS

Binders control the stability and rheology of printing pastes and enable uniform colour distribution, adhesion, and film formation on textile substrates. Sodium alginate is the most widely investigated bio-based binder due to its compatibility with aqueous extracts, adjustable viscosity, and limited interaction with colourants, while starch- and cellulose-based thickeners remain attractive biodegradable options but often require optimisation to improve mechanical durability. Polyvinyl alcohol (PVA) is a water-soluble, film-forming polymer with favourable barrier and abrasion resistance, frequently used as a mechanical reinforcement and printability enhancer in coating and printing systems [59]. Carrageenans, extracted from red marine algae, provide strong gel-forming and thickening behaviour and are increasingly explored in active and intelligent materials [60][61].

Current research increasingly favours multifunctional formulations based on binder–modifier combinations rather than single-component systems. Alginate- and carrageenan-based blends – often combined with CMC and anthocyanins – have been applied as pH- and TVB-N-sensitive indicators for fish and meat freshness monitoring [62][63][64]. In printed films and coatings, alginate/PVA and carrageenan/CMC mixtures offer tunable rheology and improved uniformity, while humectants such as glycerol support levelling during application [65][66]. Beyond packaging, alginate-based hydrogels filled with carbon nanomaterials (graphene/graphite) have enabled conductive inks for 3D printing and screen printing, supporting sensor and functional printing applications [67][68].

4. FUNCTIONAL PROPERTIES OF NATURAL INKS

One of the key advantages of natural dyes and pigments is not only improved environmental acceptability but also the potential to impart functional properties to printed textiles, enabling multifunctional and smart materials. The final performance of printed textiles depends on the substrate, colourant chemistry, printing method, and post-treatment, which jointly determine visual quality, durability (washing/light), and surface feel [69]. Compared with conventional finishing, printing allows a more economical and localised deposition of bioactive ingredients with controlled layer thickness and dosage, often reducing water and chemical consumption while enabling decoration and function within the same layer.

Bio-based binders combined with natural extracts can produce decorative prints with antimicrobial activity [5][70]. Chitosan is among the most frequently investigated antimicrobial additives and can be printed alone or combined with plant polyphenols to create functional patterns with attractive appearance [71][72]. In packaging-related systems, encapsulated essential oils applied by printing provide controlled-release effects (e.g., anti-odour/repellent layers) [73][74] , while pH-sensitive natural dyes (notably anthocyanins) are widely used in indicators responding to pH/TVB-N/VOC changes, from small “indicator spots” to full labels for fish and meat freshness monitoring [34][75][76]. Natural UV-absorbing compounds (e.g., flavonoids) can increase fabric UPF through printed layers, and mild crosslinking strategies can improve fixation and reduce leaching [69][77]. Green flame-retardant approaches based on phytic-acid-type systems have also been reported as simple coatings that can reduce flammability and, in some cases, moisture uptake [78][79]. Finally, biochar/graphite-based particles derived from agro-waste can be formulated into functional pastes for antistatic coatings, EMI shielding,

or adsorption layers; for wearable and sensor applications, additional optimisation of elasticity and wearability remains necessary [80][81].
Research conducted to date in the field of natural dyes and pigments shows that it is possible to formulate sustainable printing systems that imitate CMYK process colours. In this context, anthocyanins from agro-industrial waste represent the main source for magenta hues, whilst biochar, activated carbon and graphite give stable black and grey tones. The yellow component is in the literature often associated with readily available natural sources such as curcumin from turmeric or flavonoids from certain plant species, whilst cyan/blue is significantly harder to obtain from natural spectrum due to the limited distribution of plants which give stable blue pigments. For this reason, the largest number of investigations focus on the development of magenta and black components as the most promising for industrial application. This approach confirms that natural sources of colour, in combination with environmentally acceptable binders, can represent the foundation for the development of a process printing system with the potential to replace synthetic dyes in specialised applications of the textile and graphic industry.

5. CONCLUSIONS

This review indicates that eco-friendly printing based on natural pigments from agro-industrial waste is a promising route toward more sustainable textile production, offering both reduced environmental impact and opportunities for value-added functional textiles. Key conclusions are:

- Natural pigments from agro-industrial waste (e.g., anthocyanins, biochar, activated carbon) show strong potential to substitute conventional synthetic colourants in textile printing.
- Bio-based and eco-acceptable binders (sodium alginate, carrageenan) and supportive film-formers such as PVA enable stable, printable formulations across different printing techniques.
- Beyond coloration, natural-pigment prints can provide functional effects (antimicrobial, antioxidant, UV-protective), increasing product value.
- Remaining challenges include colour stability and scalability, requiring optimisation of extraction, formulation, fixation, and application parameters.
- Future work should prioritise standardised protocols for extraction and characterisation, together with long-term performance evaluation under real-use conditions.

Overall, the transition to sustainable textile printing is increasingly driven by environmental requirements and market demand. Addressing stability and scale-up limitations will be decisive for broader industrial adoption.

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RESEARCH ON THE INFLUENCE OF PACKAGING DESIGN AND MATERIALS ON CONSUMER CHOICE IN CHOCOLATE PURCHASES

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Abstract:

This study focuses on the design of cardboard chocolate packaging that combines functionality with aesthetic appeal. Emphasis is placed on the use of environmentally friendly materials and current trends in packaging design. Three distinct designs on three different materials were developed, each representing a unique approach – minimalist, eco-friendly, and playful – to explore how varying styles and materials influence consumer perception. Using an online survey and a focus group, consumer opinions regarding various packaging concepts were gathered. Prior to conducting the study, three hypotheses were proposed regarding the impact of packaging on consumer purchasing decisions. Hypothesis 1 stated: Packaging design significantly affects purchasing choices, with consumers showing greater preference for chocolate with distinctive and eye-catching packaging. Hypothesis 2 posited: Consumers favor packaging made from environmentally friendly materials. Hypothesis 3 suggested: Hidden messages within packaging enhance customer loyalty and encourage repeat purchases. Based on the results of the online survey and the focus group, the findings confirmed that consumers value eco-friendly materials and standout designs, while also responding positively to the idea of hidden messages as a strategy to foster repeat purchases. The study concludes that packaging strongly affects product perception, underscoring the importance of thoughtful, user-oriented, and environmentally conscious design.

Keywords: *Packaging design, Visual appearance, Cardboard, Survey, Consumer opinion*

1. INTRODUCTION

In today's highly competitive marketplace, packaging plays a far more complex role than merely protecting a product during transport and storage. It functions as a key visual and communicative element that influences consumer decision-making at the point of sale [1]. Beyond its protective role, packaging serves as a recognizable identity and a symbol of reliability and quality, both of which are essential for building consumer trust [1]. Consequently, packaging has evolved into a strategic marketing tool and one of the primary factors that capture consumers' attention and influence purchasing decisions [2].

Packaging often represents the first physical and visual point of contact between a product and a potential buyer, acting as a silent communicator that conveys information about product attributes and brand promises before direct interaction occurs [1]. This initial visual impression plays a crucial role in consumer psychology, as the external appearance of packaging strongly shapes expectations about the product inside [2]. Visual elements such as colour, imagery, texture, and typography are therefore deliberately selected to evoke specific emotional responses and associations in consumers' minds [2].

Among visual elements, colour is one of the most influential factors in how consumers perceive and react to products [3]. Different colour trigger distinct emotions, associations, and expectations, making colour a powerful tool in packaging communication [3], [4]. In the context of packaging design, colour is often the first element noticed by consumers, as it is more visible from a distance than text or detailed graphics [5]. When applied strategically, colour can create positive associations, enhance brand recognition, and stimulate desired emotional responses, provided it aligns with the target audience, product category, and intended message [3], [4].

In addition to color, form and shape play a significant role in shaping consumer perception. Different shapes communicate different values and emotional qualities, such as softness, friendliness, stability, or strength [3]. Although many packaging forms are standardized, unique and unconventional shapes tend to attract more attention and remain longer in consumers' memory, thereby contributing to stronger product differentiation on crowded shelves [6]. Establishing a coherent and recognizable design language is therefore essential for building product identity and memorability [3].

Typography represents another crucial design element in packaging, functioning as both a carrier of information and a visual expression of brand personality [6], [7], [8]. Similar to colour and form, typography conveys emotional and symbolic meaning and must be selected carefully to reflect the tone, values, and positioning of the brand [3], [9]. Serif typefaces are often associated with tradition, elegance, and authority, whereas sans-serif typefaces tend to communicate modernity, simplicity, and clarity [3], [7]. Clear and legible typography is particularly important for informative purposes, as it ensures effective communication and enhances readability [7], [8].

Material selection further extends the communicative and functional role of packaging. From a logistical perspective, packaging materials protect products throughout the supply chain, preserve freshness, and ensure safety and usability for consumers [1]. At the same time, materials contribute to the tactile experience of packaging, influencing perceived quality through texture, weight, and rigidity [6]. A pleasant tactile experience can encourage prolonged interaction with a product, increasing the likelihood of purchase, whereas poorly chosen materials may negatively affect perceived quality and usability [1], [6].

In recent years, material choice has become increasingly linked to sustainability, as rising environmental awareness has led consumers to favour eco-friendly and recyclable packaging solutions [2]. Research shows that consumer understanding and perception of sustainable packaging vary considerably, and that clear environmental communication and labelling can positively influence consumer attitudes and purchase intentions [10], [11]. Several studies indicate that sustainable packaging attributes – such as recyclability, renewable materials, and reduced environmental impact – are associated with higher consumer acceptance and more favourable brand evaluations, even though environmental concern does not always directly translate into purchasing behaviour [12], [13].

Packaging design also plays a crucial role in shaping consumers' perceptions of product quality. Well-designed and high-quality packaging can enhance perceived value and create expectations of superior product performance, even prior to consumption [14]. Conversely, weak or poorly designed packaging may undermine consumer confidence and reduce perceived product quality, regardless of the actual quality of the product inside [14]. Emotional responses triggered by packaging design – such as excitement, anticipation, or a sense of luxury – can further strengthen brand attachment and encourage repeat purchases [14].

Despite the increasing digitalization of marketing and retail environments, packaging remains one of the few tangible brand touchpoints available to consumers. Empirical research indicates that packaging can stimulate impulse buying, even when consumers did not initially intend to make a purchase, highlighting its strong influence on consumer behaviour at the point of sale [6].

The present research project focused on the design of chocolate packaging as a case study. The aim was to develop three distinct packaging concepts with diverse graphic identities that reflect contemporary market trends and consumer expectations [15], [16]. Each concept was paired with a different material choice and design approach – minimalist, eco-friendly, and playful – allowing for a comparative analysis of how visual style and material selection influence consumer perception.

The purpose of the research was to investigate how different design and material choices affect consumers' purchasing decisions. Consumer responses were collected and analysed through an online survey and a focus group, enabling the examination of both perceptual and emotional reactions to the proposed packaging designs.

The study was guided by three hypotheses. Hypothesis 1 proposed that packaging design significantly affects purchasing decisions, with consumers showing a stronger preference for chocolate products featuring distinctive and visually engaging packaging. Hypothesis 2 suggested that consumers favour

packaging made from environmentally friendly materials. Hypothesis 3 assumed that the inclusion of hidden messages within packaging enhances customer loyalty and encourages repeat purchases.

2. EXPERIMENTAL

The research project aimed to examine how packaging design and material selection influence consumer perception and purchasing decisions for chocolate products. Three packaging concepts were developed to reflect distinct stylistic and communicative approaches commonly identified in contemporary packaging design literature: an ecological (Figure 1), a minimalist (Figure 2), and a playful (Figure 3) concept [15].

Figure 1: Chocolate packaging with an ecological concept emphasizing natural appearance and sustainability cues

Figure 2: Chocolate packaging with a minimalist concept with restrained typography and high-contrast layout

Figure 3: Chocolate packaging with a playful concept characterized by vivid colors and informal graphic elements

Each prototype was produced using different paperboard materials suitable for professional folding carton production. The ecological concept was made from handmade paper derived from Japanese knotweed (*Reynoutria japonica*), produced at the Institute of Pulp and Paper (ICP Ljubljana), with a grammage of 230 g/m². Alternative fiber-based materials and invasive plant fibers have been identified in previous studies as promising sustainable resources for packaging applications due to their renewable origin and reduced environmental impact [17], [18]. The paper was naturally beige, with visible fibers and slight surface irregularities, which visually reinforced its ecological narrative. The minimalist concept was printed on black-through solid board (270 g/m²) with a smooth, non-reflective surface. The deep black background emphasized typographic contrast and created associations with elegance, exclusivity, and premium product positioning, characteristics commonly attributed to minimalist packaging aesthetics [19], [20]. The playful concept was produced using white GC1 food-grade cardboard (300 g/m²) with a coated front surface, offering high color saturation and durability, suitable for vibrant graphics and frequent handling.

All prototypes were digitally printed in CMYK and finished by manual folding and gluing to maintain dimensional consistency. The dieline was identical for all versions, ensuring that differences in evaluation could be attributed exclusively to graphic design and substrate properties, a standard control approach in packaging perception studies [19].

A quantitative online survey was completed by 57 respondents, of whom 73.2% were female and 26.8% male, with the majority belonging to Generation Z (91.2%). In addition, a moderated focus group consisting of 10 participants (90% female, 10% male, all Generation Z) provided qualitative feedback. The focus on younger consumers aligns with previous research indicating that this demographic is particularly responsive to visual design and sustainability cues in packaging [21].

Participants evaluated each packaging type for visual appeal, perceived quality, environmental friendliness, purchase intention, and emotional impression. Responses were collected using five-point Likert scales, a widely accepted method for measuring attitudes and perceptual responses in consumer research [22]. Open-ended questions were included to capture qualitative insights. Quantitative data were analyzed using descriptive statistics, while qualitative responses were thematically categorized to identify recurring patterns in emotional and symbolic interpretation.

3. RESULTS WITH DISCUSSION

The results revealed clear differences in how participants perceived the three packaging concepts and materials (Figure 4, Figure 5). According to the online survey (Figure 5), the minimalist design was chosen as the most appealing by 40% of respondents, followed by the playful design, while the ecological concept received the fewest votes, with 20% of participants selecting it as their preferred option. In contrast, within the focus group, the playful concept stood out markedly – it was favored by 70% of participants, mainly due to its vibrant colors, playful typography, and positive emotional tone.

The ecological concept, printed on handmade paper from Japanese knotweed, was appreciated mainly for its natural appearance and tactile quality, but it was perceived as less durable and somewhat less refined. This finding is consistent with previous research indicating that although consumers value sustainable packaging attributes, these do not necessarily translate into the highest aesthetic preference or purchase intention [23].

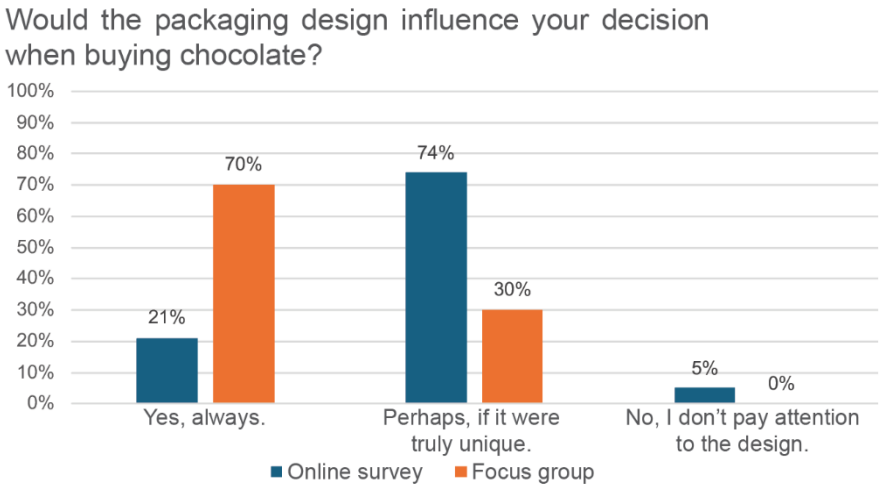

Figure 4: Impact of packaging design on chocolate purchase intentions

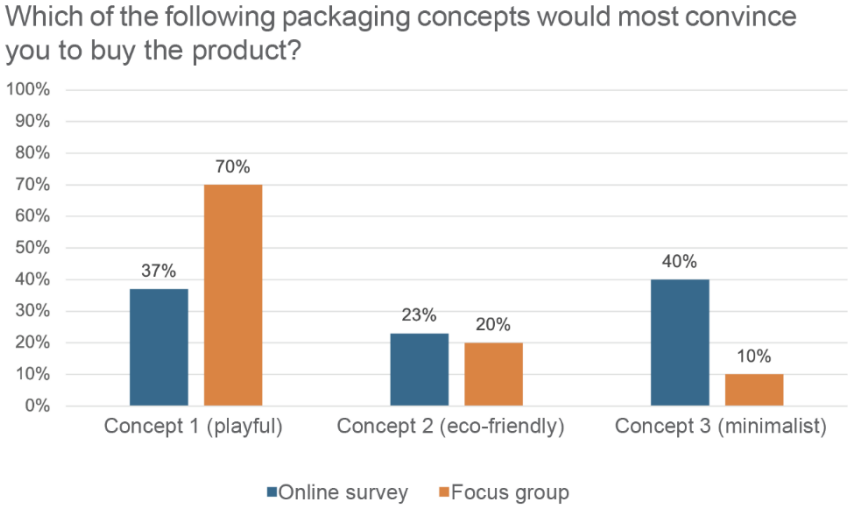

Figure 5: Preferred packaging concept influencing chocolate purchase decisions

Participants consistently rated the ecological packaging highest for environmental friendliness, with an average score of 4.8 out of 5, confirming that sustainability remains a key consumer value. The minimalist packaging achieved strong scores for premium perception, with an average score of 4.2 out of 5, associated with elegance and modern aesthetics. The playful design achieved the highest overall rating for visual appeal, with an average score of 4.6 out of 5, reflecting its vivid colors and emotionally engaging presentation.

The material evaluation added valuable context to these findings. The black solid board used in the minimalist concept was described as elegant, modern, and high-quality, although some respondents noted it felt "cold" or "too formal." The Japanese knotweed paper was praised for its unique texture and visible natural fibers, which conveyed ecological authenticity; however, a number of participants mentioned that it appeared less resistant to handling and moisture. The white GC1 cardboard used for the playful version was viewed as visually bright, structurally solid, and suitable for vivid colors, making it the most universally accepted substrate in terms of usability and perceived quality.
Responses concerning the hidden message – a subtle graphical element symbolizing natural origin and emotional warmth – were particularly significant. In the online survey, 65% of respondents stated that discovering such a hidden detail would delight them, while 32% reported that it would motivate them to repurchase the product (Figure 6). Within the focus group, these effects were even more pronounced: 80% of participants reported positive emotional responses to the hidden message, and 70% stated that it would encourage brand loyalty and repeat purchase. These results demonstrate that even minimal symbolic cues can enhance consumer engagement and strengthen brand perception. Similar effects of subtle symbolic and sensory cues on emotional engagement, brand recall, and product appreciation have been reported in previous consumer and packaging studies [24] .

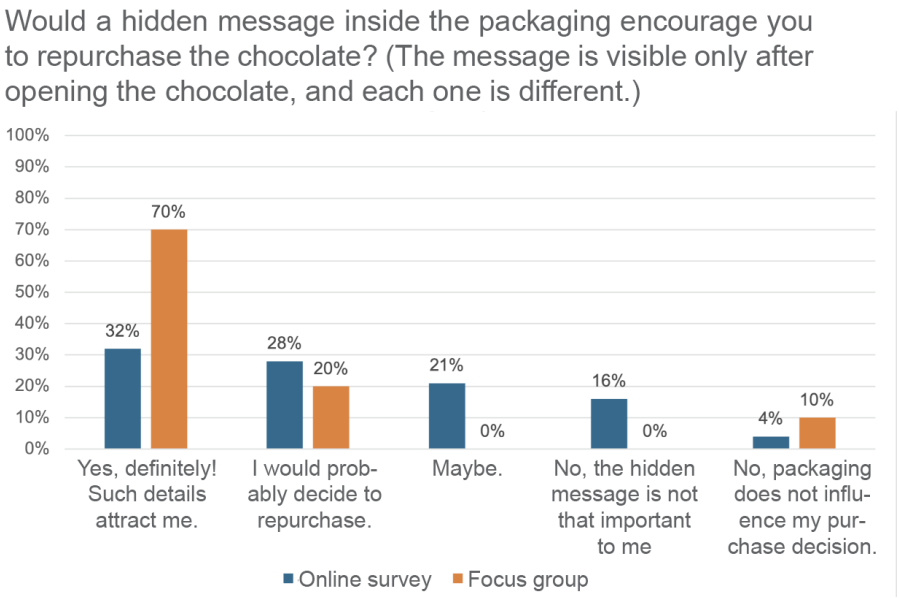

Figure 6: Effect of a hidden message on consumers' willingness to repurchase chocolate

Qualitative feedback from the focus group further supported these results. Participants described the playful design as friendly, fun, and emotionally engaging; the minimalist design as sophisticated and luxurious; and the ecological design as authentic and artisanal. Those who consciously noticed the hidden message reported stronger emotional connection and recall, confirming that subtle symbolic elements can successfully reinforce brand storytelling.

Overall, both visual design and material selection substantially affected consumer evaluation. Packaging that combined coherent graphic expression, tactile quality, and symbolic communication achieved the highest overall effectiveness and credibility in representing a brand's identity.

4. CONCLUSIONS

The research confirmed that packaging design plays a crucial role in consumer decision-making. The results demonstrated that consumers preferred packaging that was visually distinctive, emotionally engaging, and conveyed a sense of quality. Sustainability also proved to be an important factor, as environmentally friendly materials enhanced the perceived responsibility and trustworthiness of the brand.

The findings supported the first hypothesis, which stated that packaging design influences consumer purchasing decisions. The playful design received the highest ratings for attractiveness and purchase intention, confirming that visually appealing packaging can significantly increase consumer interest.

The second hypothesis – that consumers prefer packaging made from environmentally friendly materials – was also confirmed. The ecological packaging, made from Japanese knotweed paper, was rated highest for environmental awareness and brand responsibility, even though it scored slightly lower in visual appeal.

The third hypothesis proposed that a subtle or hidden message embedded in packaging design contributes to greater customer loyalty and repeat purchases. This was partially confirmed, as participants expressed stronger emotional connection and brand recall when the design included implicit symbolic elements, such as natural motifs or personal storytelling. However, long-term loyalty could not be fully assessed within the scope of this study.

In summary, the study demonstrated that the combination of aesthetically distinctive, sustainable, and emotionally meaningful packaging creates the most positive consumer response. These results emphasize the importance of aligning visual communication, material selection, and brand values to achieve both functional efficiency and ethical resonance with consumers.

Future research could extend this study by involving a broader demographic sample, additional product types, and an exploration of interactive or digital packaging solutions.

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CHANGES IN THE GLOSS OF OXIDATIVELY DRIED OFFSET PRINTS DURING THE DRYING PROCESS

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DOI: 10.12700/STAR.2026.220
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Abstract

In this article, we examine the changes in the gloss of offset prints after printing. At the moment of printing, the ink transfer occurs under the influence of the pressure force and several processes are initiated simultaneously: the ink is absorbed into the print medium, and the ink begins to crosslink under the influence of oxygen in the air. The ink is applied to the print medium while still wet and reflects the light radiation falling on it differently than the already dried ink. The aim of our study is to find a correlation between the change in surface gloss and the drying process of the printing ink. During the test prints, we used oxidatively dried printing ink and two paper-based print media with different structures, absorbent offset paper and glossy art paper with a coated surface. For both types of paper, measurements were made immediately before printing, immediately after printing, and in the hours and days that followed. The measurement results and their evaluation confirm that the surface gloss of the prints changes as a function of time. The drying time, the gloss change, and the formation of the cross-linked structure are influenced by the storage conditions. In the case of absorbent paper, the printing ink loses its surface gloss, while in the case of non-absorbent paper, the gloss increases during the drying process, since the ink film dries on the surface of the print medium, and the formation of the cross-linked structure also takes place here.

Keywords*: offset printing, offset ink gloss, color measurement, paint drying, color change*

1. INTRODUCTION

The Dry-back effect: the color change of color products printed in the printing house during the drying of the ink. During direct printing, during sheet-by-sheet quality control, the ink on the prints is not yet dry, so the print is still “wet” at that moment and reflects light differently than after a few hours or days, when it has dried. Therefore, different data is received by the sensor of the measuring instrument than when examining a dry print. In a wet state, the brightness of the print is also different, and they create a different color sensation than after complete drying. The topic of my doctoral thesis is the investigation of back-drying of prints, i.e., the determination and explanation of the color change that occurs during print drying. The objective of this poster is to determine how, under given conditions, the brightness of prints changes over time during drying, and to what extent this phenomenon affects color reproduction.

2. MATERIALS AND METHODS

For the test, the test image (Figure 1) was produced using autotype four-color offset printing technology (Heidelberg Printmaster 52-4) on offset and coated, glossy art paper.

Figure 1: Test image used during the test

Preliminary material tests were performed on the printing media used under operating conditions for weight per square meter, thickness, absorbency, opacity, tear strength, and surface gloss (Table 1).

Table 1 Properties of the printing media used

Property	80 g/m² Offset Paper	130 g/m² Glossy Coated Paper
Basis Weight (g/m²) (or Grammage)	*79,4*	*124,6*
Thickness (µm)	*98,2*	*93,6*
Opacity (%)	*2,3*	*1,94*
Surface Water Absorption; Cobb60 (g/m²)	*58,6*	*63,5*
Tear Strength	*16*	*11*
Surface Gloss (%)	*3,1*	*68,9*

During the test printing 4-color autotype inks with oxidation drying were used, their viscosity values were between 100 and 140 Pa x S. During the permanent fixation (drying) of the printed image, chemistry (during oxidative polymerization, the carbon chains of unsaturated organic compounds break down and connect due to oxygen absorption, creating giant molecules) and physical processes (incorporation) take place. These processes and the actual drying take days. The test printing was carried out on a Heidelberg Printmaster 52-4 type 4-printing press with an alcohol dampening unit.

3. THE MEASUREMENTS

We performed tests on the test prints with two types of instruments:

- Operation Manual IGT Gloss Meter G75 to determine the degree of gloss.
- XRite exact Spectrophotometer to measure density, L*, a*, b* values, and tone value growth.

The prints were tested in two runs. First, immediately after printing, gradually increasing the time interval between measurements for 3 hours. Then, one sheet of the test prints was stored in a closed place under operating conditions, protected from direct sunlight, and one sheet was also kept under the same conditions, in a place where it was exposed to direct sunlight. The sheets were stored for 2 weeks, and their gloss was measured once a day. The results of the test were as follows:

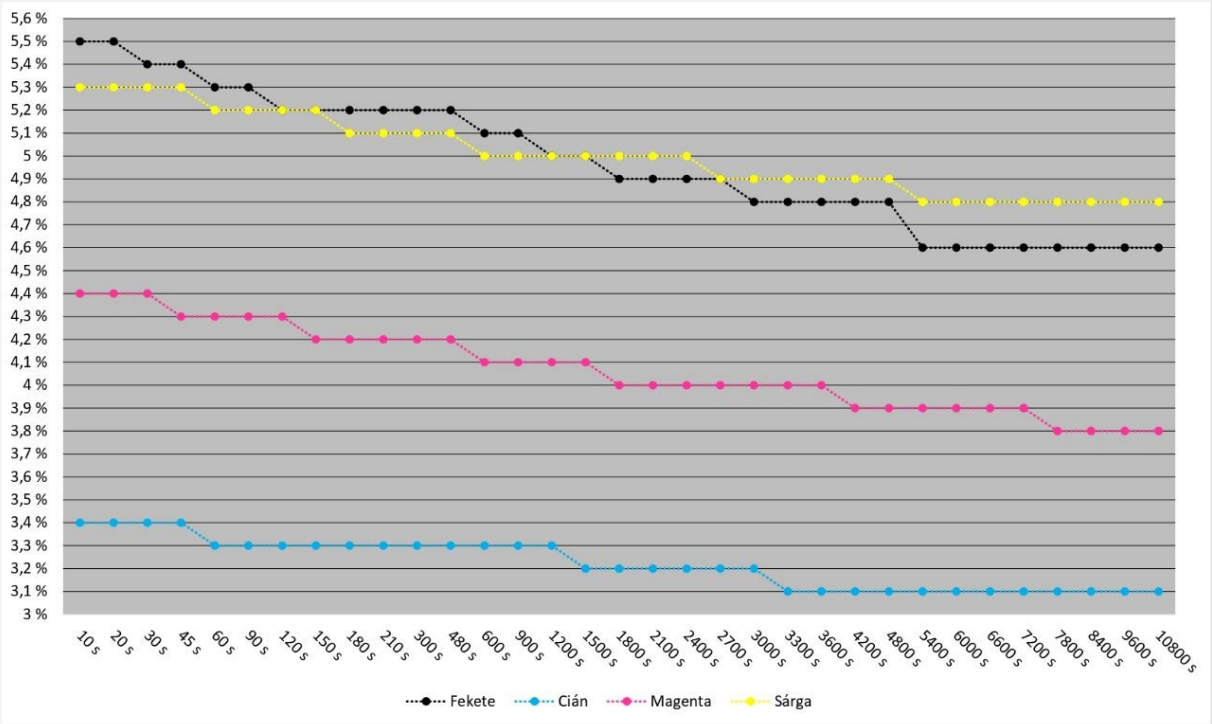


Figure 2: Gloss change on offset paper

In the case of absorbent, porous print media, no significant gloss change is observed after printing. The reason for the decrease in gloss value is that the binder and pigments of the printing ink penetrate more deeply into the paper fibers and drying also takes place here. As a result, a film layer with a more uneven surface is formed on the surface of the print media, which diffusely reflects the light rays. The measurement results show that the density of all colors except black decreased by approximately three to four hundredths of a value within three hours after printing, under operating conditions, under standard D65 illumination. When printing on offset paper or similar absorbent media, the color reproduction of fresh prints always appears lighter. However, in the case of black, drying is inversely proportional to the change in color perception, with black shades and solid tones appearing brighter and cooler over time. The color changes occurring during proofing and the subsequent few hours show a large color difference for black and magenta colors.

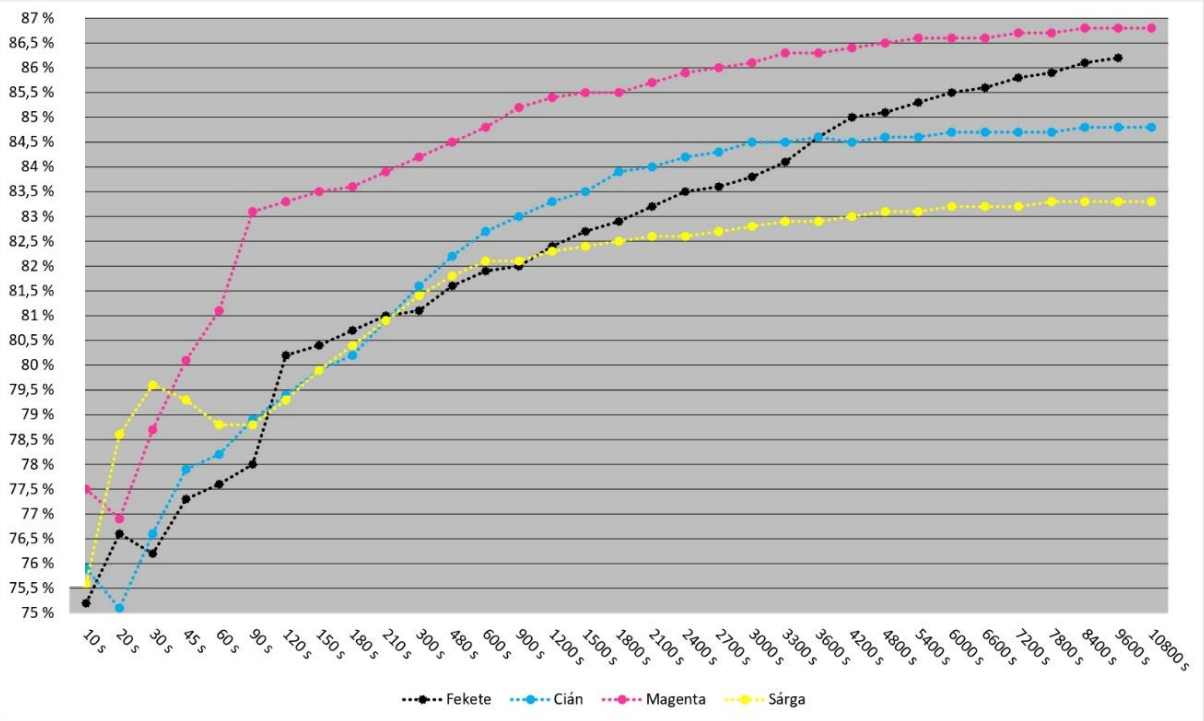
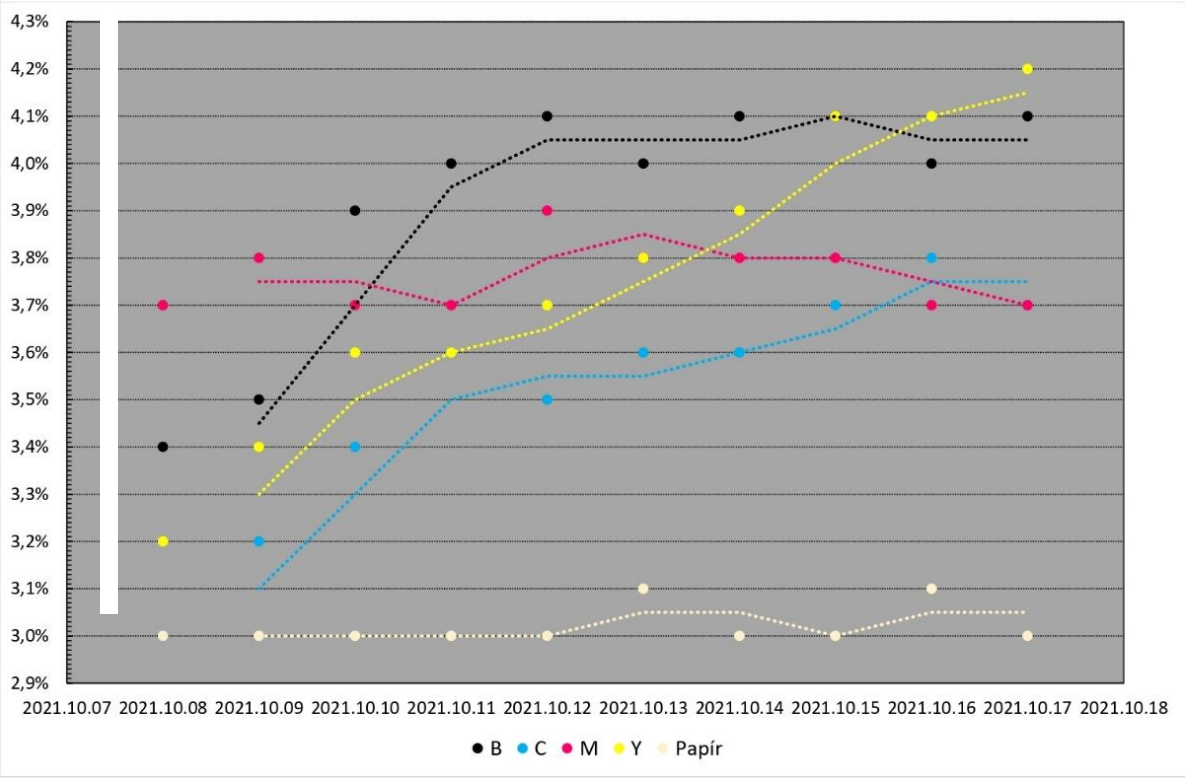


Figure 3: Gloss change on glossy art paper

In the case of coated, glossy, closed-surface media, the gloss of the prints changes significantly after proofing. When printing on glossy art paper, a 10% increase in gloss can be observed in the three-hour time interval of the prints. Since the drying of the printing ink takes place predominantly on the surface of the paper, the connection of the macro-molecular chains in the binders forms a uniform film-like layer, which reflects the incident light rays similarly to a specular reflection. During the drying of the printing ink, the formation of the cross-linked structure forms a top layer on the surface of the print medium. When examining the density and color changes on glossy art paper, we found that no density decrease of more than two or three hundredths occurred for any color, i.e. in the case of printing on glossy art paper, the coverage measured at the moment of printing is approximately the same as the coverage value of the prints measured again after drying. The reason for this is that in the case of print media with a closed surface structure, the paper fibers do not absorb either the pigments or the binder to the same extent as in offset papers, where the capillaries are open.



4 Figure 4: Gloss change on closed offset paper

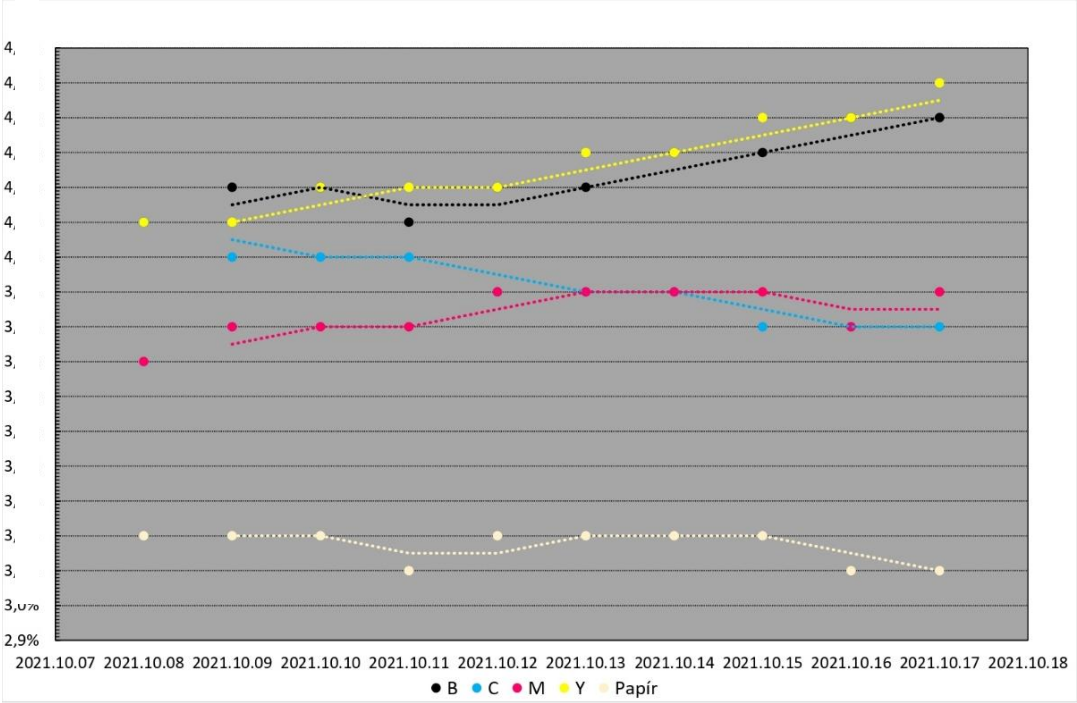


Figure 5. Gloss change on freely stored offset papers

Figure 4 shows the surface gloss values measured on solid fields for individual colors of the offset print stored in a locked in a drawer environment, and Figure 5 shows the gloss values of the prints exposed to sunlight and UV radiation outdoors. When printing on offset paper, the surface gloss of the prints increases slowly after printing and final drying, even in the case of sheets exposed to light and stored in a locked in a drawer environment, but under the influence of UV radiation, the prints dry faster and more evenly, and their gloss values are also more easily monitored.

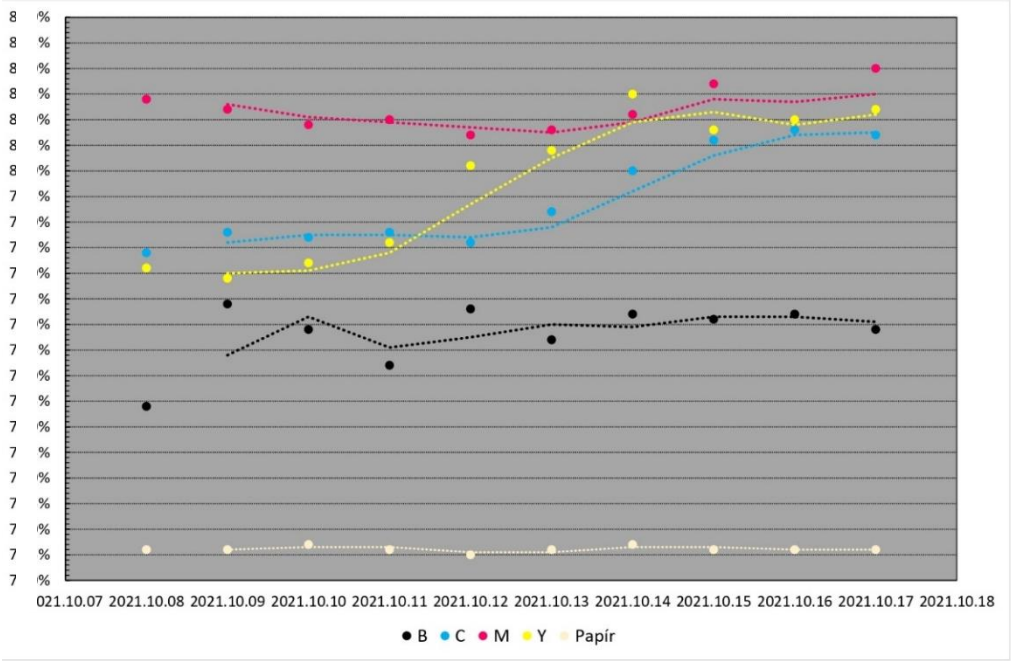


Figure 6. Gloss change on locked in a drawer art paper

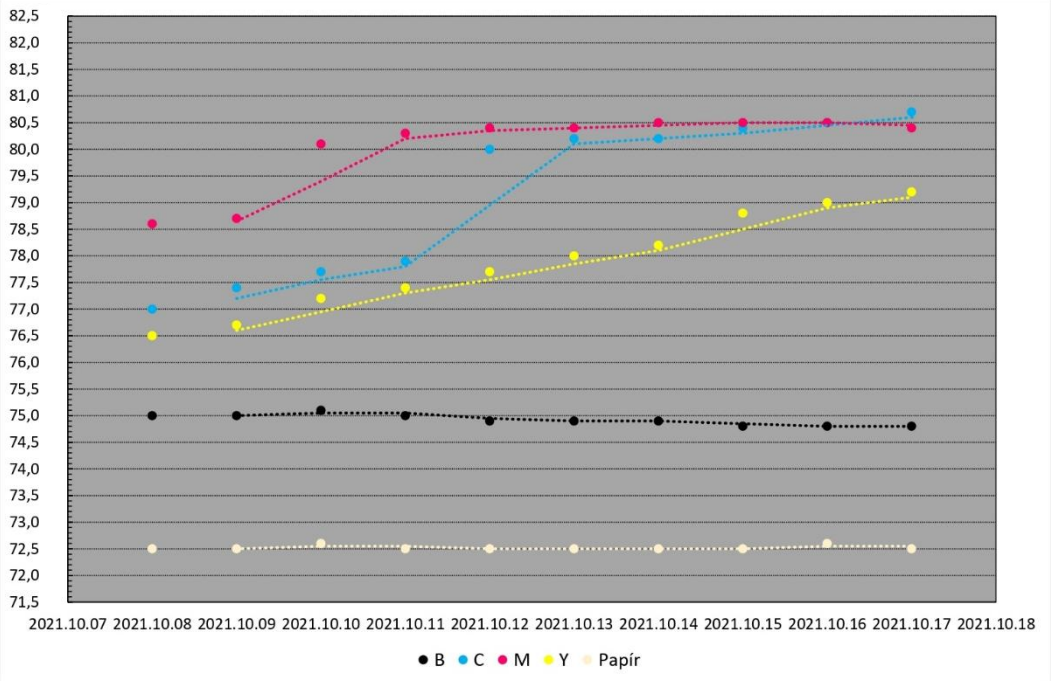


Figure 7. Gloss change on free-standing art paper

Figures 6 and 7 show the changes in the surface gloss values of the glossy art paper stored in a locked in a drawer environment and the print exposed to sunlight and UV radiation outdoors. Based on the results of the test, when printing on glossy art paper, the surface gloss of the prints increases slowly after printing, even in the case of sheets exposed to light and stored in a closed state. Under the influence of UV radiation, the drying of the printing ink on the surface of the paper occurs faster and more evenly, the cross-linked structure is formed sooner and their gloss value also changes more evenly.

4. CONCLUSION

Based on the measurement results, we have come to the conclusion that possible color changes must be taken into account during post-production in the case of absorbent print media. In periodically recurring productions, it is advisable to store the standards stored away from sunlight and UV radiation and to periodically prepare new standards, the properties of which are adjusted by objectively measuring them at the moment of printing. In the case of absorbent printing media, surface gloss cannot be achieved by increasing the ink coverage value; for this type of paper-based printing media, it is advisable to coat the prints with a varnish layer or foil in order to meet the customer's needs. In addition to mechanical protection, a unique appearance can be provided for the printed product by full-surface or form varnishing. In the case of coated, surface-treated printing papers, it is advisable to use printing inks that dry under the influence of UV radiation instead of inks that dry by oxidation polymerization, because the polymerization processes taking place in the binder of the printing ink occur immediately under the influence of radiation, and the surface gloss shows an almost final value immediately after printing. Another advantage of this type of printing ink is that the risk of peeling is reduced, thereby making production more efficient.

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ELECTRICAL STABILITY UNDER MECHANICAL DURABILITY TESTS ON DIFFERENT SUBSTRATES

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Abstract:
With the ever-accelerating technological progress, there is an increasing awareness of more environmentally friendly materials and acceptance of the fact that the development of such materials in all fields of industry has become a necessity. The development of environmentally friendly conductive ink was the aim of this research, where the synthetic base was replaced with a natural one, given that the synthetic base, although water-based, still contains harmful compounds. Tapioca starch was proven to be a worthy replacement for synthetic base, and the conductive material graphite as a replacement for rare metals that are unsustainable, both environmentally and financially. Environmentally friendly conductive ink was prepared by homogenization on a magnetic stirrer with heating until the desired viscosity was achieved, i.e. gelatinization of tapioca starch, and after cooling, it was coated onto different substrates. Electrical conductivity of the printed samples was measured before and after mechanical tests to evaluate the durability and functional stability of the developed ink across different substrates. The development of the new ink formulation focuses on its application as a visible design element on packaging.

Keywords: *conductive ink, graphite powder, tapioca starch, electrical stability, mechanical durability*

1. INTRODUCTION

Environmentally friendly electronic systems imply the use of sustainable or biobased materials, or biodegradable and/or recyclable materials. Biodegradable electronics, commonly referred to as green electronics, remain a challenge since the composition of conductive inks must also be sustainable. A typical conductive ink consists of a functional material, a binder, a solvent, and optional additives combined to ensure electrical conductivity and stability [1], [2], [3]. Conductive inks are typically made from metallic (e.g., silver, copper), carbon-based (graphite, graphene, carbon nanotubes), or polymeric materials dispersed in a suitable binder and solvent. Graphite is inexpensive, chemically stable, and environmentally friendly. These characteristics make it a suitable material for printed and disposable electronics. It also offers sufficient electrical conductivity for flexible electronic applications[4], [5], [6]. Tapioca starch is a biodegradable and renewable biopolymer. It has good film-forming ability and flexibility, and it is low-cost. In conductive inks, it is used as a natural binder. It represents a sustainable alternative to synthetic polymers for eco-friendly printed electronic sensors. [7], [8], [9], [10].
In this study, a conductive ink based on graphite, tapioca starch, D-sorbitol, and water was investigated. The focus was on the electrical stability of the printed ink after mechanical durability tests on different substrates. Graphite provides electrical conductivity due to its layered carbon structure. Tapioca starch acts as a bio-based binder, forming cohesive films and helping to maintain particle dispersion during drying. D-sorbitol is added as a plasticizer to improve the mechanical and barrier properties of the starch-based film, particularly tensile strength and thermal stability. Water is used as the solvent, enabling safe and simple processing.

2. EXPERIMENTAL

Conductive ink containing 30% graphite powder was prepared by mixing 6 g of tapioca starch, 0.06 g of D-sorbitol (1% of the tapioca mass), and 24 g of fine graphite powder (Sigma-Aldrich, particle size < 20 µm). Distilled water was added to reach a total volume of 50 ml. The mixture was then heated to 80 °C on a magnetic stirrer with a heater (IKA RCT basic IKAMAG® safety control, Germany) until gelatinization occurred. After cooling to room temperature, additional graphite powder was gradually added while stirring continuously, resulting in a homogeneous ink.

Two types of paper were used as substrates: a coated paper (UPM Finesse White Gloss, 300 g/m²) and an uncoated bio-based paper (250 g/m²). The coated paper has a smooth, stable surface that helps prevent deformation during coating and allows for a more consistent evaluation of the ink's properties. The uncoated paper is made from a mix of 15% citrus-based agro-industrial by-products, 40% recycled fibres, and 45% virgin wood pulp, giving it a natural texture while keeping it environmentally friendly. The citrus fibres come from leftover fruit and juice-processing waste, supporting a circular use of resources.

The electrical stability of the printed coatings was tested using a simple circuit based on the Technic Conductivity Test Apparatus (Technic Inc., USA). A 4.5 V DC power source, an ammeter, a light-emitting diode (LED), and the printed coating were connected in series. Current flow was measured, and LED brightness served as a visual indicator of conductivity. Samples were tested before and after mechanical durability treatments, including rubbing and creasing. All measurements were performed at ambient laboratory conditions and repeated five times for reproducibility. The LED voltage drop was measured separately to determine the effective voltage applied to the print. Electrical resistance (R) was calculated using Ohm's law, and sheet resistance (Rs) was determined from the sample geometry.

The Hanatek Rub & Abrasion Tester was used to evaluate the rub resistance of the printed samples. Circular printed specimens (50 mm diameter) were placed in contact with paper substrates (115 mm diameter), and controlled rubbing was applied using two calibrated weights to achieve a total pressure of 2.0 psi. The tribometer operates with two rotating plates that maintain full contact, producing a uniform frictional motion. Each sample was subjected to 10 complete rotations, including areas of high ink coverage and fine printed lines, to observe differences in abrasion behaviour. The Zünd M-800 digital cutter was used to crease the printed samples at depths of 0.33, 0.66, 0.99, 1.33, 1.66, and 1.99 mm.

Microscopic analysis was performed using an Olympus BX51 optical microscope (Olympus, Japan) equipped with a DP72 digital camera (12.8 megapixels, 4140 × 3096 pixels). Images were acquired at 50× magnification for printed samples.

3. RESULTS AND DICUSSION

The following results summarize the electrical and mechanical behaviour of the conductive coatings printed on smooth coated and uncoated bio-based citrus substrates. The comparison between the two substrate types shows that the uncoated bio-based surface provided significantly better conductivity (lower sheet resistance) compared to the smooth coated paper (Table 1).

Table 1. Mean sheet resistance (R_s) of starch-based conductive coatings printed on different paper substrates

Substrate	Sample	Rs/$\Omega \cdot m^{-2}$
uncoated bio-based paper	U1	7.14 ± 0.03
	U2	3.32 ± 0.07
	U3	4.29 ± 0.02
	U4	6.99 ± 0.11
coated paper	C1	14.64 ± 0.06
	C2	12.82 ± 0.07
	C3	8.18 ± 0.03
	C4	10.81 ± 0.05

This difference can be attributed to the different wetting and absorption behaviour of the substrates. The uncoated citrus-based substrate likely promotes better particle packing and film continuity, resulting in denser conductive paths. In contrast, the coated paper's smoother, less absorbent surface may cause partial segregation of graphite particles during drying, leading to thinner or less uniform conductive layers.

Despite identical printing and formulation conditions, this result demonstrates that substrate surface chemistry and topography have a decisive influence on the final electrical properties of printed conductive coatings. The small SD values within each group confirm good repeatability, while the inter-group variation highlights the need to optimize substrate–ink interactions to achieve consistent performance.

The results of creasing at different depth (Table 2) show that the uncoated bio-based U4 sample showed a strong nonlinear response to mechanical creasing. At the smallest depth (0.33–0.66 mm), the sheet resistance increased drastically—up to nearly six times the initial value—indicating disruption of the conductive network caused by microcracking and surface detachment of the printed layer.

Table 2. Average sheet resistance (R_s) of starch-based graphite conductive coatings after creasing at different depth (0.33, 0.66, 0.99)

Creasing depth (mm)	Rs(U4)/ $\Omega \cdot m^{-2}$	U4 (Change) /%	Rs(C3)/ $\Omega \cdot m^{-2}$	C3 (Change) /%
0.00	4.29 ± 0.02	—	8.18 ± 0.03	—
0.33	24.47 ± 1.12	470.0 %	26.38 ± 0.39	222 %
0.66	28.85 ± 0.80	572 %	26.29 ± 0.18	221 %
0.99	18.70 ± 0.58	336 %	31.04 ± 0.17	280 %

However, at a depth of 0.99 mm, resistance partially decreased, which suggests partial recovery of conductivity due to elastic relaxation and reconnection of conductive particles within the composite matrix. In contrast, the smooth coated substrate (C3) exhibited a monotonic increase in sheet resistance throughout creasing, reaching almost three times the initial value at the largest depth. This steady degradation points to progressive crack propagation and loss of interparticle contact, characteristic of a stiffer, less compliant surface that does not permit elastic recovery.

Table 3. Average sheet resistance (R_s) of starch-based graphite conductive coatings after creasing at different depth (1.33, 1.66, 1.99)

Creasing depth (mm)	Rs(U2)/ $\Omega \cdot m^{-2}$	U2 (Change) /%	Rs(C2)/ $\Omega \cdot m^{-2}$	C2 (Change) /%
0.00	3.32 ± 0.06	—	12.82 ± 0.07	—
1.33	6.13 ± 0.01	+84.6 %	10.51 ± 0.04	−18.0 %
1.66	4.58 ± 0.02	+37.9 %	12.22 ± 0.18	−4.7 %
1.99	4.24 ± 0.02	+27.7 %	14.90 ± 0.20	+16.2 %

For the smooth substrate (C2) (Table 3), the sheet resistance initially decreased upon creasing to a small depth (1.33 mm), likely due to temporary compression of the conductive graphite network and improved interparticle contact. However, further creasing led to an increase in resistance, exceeding the initial value at 1.99 mm, which indicates mechanical degradation of the conductive layer through the formation of microcracks and partial loss of continuity. This trend reflects an elastic–plastic response, where initial deformation enhances conductivity before structural damage dominates.

In contrast, the uncoated citrus-based substrate (U2) exhibited an opposite trend. A sharp initial increase in sheet resistance (≈ +85%) was observed at the smallest creasing depth, suggesting crack initiation or delamination between the conductive layer and the less uniform bio-based surface. As the creasing depth increased, the resistance gradually decreased, implying partial re-establishment of conductive pathways due to relaxation of surface strain and elastic recovery of the substrate.

The results indicate that the substrate type strongly influences the mechanical–electrical stability of the printed conductive film. The smooth coated paper provided a more stable and uniform conductive response, while the uncoated citrus-based substrate demonstrated greater flexibility and recovery potential, though at the cost of higher initial sensitivity to deformation.

The results showed that the uncoated citrus-based substrates had higher mechanical flexibility. They also displayed partial recovery of conductivity after creasing, reflecting their elastic and compliant surface characteristics. The smooth coated papers, in comparison, showed greater structural stability but a progressive loss of conductivity. This indicates that substrate stiffness limits the mechanical–electrical resilience of printed conductive layers.

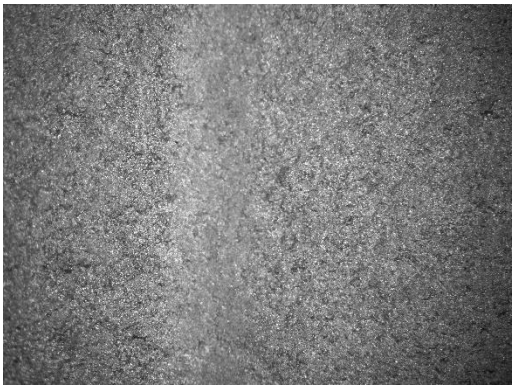
Table 4. Sheet resistance of printed conductive layers before and after abrasion test

Substrate	Condition	Rs/ $\Omega \cdot m^{-2}$	Change/%
Uncoated bio-based paper	Before abrasion	6.31 ± 0.45	—
	After abrasion	8.18 ± 0.02	+29.7 %
coated paper	Before abrasion	14.64 ± 0.09	—
	After abrasion	14.59 ± 0.04	−0.34 %

The mechanical–electrical characterization revealed distinct behaviors of the conductive coatings depending on substrate type (Table 4).

During creasing tests, uncoated citrus-based substrates showed higher flexibility and partial recovery of conductivity. This suggests an elastic and compliant interface that allows reconnection of conductive particles after deformation. However, under rubbing, these same samples showed an increase in sheet resistance (≈30%). This indicates that their surface cohesion is lower, and the conductive network is more sensitive to abrasion and surface disruption.

Conversely, smooth coated paper substrates displayed greater dimensional and structural stability. Their sheet resistance remained nearly unchanged after rubbing (−0.3%), suggesting good mechanical integrity and strong adhesion of the conductive layer. Nevertheless, creasing caused a progressive increase in resistance, implying microcrack formation within the stiffer, less elastic surface.



a) Uncoated bio-based paper *b) coated paper*

Figure 1. Surface morphology of creased conductive coatings printed on uncoated bio-based and coated paper substrates at 50× magnification

Microscopic examination (Figure 1) showed differences in the surface of the conductive coatings after creasing. On the uncoated citrus-based paper, small microcracks and partial layer deformation were observed. Most of the conductive film stayed intact, indicating good flexibility and partial recovery of the conductive network upon creasing. The coated paper exhibited more noticeable cracking and flake detachment, reflecting its stiffer surface and limited ability to deform elastically. These observations suggest that the electrical and mechanical results are consistent with the idea that substrate texture and flexibility play a role in crack formation, adhesion, and the stability of the conductive layers under mechanical stress.

Visual inspection after the abrasion test showed difference between the two substrates. The uncoated citrus-based paper showed a transfer of graphite onto the white sheet, indicating weaker surface cohesion and higher material loss during rubbing. The coated paper showed only slight grey traces with minimal visible damage on the rubbed area, suggesting better adhesion and abrasion resistance of the conductive layer.

4. CONCLUSION

The results suggest that substrate morphology and mechanical properties influence the performance of starch–graphite conductive coatings. The uncoated bio-based citrus paper tended to have lower sheet resistance and offered greater flexibility. It also showed reduced surface cohesion and was more sensitive to abrasion. The smooth coated paper provided better adhesion and mechanical stability, although conductivity gradually decreased when the surface was creased. Microscopic observations of creased surfaces supported these trends, showing crack patterns that matched the observed electrical behavior. The balance between conductivity, flexibility, and durability seems to depend largely on the properties of the substrate surface. Future research should explore changes to the ink composition or surface modifications to improve adhesion and resistance to mechanical stress, while still maintaining good electrical performance and environmental friendliness.

5. ACKNOWLEDGEMENT

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THERMO- INSULATION MATERIALS FOR TEXTILE GOOD MANUFACTURING

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Abstract:

Different thermo- insulation materials are used manufacturing garments and other textile goods to create a layer of trapped air to retain heat of a human body. The insulation materials can be divided into two groups: flat 2D materials and free fibres. On the bases of the origin, there are available natural material waddings and synthetic fibre waddings. Cotton, silk, wool and down as wadding materials have longest application. They can ensure different comfort level and properties. Polyester waddings are used starting from 20th. They are hydrophobic and cheaper than the most part of natural origin waddings. Sustainable and advanced wadding materials improve performances to reduce negative properties of both, traditional natural and synthetic origin waddings.

Keywords: *Thermal insulation; Wadding materials; Natural fibres; Synthetic fibres; Sustainability; Comfort.*

1. INTRODUCTION

Bulky insulation materials called waddings (in Europe, UK, Australia) and paddings (in USA) are used in garments and other textile goods to create a layer of trapped air and with it to retain heat of a human body and add a fuller and more padded appearance (see Fig.1). Waddings are also commonly used in quilting to manufacturing bed cloths.

Figure 1: Garments with insulation materials

Insulation materials for textile goods can be divided into two groups: flat 2d materials and free fibres (see fig.2, a). 2D goods are non-woven fabrics which can be packaged and transported in rolls. They use to be cut in necessary shapes like any other fabrics [13]. Free fibres, down or feather consist of millions separate small items. They are stored in bags and manufacturing textile products blown in their separate parts (see fig.2, b).

a b

Figure 2: 2d flat (a) and free fibre (b)

2. ORIGIN OF ISOLATION MATERIALS

According to the origin of materials waddings can be divided in two groups: synthetic origin and natural origin materials.

2.1 Natural origin padding

Natural origin waddings have the longest application. They are used creating clothing and different other textile goods many centuries. Natural origin waddings are manufactured from plant and animal fibres and s of birds.

2.1.1 Natural origin fibre wadding

Natural origin fibre waddings are produced from cotton, hemp, silk, wool or cashmere. Currently the most often natural fibre waddings are used in quilting processes manufacturing bed cloths. Natural waddings are manufactured opening, carding, and layering natural fibres to form a web, and bonding them mechanically or thermally [13]. Using needle punching method the fibres are interlocked punching them with barbed needles. The fibres can also be bonded by heat. Then they pass through hot air ovens, infrared heaters, or heated rollers.
Cotton is the least expensive natural fibre wadding material. It has a low loft, drapes well, and is soft, cuddly. However, it is heavy. Bamboo wadding is softer and have silky feel, drapes well and also has low loft. Cotton and bamboo materials are good choice for textile goods used in warmer climates. Wool wadding is lighter, has medium to high loft. It is soft and has very good thermo-insulation properties. Silk wadding is a very soft and lightweight, good thermo insulator, too [1, 2]. Wool and silk waddings are preferable for goods used in cooler climates. There are also available blended waddings in the market. Polyester use to be added to cotton to reduce weight and price of a natural origin wadding. The most common blends found in the market are 80% cotton and 20% polyester. Eco-friendly waddings are a 50/50 blend of bamboo and cotton. Cotton, wool, silk and bamboo waddings have tendency to shrink. Comparing with other kind of waddings, natural ones are heavier and have higher cost.

2.1.2 Bird down and feather wadding

Duck and goose down and feather are usually used as wadding material in garments, bed cloths and other textile goods (see Fig.3). The quantity of down, in relation to feathers in textile goods can varies. The highest level thermo-insulation is obtained using proportion 90/10 when 100g of wadding has 90g down and 10g of farther. Down is the soft, small feather found underneath the larger feathers that give

the bird warmth and this down doesn't have a quill (see Fig. 3). Down has very good thermal insulation qualities. It is very light, able to trap air and has high resilience properties [16].

Figure 3: Bird downs

Down quality is characterized by two parameters: *down fill* power and *fill weight*. The *fill power* is a measure (in cubic inches) of how much space is filled by one ounce of down (see Fig. 4). A higher *fill power* number indicates greater wadding loft, meaning the down can trap more air and provides better insulation and a higher warmth-to-weight ratio. *fill power* of down can vary from around 450 to over 900, with most high-quality down products featuring a *fill power* of 800 or above.

Figure 4: Fill power measuring tubes

Down *fill weight* is the actual amount of down insulation in a product, measured in grams or ounces. A higher *fill weight* generally indicates a warmer but a heavier and bulkier textile product [4].
Down is famous for its ability to deliver extraordinary warmth. The structure of down (its loft) allows it to trap body heat very efficiently. The same time goods with down wadding are very light, easy to compress. After relaxing pressed goods, down does not lose its loft. Down is very durable. However, down has also several disadvantage. When it gets wet or damp, it loses shape and insulation ability. Down takes a long time to dry, it sticks together drying. The down as a wadding material also has high cost, goods with down wadding are usually more expensive than others with synthetic fill. Down can also cause allergic reactions to sensitive people [5].
Has to be added that several serious problems exist using traditional down and feather production methods. Firstly, the down is obtained from animals - geese and ducks. For people who do not want to use animal products, this is a significant drawback. Secondly, in farms the birds use to be force-fed to grow faster. The down use to be plucked from live animals, creating them stress and pain. To avoid

these disadvantages, many manufacturers of textile products already use down certified by the Responsible Down Standard (RDS) [7]. The RDS is a global certification given to high quality down products to ensure that the birds were treated humanely and not subjected to unnecessary harm, such as force-feeding or live-plucking. In addition to RDS, some companies have developed their own standards and means of controlling their down sourcing, for example, Traceable Down Standard by Patagonia [6,8] and Mountain Equipment's Down Codex [9].

2.2 Synthetic fibre wadding

Synthetic waddings are developed in 20 century when polyester fibres got wide application in textile industry. Generally, synthetic waddings are more breathable than down waddings, but they are less warm, and less compressible than down. Being hydrophobic they are best choice for textile goods used in damp climates. Wet synthetic fill does not lose its loft, continues to insulate human body even when soaked, and dries out quickly. However, over time, synthetic waddings compress, lose their ability to loft, become less warm resulting in a shorter lifespan. Often synthetic waddings are cheaper than other kind of fill. Advanced synthetic insulation can also be pricey, particularly newer high-end products designed to replace down. As synthetics are petroleum based, they result in greenhouse gas emissions. Some synthetic waddings can release micro pieces of plastic into the water during each wash. Currently many wadding manufacturers already use recycled polyester to make their production more sustainable. Manufacturing 2D rolled waddings two different techniques are used to hold synthetic fibres together: thermal and resin bonding [13]. Thermal (heat) bonding method uses small low melt polyester fibres which melt easy under heat. They stick or bond to the larger polyester fibres. Bonding creates a lofty wadding product. Using resin bonding method fibres are glued by specially selected polymer resins. They provide elasticity to the end product and prevent individual fibres from migrating. Advanced waddings are manufactured from bi-component fibres which consist of a standard polyester core and a low-melting membrane on the outside [14].

3. ADVANCED WADDING MATERIALS

During the last decades many companies are developing new kind of wading materials which are friendlier to nature and human society. The most part of manufactures are already offering synthetic materials produced from recycled polyester. Advanced polyester waddings are manufactured from hollow fibres (see fig, 5) which ensure higher thermal resistance [9, 15].

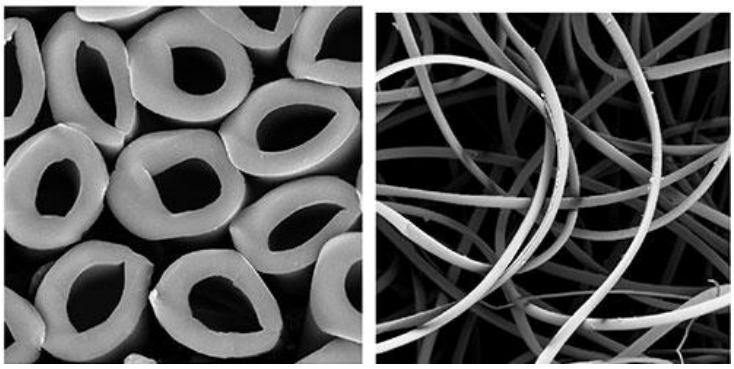

Figure 5: Hollow fibre cross section

Companies Freudenberg and Vilene (Vlieseline) produce 100% biodegradable wadding from Lyocell fibres [11, 12, 17]. These fibres are obtained from eucalyptus or bamboo and can break down into soil over time. New blends of different natural origin waddings, such as, merino wool and down can ensure increased thermo-isolation level suitable for both summer and winter textile goods [10]. Researches are conducted to create down composite wadding materials from down and melt-blown polypropylene. Such material has increased thermo-insulation and higher moisture permeability comparing with 100% down waddings [13].

4. CONCLUSION

Different thermo-insulation materials are used in textile industry manufacturing wide variety of goods. There are ensuring higher or lower thermal resistance and specific appearance to garments, bed cloths, and other products. The most important properties of wadding materials which determine their application are: thermo-isolation ability, moisture permeability, weight, loft, composition, and manufacturing cost. Generally, the longest application and best qualities can ensure natural origin wadding materials. However, because of their several disadvantages synthetic wadding materials are developed and used starting with 20th. Advanced wadding materials try to reduce negative properties of both, natural and synthetic origin waddings.

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DENIM UPCYCLING AND THE REVIVAL OF CRAFT TECHNIQUES: A SUSTAINABLE APPROACH TO CONTEMPORARY FASHION

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Abstract:

The textile industry has a significant negative impact on the environment, as exemplified by the production of a single pair of jeans, which requires approximately 3,500 liters of water and releases around 33.4 kg of CO_2 into the atmosphere—contributing to the acceleration of climate change in the long term. Moreover, this type of production relies heavily on the use of harmful chemical substances, which can cause various health problems for workers who are directly exposed to them. Improper disposal of these chemicals into the environment can lead to the pollution of waterways and ecosystems. In a world increasingly confronted with the consequences of overconsumption and environmental degradation, unique, handcrafted clothing is emerging as an important factor in sustainable development, standing in contrast to the widespread influence of fast fashion. Such garments are not merely an aesthetic choice, but also a profound ethical and ecological decision made by the individual. The aim of this paper is to present the process of creating garments using traditional textile enhancement techniques such as patchwork, macramé, smocking, natural fabric dyeing, and redesign.

Keywords: *denim, sustainable practices, upcycling, textile waste, fabric enhancement techniques*

1. INTRODUCTION

Over the past nearly half-century, the way fashion is produced and consumed has drastically changed. The growth of the world population and its needs has led to a threefold increase in textile production volume, resulting in the phenomenon known as "fast fashion." Excessive seasonal collections, low prices, discounts and promotional campaigns, the ease of one-click online shopping, and the influence of social media have all contributed to individual consumption reaching levels where as much as 85% of textile items are discarded annually into landfills and illegal dumpsites instead of being sent to recycling centres and further degraded back into the environment. [1]

Denim is a durable twill-woven fabric characterized by dyed warp and undyed weft yarns. It is estimated that a single pair of jeans consumes over 3,500 liters of water throughout its entire production chain—from cotton cultivation, through dyeing, to washing processes used to achieve desired colors and patterns [2]. An environmentally sustainable value chain in the fashion industry involves the rapid adoption of high-performance innovative technologies, equipment, and materials that lead to reduced consumption of energy, water, and resources, as well as improved health, safety, and environmental standards for workers in the textile industry [3, 4]

This paper explores sustainable denim transformation through recycling and upcycling processes, emphasizing the artistic and educational aspects of creating unique garments from discarded materials.

2. PRODUCTION PROCESS AND ENVIRONMENTAL IMPACT OF DENIM

The most common twill weave used in denim involves passing the weft yarn over two and under two warp yarns, although it can also be formed by passing the weft over one and under two warps, or over one and under three warps. This weaving method is responsible for the characteristic appearance of denim fabric: the warp yarns are dyed with indigo, while the undyed weft yarns give the fabric its recognizable blue face and lighter reverse side. This material is flexible, elastic, and strong due to the

higher number of threads per inch. The yarn fineness ranges from 30 to 125 tex, depending on the desired outcome of the finished denim. For heavier denim, yarns with a fineness of 50–150 tex are typically used in twill weave, while lighter denim is made using finer yarns of 20–50 tex, sometimes woven in plain weave [1-3].

The denim garment production process consists of four main stages: cutting, sewing, washing, and finishing. To meet environmental standards, washing is performed using machines that utilize ozone and water vapor extracted from the air to clean the garments. This method reduces water consumption by up to 50%, which is equivalent to saving approximately 60 liters of water per garment. The faded appearance of denim is traditionally achieved through sanding, which poses serious health and safety risks to workers due to the inhalation of fine dust particles. A potential solution to this problem is the introduction of laser technology, which lightens the denim without the use of water, sandblasting, or other harmful substances and methods [3].

Billions of denim garments are produced each year. Denim manufacturing methods have a negative environmental impact due to the discharge of dyed wastewater, heavy metals, acids, bases, enzymes, and other pollutants into the environment. Textile workers are exposed to these chemicals, which can be toxic and carcinogenic. For dyeing, manufacturers traditionally rely on indigo pigment, which is naturally derived from plants of the *Indigofera* genus. Indican, a β-O-glucoside of indoxyl (the precursor of indigo), is the natural storage form of indigo in indigo-producing plants. The growing demand for jeans throughout the 20th century led to the development of synthetic indigo, considered a more environmentally friendly option for denim dyeing. The use of artificially engineered enzymes for dye production—such as indican—has eliminated the need for reducing agents and reduced annual carbon dioxide emissions by more than three million tons. Emerging trends in denim dyeing technology include the synthesis of bioindigo, waterless indigo dyeing using supercritical carbon dioxide, digital printing, and other innovative techniques. Traditional desizing processes have limitations that can be overcome through enzymatic desizing; α-amylase can remove insoluble starches from denim using simple hydrolysis methods [4-5].

3. SUSTAINABLE PRACTICES THROUGH RECYCLING AND UPCYCLING

Recycling represents a method of creatively utilizing textile materials of any kind or finished garments that would otherwise end up in landfills or be incinerated, serving as starting points for various fashion products with high artistic value. This process is one of the ways to reduce the negative environmental impact of the fashion industry. Traditionally, textile waste recycling involves its reprocessing through mechanical or chemical means, preparing it for reuse as part of new textile and non-textile products. Adapting one's own clothing means creating a unique style that reflects the taste and lifestyle of each individual, fostering a sense of diversity and individuality in contrast to the modern look shaped by mass media. [4-7]

Upcycling represents a circular fashion approach based on design, where textile waste generated during the production process or after a period of use and wear is reused to create new garments. This method involves the practice of creating new products from old items, components, or materials that have reached the end of their life cycle. The process enables the extension of a product's lifespan, which contributes to reducing the overall demand for newly manufactured products, resources, and energy. By adopting upcycling on a larger scale, industries could significantly reduce environmental harm by lowering emissions associated with the production of new products and materials. Considering these theoretical advantages, upcycling has increasingly been recognized in recent years as a sustainable alternative to traditional manufacturing. [4-7]

Overview of Fabric Enhancement Techniques Applied to the Unique Model

Although modern technology enables mass and rapid processing of textiles, hand finishing still holds a special place, especially in the creation of unique clothing pieces. Aesthetic enhancement methods improve the visual appearance and texture of materials, such as embroidery, braiding, painting, fraying

(leaving raw edges), and similar techniques. These methods not only contribute to the aesthetic value of the garment but also tell a story — about the work process, the designer's inspiration, and even a sustainable approach to production. In an era where mass production often overlooks individuality and creativity, hand-finishing denim brings the focus back to craftsmanship, precision, and personal touch. By using existing garments and various techniques such as patchwork and deconstruction, a completely new and unique clothing piece with a nostalgic flair was created [5].

4. EXPERIMENTAL PART

The experimental part involved redesigning an old denim garment using traditional hand-finishing and embellishment techniques, to demonstrate the creative potential of textile reuse. Inspiration and fashion illustration of the model is shown in the figure 1.

Figure 1: Fashion illustration and technical sketches of the unique garment model (Illustration made by authors)

Figure 2: Bleaching of blue denim by stamping crochet coated with bleach (Photos made by authors)

Sodium hypochlorite (NaOCl), a chemical compound widely used as a disinfectant and bleaching agent due to its strong oxidative potential, was applied in the experimental process for controlled colour removal on denim fabric. In this study, a commercially available household bleach (Domestos, containing approximately 4.5% sodium hypochlorite, <5% chlorine-based bleach, <5% non-ionic and cationic surfactants, soap, and fragrance) was used as the bleaching medium [9]. The solution was applied manually by stamping a crochet tool previously coated with the bleach to achieve localized fading effects on the denim surface. This approach allowed for partial decolorization without significant damage to the fabric structure, simulating sustainable and low-cost surface modification techniques under household conditions. In Figure 2 it is shown the bleaching technique with the crochet.

The **tie-dye** or **shibori** method is one of the physical dyeing techniques that utilizes binding and compression to create patterns on fabric [2] and it is used for light denim for model creation. This manual process involves tying the twisted or gathered sections of the fabric with thread, cord, or rubber bands to protect certain areas from dye penetration. After dyeing, once the ties are removed, the pattern is formed from the original fabric colour—usually white—in contrast to the dyed sections. Typically, the most basic patterns include circles, dots, squares, diamond shapes, or "spider webs," which repeat in various sizes and proportions [8,10].

Figure 3: Dyeing light fabric using the shibori method (tying with cord + needle/thread) (Photos made by authors)

In the creation of the unique garment, several traditional textile enhancement techniques were applied to achieve both aesthetic and conceptual effects. Illustrations on denim are created using the technique of hand-painting denim fabric with textile paint, which represents a form of visual art depicting human figures or motifs from nature. This method simultaneously adds functional value when the artwork is transferred onto wearable clothing items. Denim as a base is directly painted using a brush and paint over a previously drawn sketch (made with white wax pencil, chalk, or pastel pencil) (Figure 3).

Patchwork is involved as a sewing technique to join a small piece of fabric to create a larger design. The patchwork process requires creativity and precision, as different fabric pieces must be carefully arranged and sewn together to form a harmonious whole. It can be said that patchwork represents a blend of tradition, creativity, and sustainability. This technique remains valued for its beauty, versatility, and timeless charm and this technique is used for model making [10].

Additional decorative techniques included hand embroidery, used to enhance selected areas of the garment with ornamental stitches that added visual and textural richness. Embroidery involves creating stitches on fabric with a hand needle and thread, and decorative stitches are used to make textile items (whether clothing or utility objects) more beautiful and valuable.

Canadian smocking is applied as a method of fabric manipulation creating the three-dimensional texture by stitching with a needle and sewing along a drawn grid of squares, diamonds, or dots on the reverse side of the fabric, forming a textured 3D pattern on the front (right side) of the material [11].

Finally, the macramé technique—hand-knotting cotton yarns into ornamental forms—was incorporated as a decorative element. Originating from the 13th century, this method was historically used by Arab weavers to protect tapestry edges from fraying and was here reinterpreted to add structure and artisanal detail to the final design [12].

5. RESULTS: PRESENTATION OF THE FINISHED UNIQUE MODEL

The crafted model revives memories and tradition by combining rustic aesthetics with contemporary forms. The use of old denim paired with sentimental motifs, such as *grandmother's lace doilies*, creates a unique blend of past and present. Lace details are carefully placed to fill the slits on the knees of the pants. They gently extend over the upper edge of the corset, softly framing its cups. Through the patchwork technique, smaller pieces of denim are carefully joined into a harmonious whole, transforming into large floral shapes that adorn the sides of the women's jeans. A short crinoline, barely covering the hips, is richly decorated with flowers made from thinly cut denim strips, creating a sense of movement and playfulness. The macramé technique of hand-knotting cotton thread, as another decorative element, adds an additional layer of texture, complementing the back of the vest where sparkling white flower stems are painted with a brush. The front of the vest stands out with three-dimensional textured floral patterns created by the fabric manipulation technique known as canadian smocking. This technique uses precise stitching along a predefined grid of squares, diamonds, and dots to achieve depth and tactile dynamism on the surface. The pants gradually widen from the knees downward, forming voluminous bell bottoms made from four panels. Half of these panels are created using the shibori technique of physical dyeing, where tying and compressing or stitching with needle and thread creates patterns—such as scattered concentric circles with soft edges or floral motifs. The other half of the bell-shaped legs is adorned with faded traces of floral prints. A winding botanical embroidery, made from threads of varying fineness, composition, and gloss, decorates the lower part of the corset, uniting all the clothing pieces into a poetic expression of nature, recycling, and handmade craftsmanship.

a) *b)*

Presentation of the finished model obtained by recycling old denim:
a) Front view and b) Back view

6. DISCUSSION

By observing various sustainable practices, including the field of redesign, it becomes clear that education—specifically raising environmental awareness among younger generations—is essential as the one of the numerous solutions to the problem of excessive fast fashion consumption, whose impact grows alongside the rise of social media. Instead of merely connecting through the Internet, there is a need to reconnect with roots and artisan workshops, that nurture and study traditional fabric manipulation techniques such as patchwork, embroidery, and various dyeing methods, thereby transforming garments into unique carriers of cultural value.
It is necessary to empower young designers to begin applying traditional methods of aesthetic embellishment and encourage them to further explore the potentials of sustainable fashion through creative reinterpretation of existing resources. As a result of this manual work process, a garment that combines sustainability and artistic authenticity, while simultaneously highlighting awareness of the importance of responsible approaches in fashion, was created. Unique pieces, therefore, can play a key role in shaping a market that values ethical, aesthetic, and ecological practices in the future.

7. CONCLUSSION

In today's world, increasingly faced with the consequences of overconsumption and environmental pollution, unique clothing is becoming an increasingly important factor in sustainable development, as opposed to the pervasive fast fashion. As such, it is not merely an aesthetic choice, but a profound ethical and ecological decision for each individual. Unique pieces symbolize the slow fashion philosophy, custom-made for the wearer, produced in small quantities. They are created in artisan workshops, mostly by hand, using embroidery, lace, crochet, various dyeing techniques such as shibori, and patchwork methods to join discarded fabric scraps, with hand-finished edges and macramé details. The materials used are of higher quality, and the lifespan of unique items is longer, so they won't end up in landfills after just one season. Today, vintage clothing and retro styles are everywhere, designers find inspiration for their new models in traces of the past. By reconstructing those old pieces, fresh designs are born. Without producing new materials, using natural dyes, and handmade techniques, unique clothing positively impacts the reduction of environmental pollution, supporting sustainability and the circular economy**.** Unique and sustainable clothing, therefore, is not just a passing trend, but part of a much broader shift in how fashion is consumed, emphasizing the awakening of ecological awareness when making decisions that will ensure a "greener" future.

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MEASURING THE SHAPE-CHANGING ABILITY OF TEXTILES BY DRAPE TEST WITH ANGULAR SAMPLE-HOLDING TABLE

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Abstract:

The goal of this work was to make the results of the drape measurement clearer. Draping is a 3D, complex shape change caused by gravity. It characterizes the ability of textiles, with low bending stiffness to adapt to the shape of an object in a complex way. In a draping test, a circular sample is placed on a circular sample-holding table, its edges are allowed to bend down, and then the draping coefficient and the number of waves are calculated based on its planar projection. However, both factors have a large standard deviation, and strangely, the number of waves is not unambiguous. In our research, we replaced the circular table with regular, polygonal sample-holding tables of 3-15 corners, which had the same area. We compared the results obtained on the polygonal sample-holding tables with the results measured on the circular table. In our article, we present the course of the research, the testing equipment, the tested 7 types of fabrics, and the results obtained. Our results prove that with the use of a polygonal sample-holding table, the number of waves can be clear, the size and arrangement of the waves can be uniform, and so the uncertainty of the measurement results can be reduced. Based on the data, the optional use of the hexagonal sample-holding table can be recommended, especially for comparative testing of fabrics for the same purpose.

Keywords: *Material science, Engineering, Textile testing, Draping, Shape change, Sheet-like materials*

1. INTRODUCTION

One of the important properties of textiles is the ability to adapt to the shape of an object. We can speak of low bending stiffness if the tested sheet-like material bends under its own weight and is unable to retain its shape. Draping is a 3-dimensional, complex change in shape caused by gravity, which characterizes the ability of the given material to adapt to the shape of an object in a complex way. Draping deformation is a very important and much-researched property of textiles in terms of both their use and the computer simulation of their behaviour.

Draping is measured according to the ISO standard [1], which uses the most accepted Cusick method [2]. During the test, the circular sample, usually 300 mm in diameter, is placed on the circular sample-holding table of 180 mm in diameter, letting the sample edges bend under the influence of gravity, i.e., to drape. The image of the draping sample is projected onto a horizontal plane, and the draping coefficient and the number of waves are determined from this image. Fabrics are usually compared based on these parameters (Fig. 1). The draping coefficient (*DC*) is calculated based on the generally accepted definition according to Formula (1). The lower the draping coefficient, the more flexible and softer the sample is; the higher the value of *DC*, the stiffer the sample is. In addition to the draping coefficient and the number of waves, some other parameters are also determined [3].

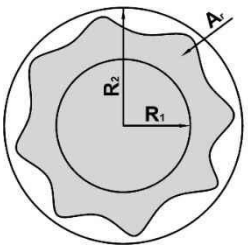


Figure 1: Planar projection of the draped sample

$$DC = \frac{A_r - \pi R_1^2}{\pi R_2^2 - \pi R_1^2} \cdot 100\ [\%] \qquad (1)$$

where:
DC is the draping coefficient,
A_r is the area of the planar projection of the draping textile,
R_1 is the radius of the sample-holding table, and
R_2 the radius of the sample before draping (Fig. 1)

The most widely used equipment is the Cusick Drape Tester [2]. In it, the light of a point light source placed under the sample table is converted into a parallel light beam by a concave mirror and directed upwards. This parallel light beam creates the planar projection shadow image of the draped sample on the surface of limited translucency placed above the sample table. This shadow image was initially copied by hand onto a sheet of paper, and the area of the shadow image was then determined based on the specific mass of the used paper. Much research has been devoted to automating the collection and evaluation of the data required to determine the draping coefficient and the number of waves [4-10].
However, it became obvious that the draping coefficient and the number of waves also have a large standard deviation, and their value greatly depends on the circumstances of the formation of the waves [3, 11-14]. Determining the number of waves is often a challenge. The draping coefficient is clear based on the projection area, while the number of waves must be counted separately. However, the number of waves is not clear in many cases, and even for the same sample, it is often not the same in successive measurements. Sometimes, it is not possible to clearly decide where a wave begins and where it ends based on the outline of the planar projection. It is also a problem that if the number of waves is not the same in two draping tests of the same fabric sample, the draping coefficient will also be different. Another problem is that the number of waves of an already draping fabric can be changed with a small external intervention, for example, by hand [15].
In this study, we aimed to make the number of waves unambiguous and investigate how this intervention affects the draping coefficient. In order to do this, we replaced the circular sample-holding table of the Cusick Drape Tester with polygonal tables of the same area and investigated how the number of corners of the table affects the draping coefficient and the number of waves.

2. EXPERIMENTAL

2.1 Materials

We chose seven fabrics of different materials and structures for our tests. The data of the fabrics is contained in Table 1. We defined the data as the average of 5-5 measurements in order to make the fabrics comparable. We calculated the bending length based on the Cantilever test and shear stiffness as the slope of the specific shear force – shear angle diagram between the shear angles of 0.5 and 5 degrees, according to the Kawabata Evaluation System.
From each of the selected fabrics, three circular test samples were cut with a diameter of 300 mm so that the samples came from areas containing different yarns.

Table 1: The basic parameters of the examined fabrics

Designation of sample	Material	Fabric structure	Mass [g/m^2]	Thickness [mm]	Bending length [mm]		Shear rigidity $[\frac{N}{m \cdot °}]$	Yarn density [piece/cm]		Yarn count [Tex]	
					warp direction	weft direction		warp	weft	warp	weft
1	PES	Plain woven	158,7	0,35	25,0	18,0	2,86	57	32	11,7	8,3
2	PES	Nonwoven	52,6	0,28	51,0	56,0	20,14	-	-	-	-
3	Flax	Plain woven	132,3	0,32	27,5	20,5	1,62	21	21	43,7	26,1
4	Cotton	Plain woven	107,6	0,25	19,5	14,0	2,71	39	28	14,5	21,5
5	PES	Knitted fabric	181,5	0,75	29,0	20,0	0,83	-	-	27,5	
6	PES	Twill woven	192,7	0,38	26,0	13,0	1,95	30	42	28,3	21,9
7	Flax	Plain woven	192,3	0,50	16,0	13,0	1,79	18	15	56,7	58,6

From each of the selected fabrics, three circular test samples were cut with a diameter of 300 mm so that the samples came from areas containing different yarns.

2.2 Methods

For the tests, we used the Cusick Drape Tester equipment, whose operation we mostly presented in the introduction. Fig. 2 shows the Cusick Drape Tester equipment, and Fig. 3 shows its operation.
We supplemented the equipment (Fig. 3) with a digital camera placed above the device and a computer performing the evaluation. During the preparation of the test, the lifting-lowering table (8) is in the preparation position (14), at the same level as the sample-holding table (2) (Fig. 2a). The 300 mm diameter test sample must be placed centrally on the sample-holding table at this point. This is followed by the lowering of the lifting-lowering table (8) to the measurement position (13), as a result of which waves form on the fabric. The light beam created by the parabolic mirror (10) projects the planar projection image of the draping fabric onto the transparent paper sheet (4) (Fig. 2b). The shadow image that appears on the paper is transmitted to the computer by the camera. The evaluation program provides the area of the shadow image of the draping textile, from which the draping coefficient can be calculated with Equation (1). The number of waves can be determined by manual counting.
We performed tests with the usual 180 mm diameter, circular sample-holding table and regular, polygonal sample-holding tables with the same area too. For our tests with polygonal tables, we had to make not only the polygonal versions of the sample-holding table (2) but also the transparent lifting-lowering tables with the shape of the tables (8) and the shading shapes (5) as well (Fig. 3). Every time we want perform a test with a differently shaped table, these elements have to be replaced. To make it easier to replace these elements, we also remanufactured the original circular structural elements. We cut the sample-holding tables and their lifting-lowering tables from 3 mm thick, transparent polystyrene sheets and the shading shapes (with the same shape as the sample-holding table) from fibreboard with the use of the laser cutting equipment available in our laboratory (Alpha Laser LCE2 CO_2-Infra Laser Cutter).

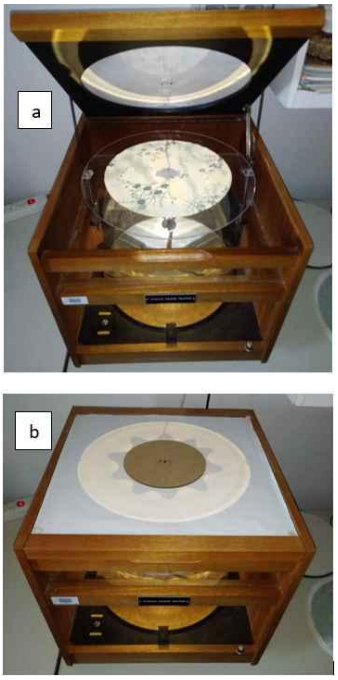


Figure 2: Cusick Drape Tester, a: preparation position, b: Testing position

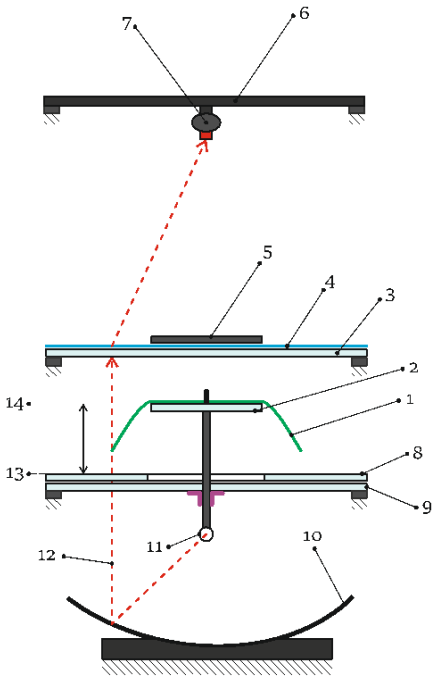
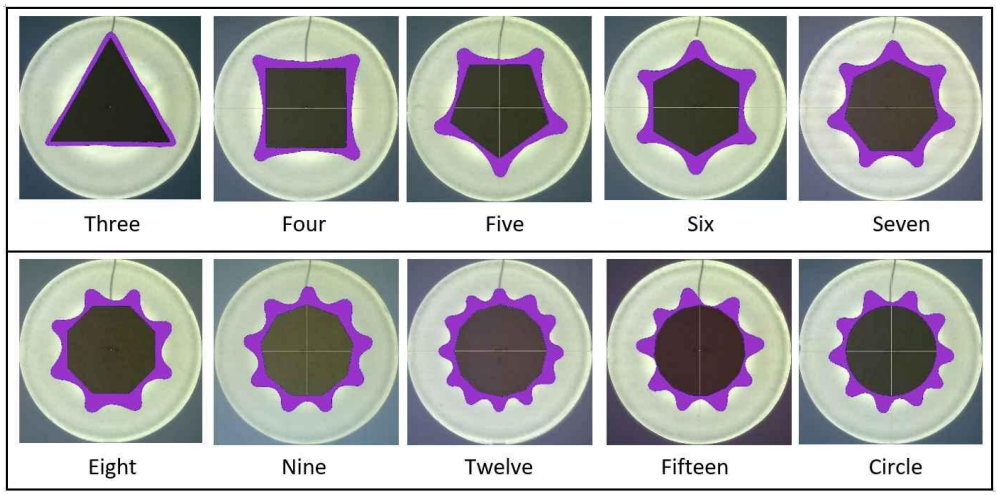


Figure 3: Schematic diagram of the Cusick Drape Tester

3. RESULTS

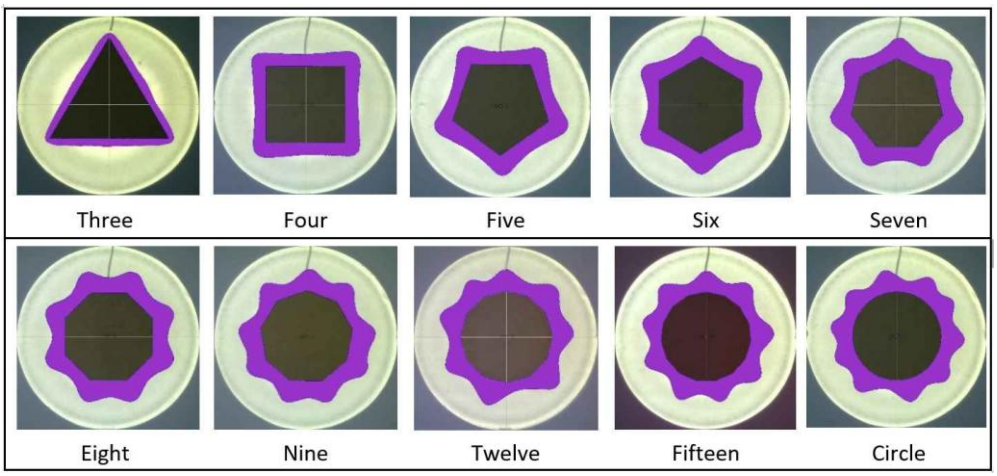
As an illustration, we present images of the draping of Fabric 1 (Fig. 4) and 7 (Fig. 5).



Figures 4: Images of the draping of Fabric 1 (PES fabric) depending on the number of table corners

In our tests, we measured each sample placed first with its right side up and then with its reverse side up on the sample holder table. We carried out the test series twice, maintaining a constant temperature (24 °C) and relative humidity (40%) throughout the tests. Since we cut out three samples from each selected fabric, so for each fabric, we performed altogether 12 tests on each different table. Figures 6-7

show the average draping coefficient with standard deviation, as well as the number with standard deviation of the waves for Fabric 1 and 7, depending on the shape of the table.



Figures 5: Images of the draping of Fabric 7 (Flax fabric) depending on the number of table corners

The change in the *DC* as a function of the number of table corners can be described with the trend function (2) with a monotonous increase tending to the horizontal asymptote. Table 2 contains the values of the parameters of the trend function (2) for the examined fabrics.

$$DC(n) = DC(3) + DC_{diff}\left[1 - e^{-\frac{n-3}{n_0}}\right] \quad (2)$$

Where:

n	is the number of corners of the sample-holding table, n≥3, and an integer.
n_0	is an estimated scaling parameter influencing the course of the function that has no physical meaning for the given fabric, n_0>0.
$DC(n)$	is the draping coefficient depending on the number of table corners.
$DC(3)=DC_{min}$	is the starting point of the trend curve, the smallest DC of the given fabric measured on the triangular sample-holding table.
DC_{max}	is an estimated *DC* value, to which the function tends asymptotically.
$DC_{diff}=DC_{max}-DC(3)$	

Table 2: The parameters of the approximating function (Equation 2)

Designation of sample	$DC(3)=DC_{min}$ [%]	DC_{max} [%]	$DC_{diff}=DC_{max}-DC(3)$ [%]	n_0 [-]	Mean squared error [%]
1	14,526	31,664	17,137	1,501	0,656
2	67,804	92,762	24,957	0,908	0,858
3	38,273	66,245	27,972	1,174	1,064
4	31,607	67,641	36,034	1,174	2,091
5	18,651	36,647	17,997	1,537	5,149
6	43,979	73,932	29,953	1,156	3,141
7	23,689	54,567	30,878	1,145	1,870

We determined the values of the DC_{max} and n_0 parameters with the Microsoft Excel Solver extension so that the mean squared error calculated from the difference between the trend curve and the measured data would be minimal. The DC_{max} value is almost the same as the *DC* value measured on the nine-sided sample-holding table for all materials except Fabric 5. The mean squared error of the approximation with the calculated parameters is given in the last column of Table 2. These data confirm that the trend function (2) describes the change in the DC with a very good approximation.
The *DC* diagrams in Figures 6-7 also contain the trend curves calculated with Equation (2). The trend curves were calculated and plotted for up to the nine-sided sample-holding table because the number of waves and table corners is mainly the same up to 9 table corners but if the table has more than 9 corners, none of the examined fabrics have the same number of waves as the number of table corners. It is clear that these curves approximate the measurement results very well and thus clearly illustrate the relationship between the number of table corners and the *DC*.

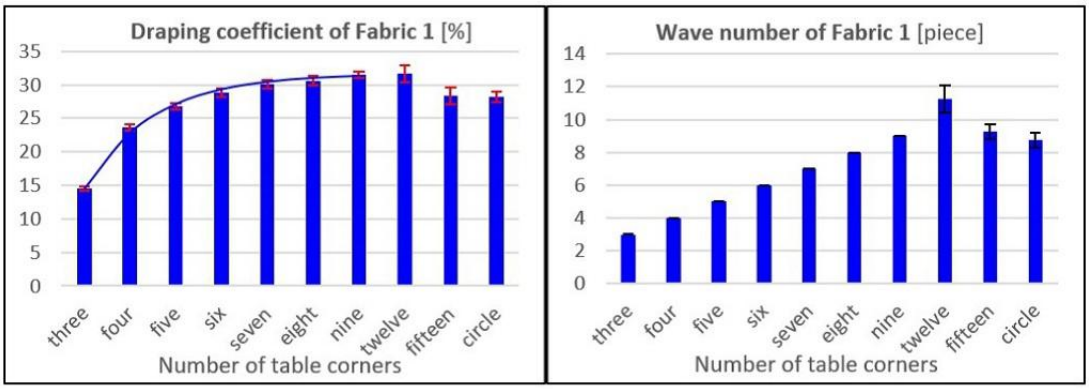


Figure 6: The draping coefficient and the number of the waves for Fabric 1 (PES fabric)

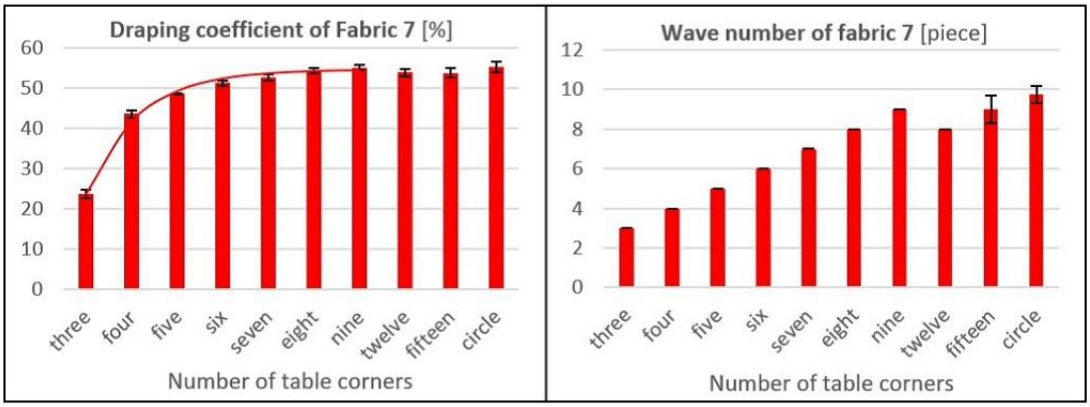


Figure 7: The draping coefficient and the number of the waves for Fabric 7 (Flax fabric)

As Figures 6-7 show, for polygonal tables, the number of waves follows the number of corners of the table when the number of corners is low. However, in the case of a circular table, as we mentioned in the introduction, the number of waves is not clear, their size and arrangement are often not uniform, and also, their number can change due to even a small external influence. Therefore, we carried out a series of experiments in which the draping of the test samples was modified by hand to another stable state, so that the number of waves in the new state differed from the original number of waves. The recordings made in this way show the Figures 8-9 of Fabric 1 and 7.

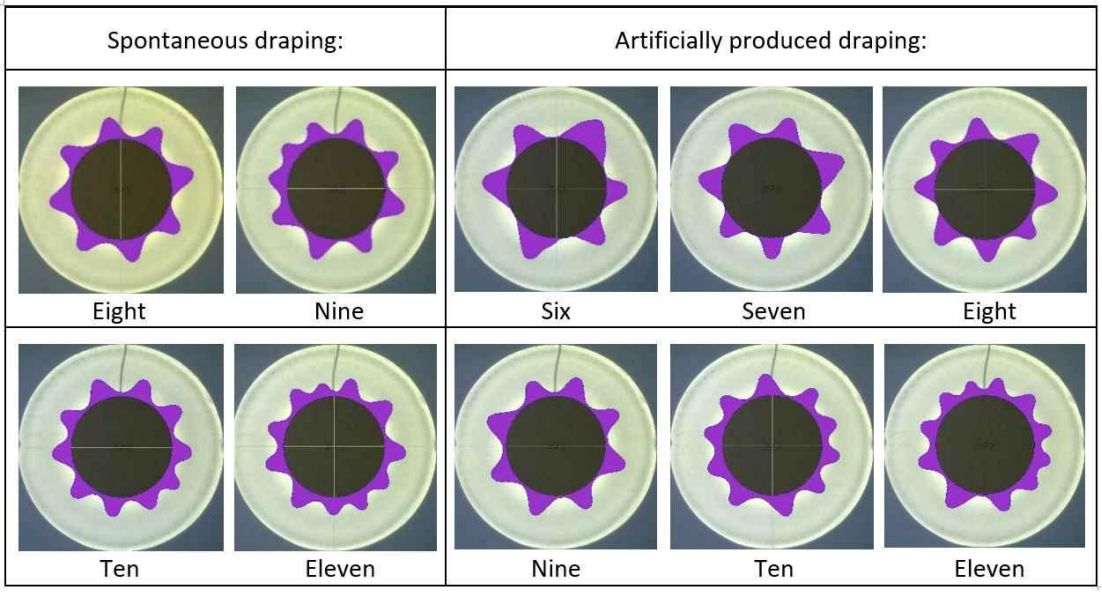


Figure 8: The images of the spontaneously and artificially formed waves of Fabric 1 (PES fabric) on the circular sample-holding table depending on the number of waves

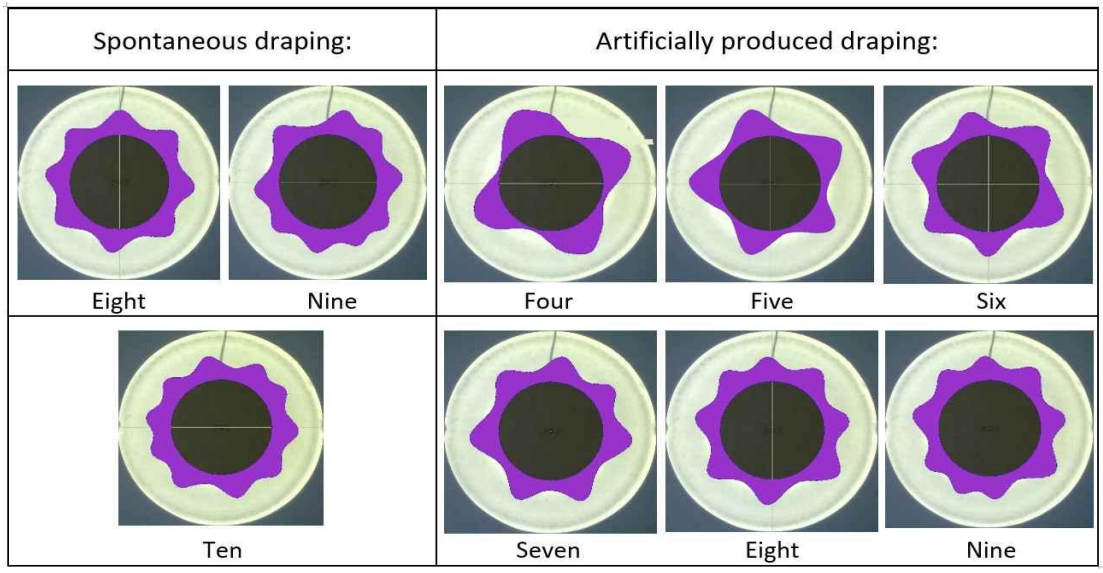


Figure 9: The images of the spontaneously and artificially formed waves of Fabric 7 (Flax fabric) on the circular sample-holding table depending on the number of waves

Figures 10–11 show the draping coefficient depending on the number of waves for each fabric on polygonal sample-holding tables and the circular sample-holding table in the case of spontaneous and artificially induced draping.

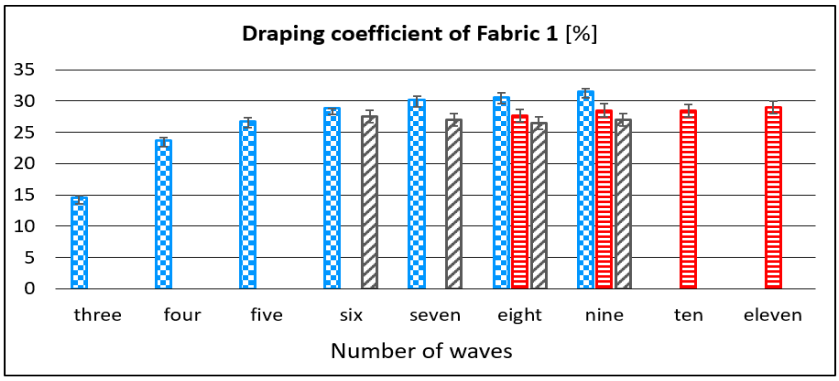


Figure 10: The draping coefficient depending on the number of waves for Fabric 1 (PES fabric)

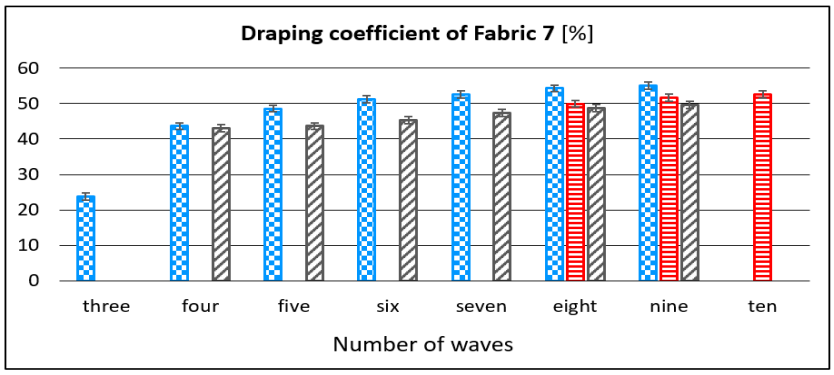


Figure 11: The draping coefficient depending on the number of waves for Fabric 7 (Flax fabric)

4. DISCUSSION

As was mentioned in the introduction, the conditions of the formation of the waves greatly influence the resulting draping image and, therefore, the draping coefficient and the number of waves. Our results support this. The images of Figures 4-5 and the diagrams of Figures 6–7 clearly show that if regular polygonal sample-holding tables are used instead of circular ones, the waves form at the corners of the tables, and their number follows the number of corners up to a limit. The extent to which the number of waves follows the number of corners of the table depends on the properties of the examined fabric and the dimensions used. The softer the fabric, the larger number of corners the waves can follow. The behaviour of a fabric can be considered soft if its draping coefficient measured on a circular table is below 60% and stiff if its draping coefficient is greater than 85%.

Among the tested textiles, Fabric 1, 5, and 7 have a soft behaviour, as the test performed on a circular table shows. These three textiles even follow the corners of the 9-sided table with their waves. The data suggest that Fabric 7 would follow the corners of a 10-sided table, and Fabrics 1 and 5 would even follow the corners of an 11-sided table with their waves. In the case of the 12-sided and 15-sided tables, none of our fabrics were able to follow the corners.

Fabric 2 was particularly rigidly and paper-like, with the highest bending length and shear rigidity. This is also confirmed by its behaviour on the circular table, where its draping coefficient was very high, and also the fact that its waves only followed the corners of the triangular and square tables. Fabric 4 and 6, whose waves followed up to eight corners, and Fabric 3, whose waves followed up to seven corners can be considered to have average behaviour.

When the waves of the tested fabric can no longer follow the corners of the table, its behaviour starts to resemble its behaviour on the round table, but the standard deviations are quite large. If the number of sides of a table increases more and more, its shape approximates a circle, and the behaviour of the fabric also corresponds to its behaviour on a circular table.
In general, Figures 6-7 show that *DC* increases as a function of the number of table corners while the number of waves is the same as the number of table corners and asymptotically approaches a maximum. This maximum is the draping coefficient that the fabric approaches when the number of waves is the same or almost the same as the number of the corners of the table.
Our series of experiments in which we set the number of waves manually on the circular table, also points to the importance of the conditions of the draping. The diagrams in Figures 10–11 show the draping coefficient as a function of the number of spontaneously formed waves on the polygonal table and the round table and as a function of the number of artificially formed waves on the round table. These results also confirm that the number of waves on a circular table is not deterministic, and the draping coefficient depends on the number of waves. It can also be seen that in the case of the same number of waves; the draping coefficient is also influenced by the conditions of the draping.

5. CONCLUSION

We performed draping tests on selected fabric samples using the usual circular and the special regular polygonal sample-holding tables with the same area as the circular table. The tests showed that the stiffer a sample is, the less it can follow the corners of a table with its waves, and the softer it is, the more it can follow the shape of the table with its waves; that is, the more table corners it can follow with its waves. In the case of polygonal tables, as long as the number of waves follows the number of table corners, the draping coefficient increases and trends asymptotically to a maximum value as a function of the number of table corners or waves. With the same number of waves, the draping coefficient measured on polygonal tables is significantly higher than in the case of circular tables.
Our series of experiments, in which we set the number of waves manually on the circular table, points to the importance of the conditions of draping. The results confirm that the number of waves on a circular table is not deterministic, and the draping coefficient depends on the number of waves. The same number of waves may be formed spontaneously and artificially but the corresponding *DC* may be different. This proves that the dynamic conditions of draping also influence the draping coefficient.
Using a polygonal sample-holding table, the deviation in the number of waves can be eliminated, and draping can be made uniform. When the waves of the sample follow the corners of the polygonal table, than the number of waves is clear, the size and arrangement of the waves are uniform, and the standard deviation in the draping coefficient is smaller compared to the value measured on the round table. In light of this, it could be advisable to perform the draping test on a polygonal table, thus excluding the measurement uncertainty resulting from the unevenness of draping and improving the repeatability of the tests. Based on the data, the regular six-sided sample-holding table can be recommended for the drape test; only very rigid samples cannot follow its corners with their waves, the draping coefficient is almost the same as that measured on a round table, and its standard deviation is smaller; therefore, the hexagonal table is suitable for testing the vast majority of sheet-like materials with low bending stiffness. We believe measurements made according to the ISO 9073-9:2008 standard could be worth supplementing optionally with measurements made on a hexagonal sample-holding table. This testing could be particularly useful when comparing fabrics for similar purposes in the fashion industry, in order to select the most suitable fabric in terms of draping.

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POSSIBILITIES FOR THE APPLICATION OF RENEWABLE ENERGY SOURCES IN RURAL AREAS

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Abstract:

*This paper explores the **possibilities of applying renewable energy sources (RES)** in rural areas of the Republic of Serbia, aiming to increase energy efficiency, reduce environmental pollution, and promote sustainable development. By analyzing the characteristics of rural areas, demographic indicators, and the current state of agricultural holding, the paper identifies key potentials and challenges in the use of RES. Special attention is given to solar energy, wind energy, biomass, biogas, and geothermal energy, as well as their technical possibilities and practical applications in agriculture and households. Based on a survey on the awareness of rural populations regarding renewable energy sources, the study analyses attitudes, knowledge levels, and readiness for investment in RES. The results show significant potential for the development of renewable energy in rural areas of Serbia, emphasizing the need for greater education, institutional support, and financial incentives. This paper concludes that integrating renewable energy sources can contribute to the development of sustainable and energy-independent rural communitas.*

Keywords: *renewable energy sources, rural development, solar energy, biomass, sustainable development*

1. INTRODUCTION

The balanced development of countries worldwide is closely linked to the development of rural areas, which plays a crucial role in ensuring economic stability, social cohesion, and environmental sustainability [1]. Effective rural development policies require a robust analytical framework based on two key components: a clear and consistent methodology for the identification and classification of rural areas, and the definition of relevant rural development indicators along with their systematic application in policy design and evaluation.[2]

Numerous international organizations, including the **Organization for Economic Co-operation and Development (OECD)**, the **European Union (EU)**, the **Food and Agriculture Organization of the United Nations (FAO)**, and the **World Bank**, have undertaken significant efforts to develop methodological approaches aimed at standardizing the identification of rural areas and minimizing the number of indicators while preserving their analytical relevance.[3] Despite these efforts, the lack of a universally accepted international standard has resulted in methodological heterogeneity, with existing approaches providing primarily general guidance rather than a fully harmonized framework.

2. EXPERIMENTAL

The study employed survey-based research design. The survey methodology is widely used in empirical research to collect data from individuals or groups through structured questionnaires consisting of standardized questions. Depending on the research design, surveys may be administered through various modes, including telephone interviews, online questionnaires, paper-based instruments, or face-to-face interviews.[4]

In this study, data was collected through a survey conducted among residents in rural areas. This method represents a systematic and non-experimental approach to data collection, enabling the gathering of

information on respondents' attitudes, opinions, beliefs, and self-reported behaviors related to the subject of the study. Due to its capacity to capture perceptions across a broader population, this approach is particularly suitable for social science and policy-oriented research.[5]
The survey constitutes a form of non-experimental research in which self-reported responses serve as the primary data source. Data was obtained using a standardized questionnaire and subsequently analyzed using appropriate analytical and statistical methods. The academic literature reflects differing views regarding whether surveys should be classified as a research method or a research technique.[6]
The study sample included residents of villages or rural areas across the Republic of Serbia. A total of 107 respondents participated in the survey. Data collection was conducted using the Google Forms platform, after which the data was systematically processed and analyzed.

3. RESULTS

The survey examining the level of awareness of the rural population regarding the application of renewable energy sources was conducted in May 2025. The sample included 107 respondents of different age groups and educational levels, with varying degrees of familiarly with renewable energy sources. Respondents were informed about the survey through social media platforms, email communication, and closed online groups.
The questionnaire consisted of 22 questions, organized into thematic groups.

Questionnaire Structure

Demographic characteristics

- Gender
- Age
- Level of education
- Type of settlement of residence
- Region of residence

Awareness of renewable energy sources

- The need to increase awareness of RES
- Ways of acquiring informatio on RES
- Primary source of information onthe application of RES

Personal attitudes

- Familiarity with renewable energy sources
- Perceived advantages of using RES
- Perceived local potencial for RES application
- Familiarity with the application of RES ageiculture
- Possible uses of RES in agricultre
- The contribution of RES to improving the quality of agricultural products
- The contribution of RES to increasing the competitiveness of agricultural products
- The potential of RES to enhance agricultural development
- The contribution of RES to the revitalization of rural areas
- Current use of RES

Financial investment

- The role of government financial support in the application of RES in agriculture
- Willingness to invest in RES **with** state support
- Willingness to invest in RES even **without** state support
- Familiarity with givernment support models for the use of RES

4. DISCUSSION

4.1 **Demographic characteristics**

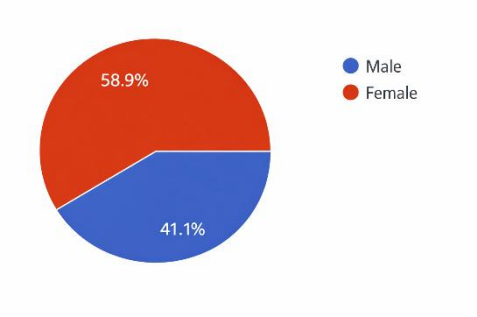

Figure 1: Gender

In response to the question regarding gender, 58.9% of respondents identified as female, while 41.1% identified as male. Accordingly, out of the total sample of 107 respondents, 63 were female and 44 were male.

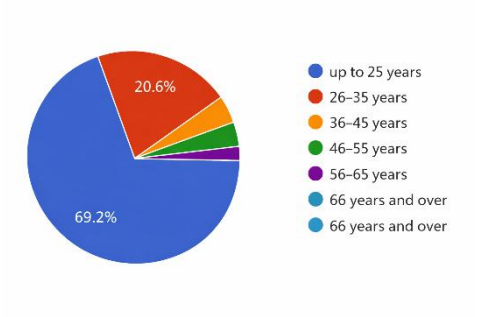

Figure 2: Age

The second question concerned the age of the respondents. The results indicate that the largest proportion of participants were aged up to 25 years, while no respondents were aged 66 years or older.

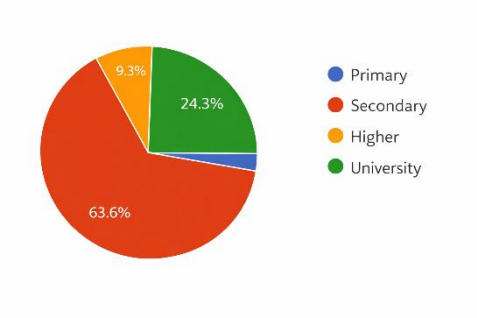

Figure 3: Level of education

With regard to educational attainment, the majority of respondents reported having completed secondary education, while the smallest proportion reported having completed only primary education.

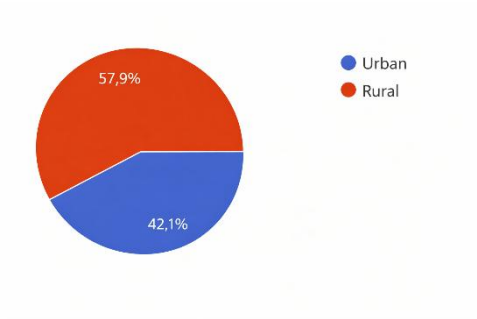

Figure 4: Type of settlement of residence

The fourth question pertains to the type of settlement in which the respondents reside. A total of 57.9% of participants reported living in rural areas, while 42.1% indicated that they live in urban areas.

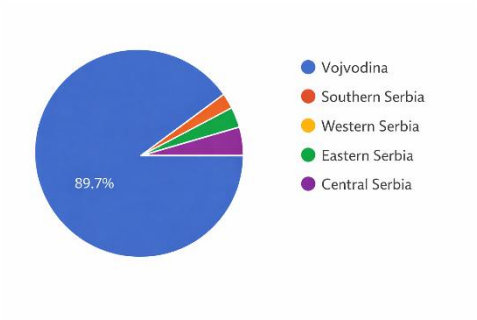

Figure 5: Region

The question addressed the region of origin of the respondents. The results indicate that the majority of participants were from the Vojvodina region, while no respondents were from Western Serbia.

4.2 **Awareness of renewable energy sources**

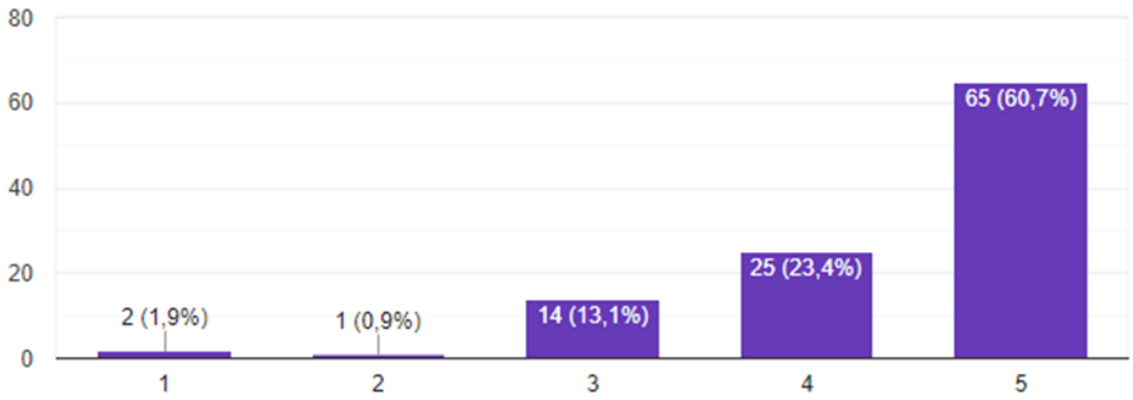

Figure 6: The need to increase awareness of RES

The question concerning the increase in awareness was presented using a scale from 0 to 5. A total of 65 respondents (60.7%) fully agreed that awareness of renewable energy sources should be increased, while 2 respondents (1.9%) disagreed with the need to enhance awareness. These results indicate a clear need for increased awareness of renewable energy sources.

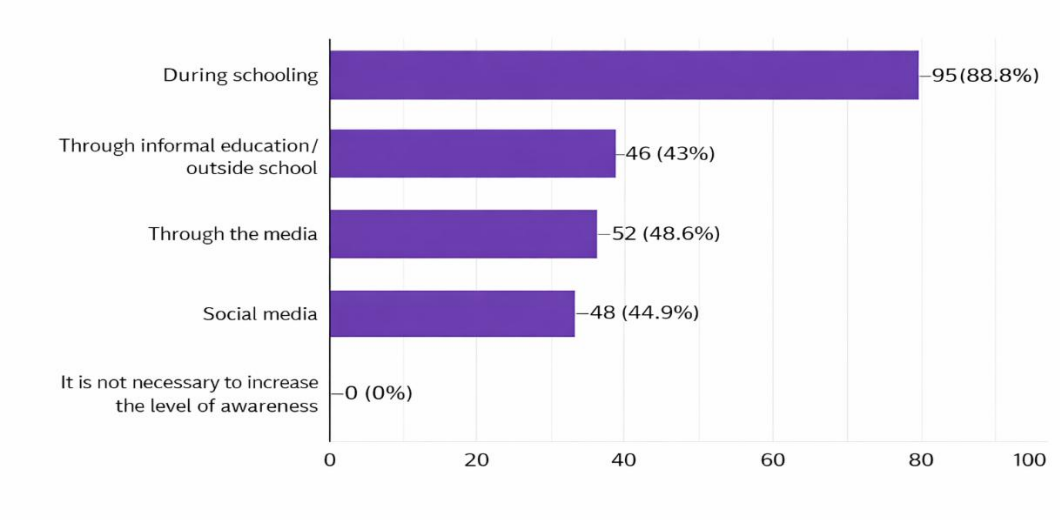

Figure 7: Ways of acquiring information on RES

The seventh question examined the sources through which respondents believe information should be acquired. Of the 107 respondents, 88.8% indicated that awareness of renewable energy sources should be developed through formal education. Notably, none of the respondents selected the option indicating that increasing the level of awareness is unnecessary.

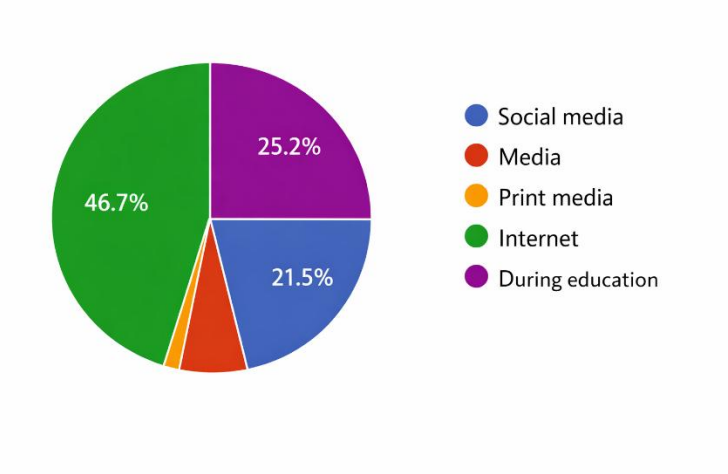

Figure 8: Primary source of information onthe application of RES

The eighth question addressed the sources of information regarding the application of renewable energy sources. The results indicate that the Internet was the primary source of information (46.7%), while print media were the least frequently reported source (0.9%).

4.3 **Personal attitudes**

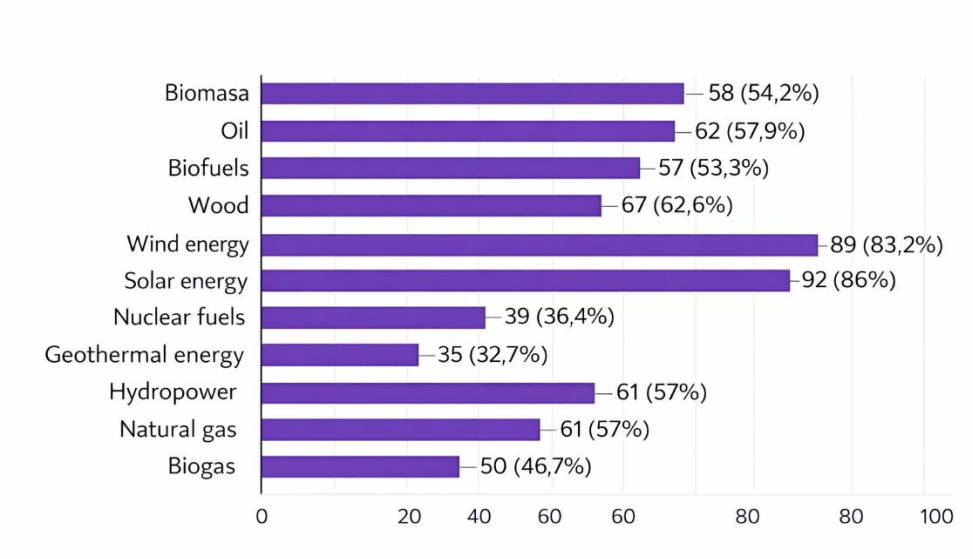

Figure 9: Familiarity with renewable energy sources

The observed pattern of responses suggests gaps in respondents' understanding, indicating limited differentiation between renewable and non-renewable energy sources.

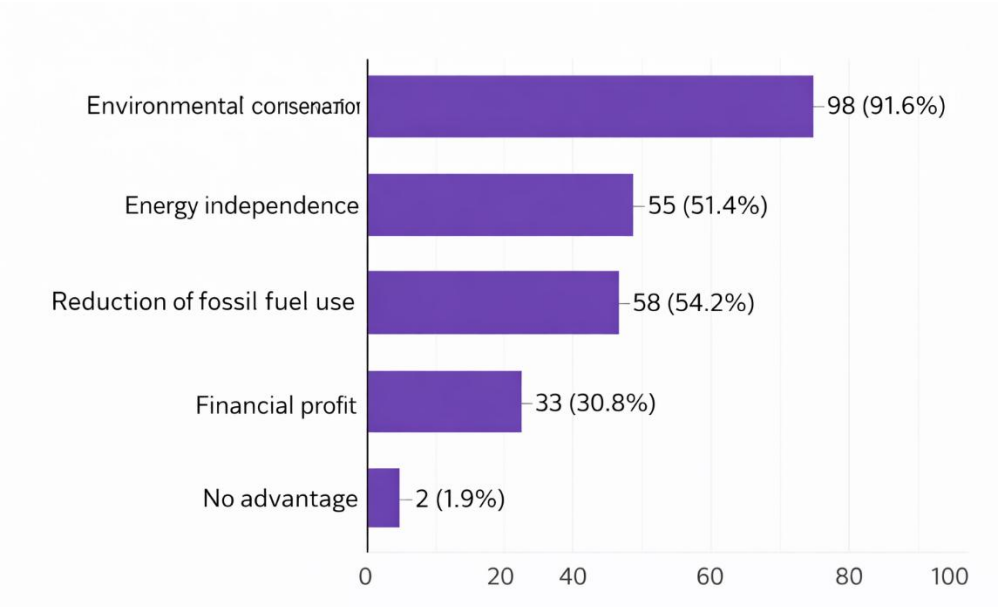

Figure 10: Perceived advantages of using RES

Environmental protection emerged as the most commonly perceived advantage of renewable energy sources (91.6%), whereas only a negligible proportion of respondents (1.9%) reported no perceived advantages.

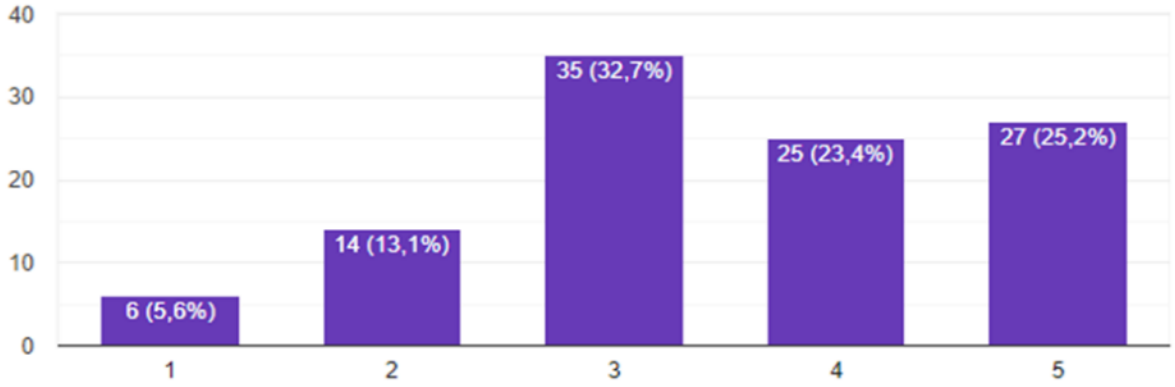

Figure 11: Perceived local potential for RES application

Respondents expressed moderate agreement with the statement concerning local renewable energy potential, indicating a degree of uncertainty regarding the feasibility of renewable energy implementation in their local environments.

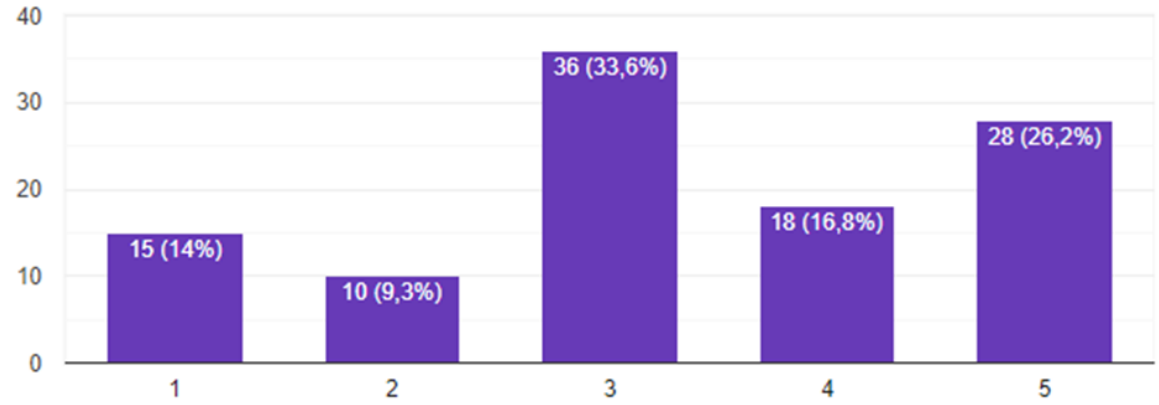

Figure 12: Familiarity with the application of RES agriculture

The question referred to the statement concerning respondents' familiarity with the possibilities for the application of renewable energy sources in agriculture. The results indicate that respondents are only partially familiar with the potential applications of renewable energy sources in the agricultural sector.These findings suggest that the majority of respondents lack sufficient knowledge regarding the application of renewable energy sources, highlighting the need for improved information and education.

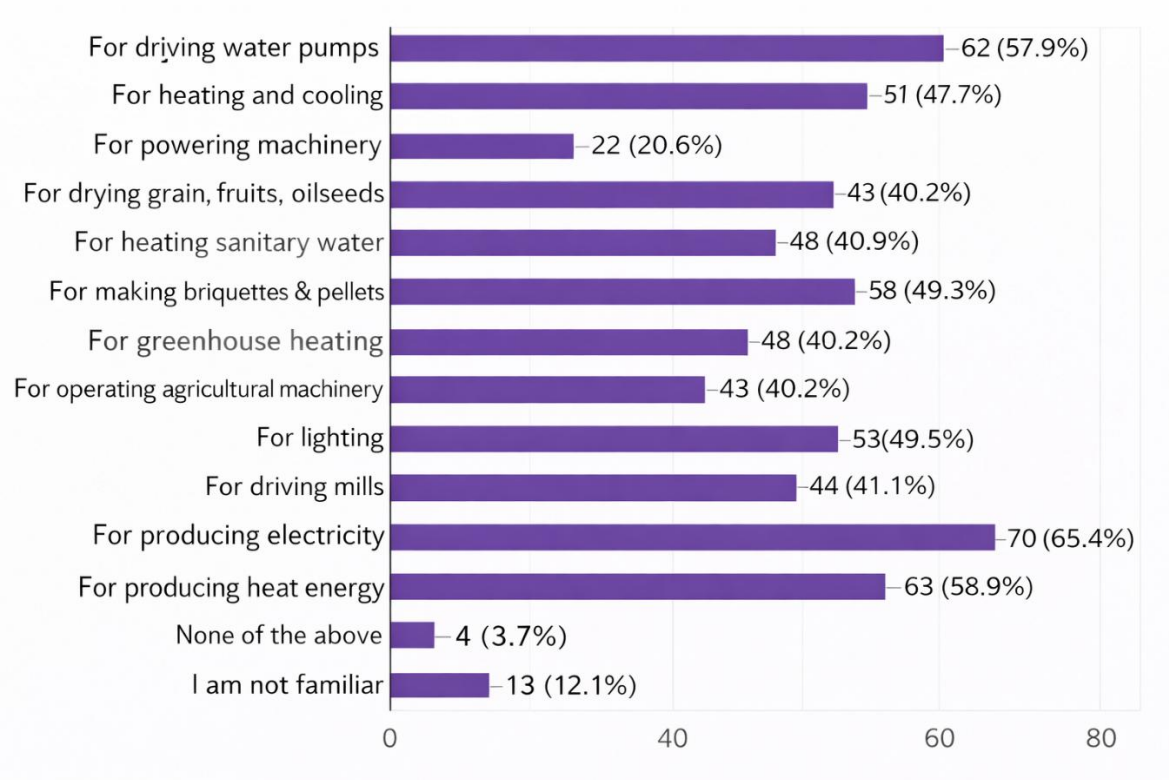

Figure 13: Possible uses of RES in agriculture

Approximately 55% of respondents reported familiarity with the application of renewable energy sources in agriculture.

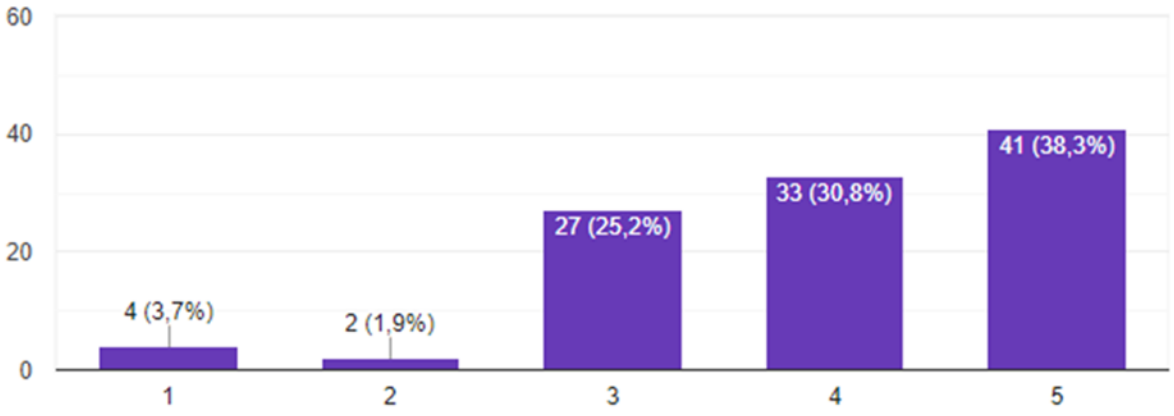

Figure 14: The contribution of RES to improving the quality of agricultural products

A majority of respondents expressed agreement with the statement regarding the positive impact of renewable energy sources on the quality of agricultural products.

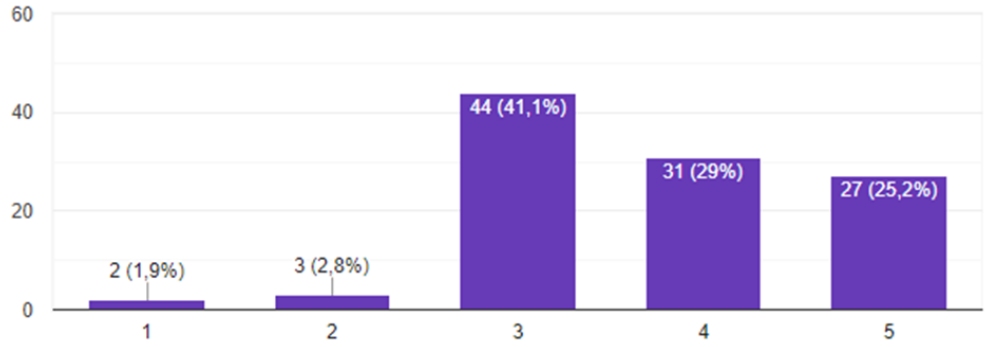

Figure 15: The contribution of RES to increasing the competitiveness of agricultural products

Partial agreement among respondents indicates a moderate perception of the role of renewable energy sources in improving the competitiveness of agricultural products.

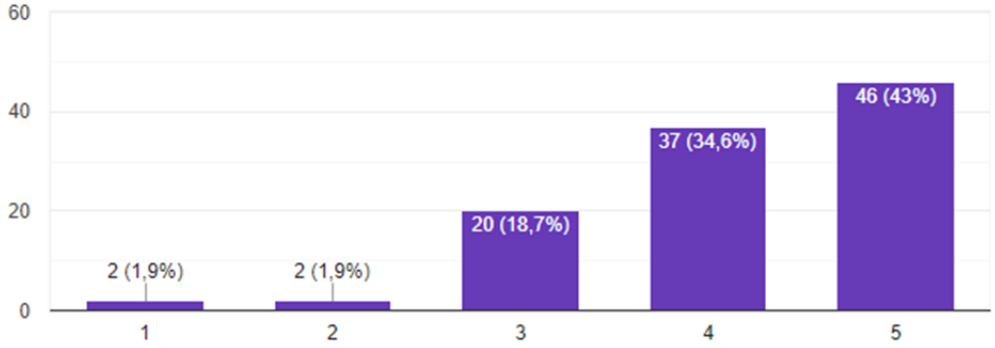

Figure 16: The potential of RES to enhance agricultural development

A plurality of respondents (43%) perceived renewable energy sources as having the potential to improve agricultural production.

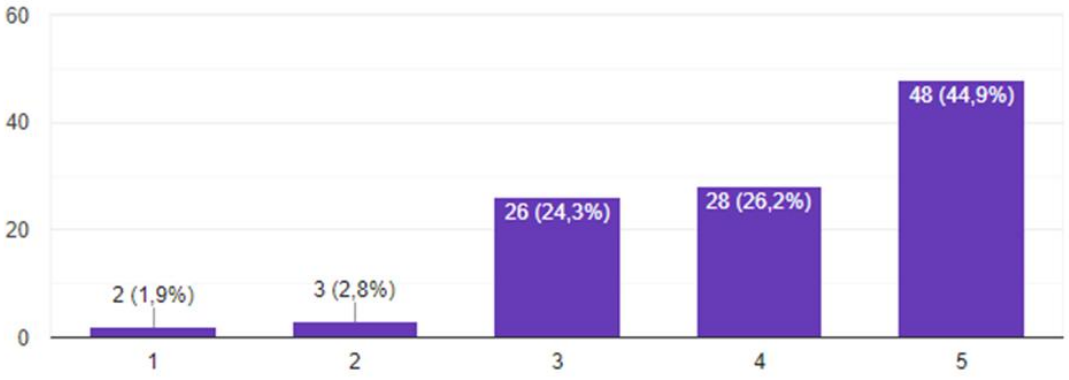

Figure 17: The contribution of RES to the revitalization of rural areas

A plurality of respondents (44.9%) perceived renewable energy sources as having the potential to revitalize rural areas.

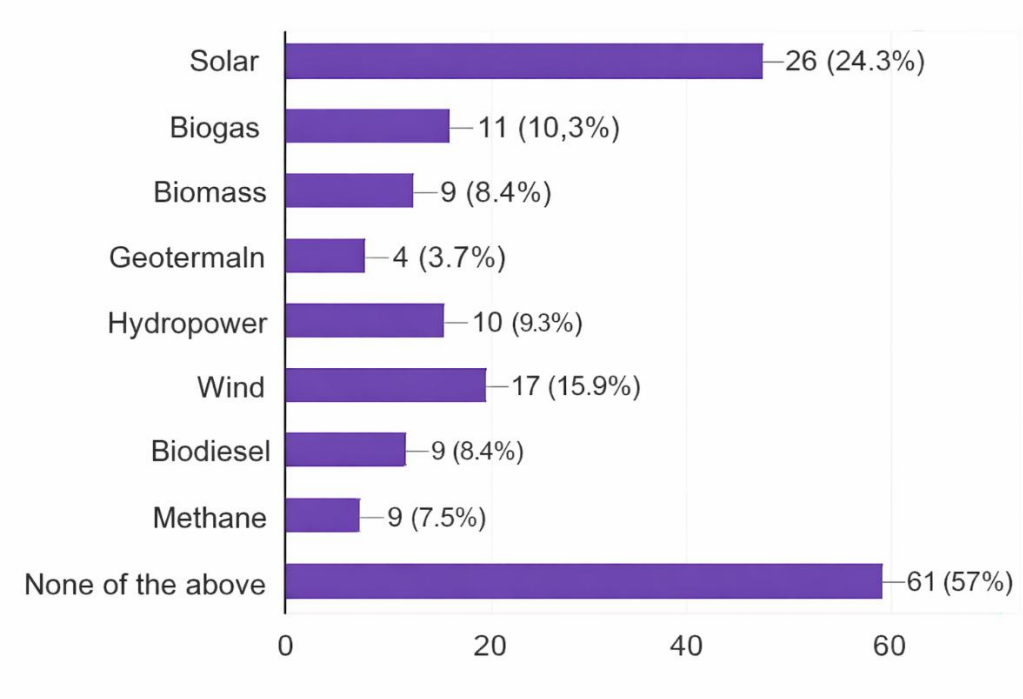

Figure 18: Current use of RES

The question examined the ways in which respondents use renewable energy sources. The largest proportion of respondents reported not using renewable energy sources, while 26 respondents indicated the use of solar energy. These results indicate that only a small proportion of respondents currently use renewable energy sources and that familiarity with the available possibilities for their utilization remains limited.

4.4 **Financial investment**

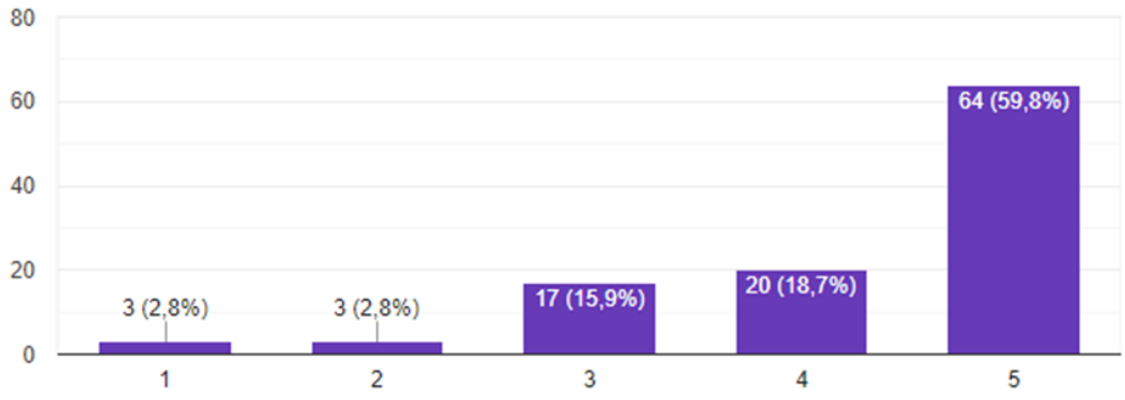

Figure 19: The role of government financial support in the application of RES in agriculture

The question examined respondents' opinions regarding government financial support for the implementation of renewable energy sources in agriculture. The majority of respondents expressed the view that state support is necessary for the adoption of renewable energy sources, while only a small proportion considered such support unnecessary. These results indicate broad agreement among respondents on the importance of financial assistance in facilitating the implementation of renewable energy sources.

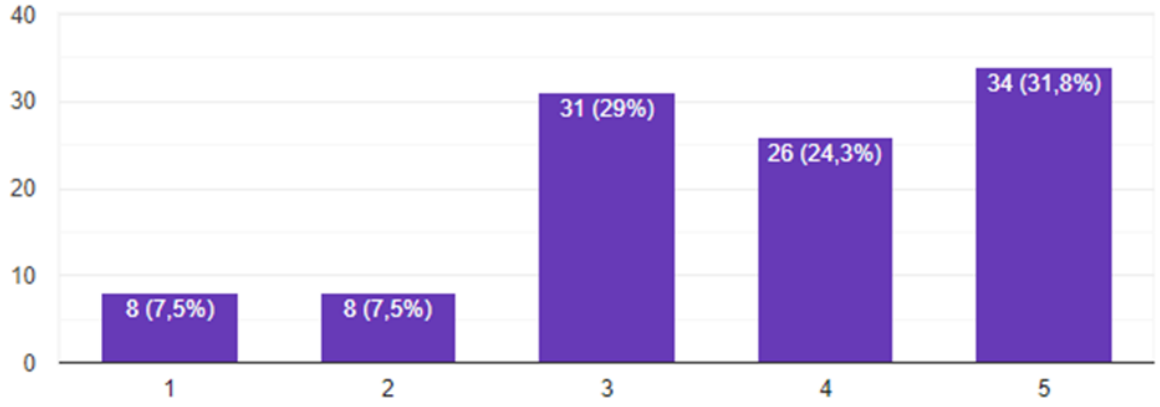

*Figure 20: Willingness to invest in RES **with** state support*

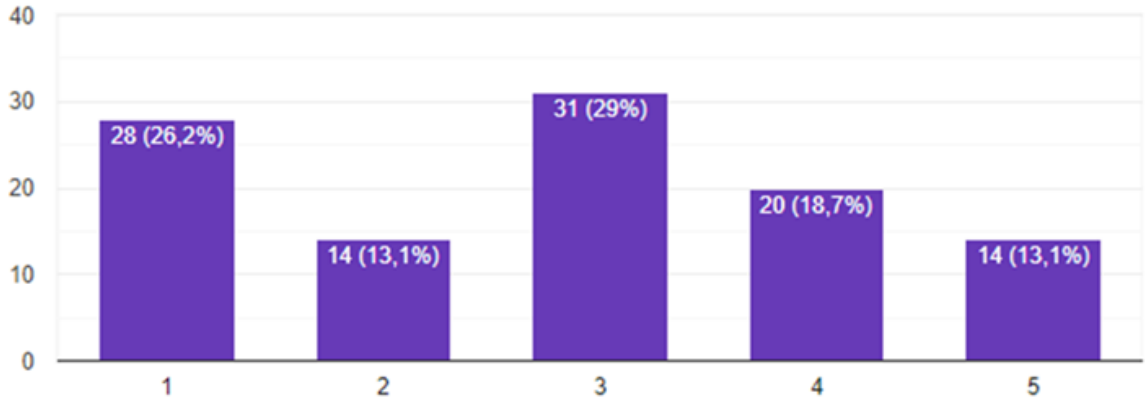

*Figure 21: Willingness to invest in RES even **without** state support*

Questions 20 and 21 examined respondents' willingness to invest in renewable energy sources with and without government support. The majority of respondents expressed willingness to invest when government support is available, while the same group reported only partial willingness to invest in the absence of such support. These results indicate a stronger inclination toward investment in renewable energy sources when financial support from the state is provided.

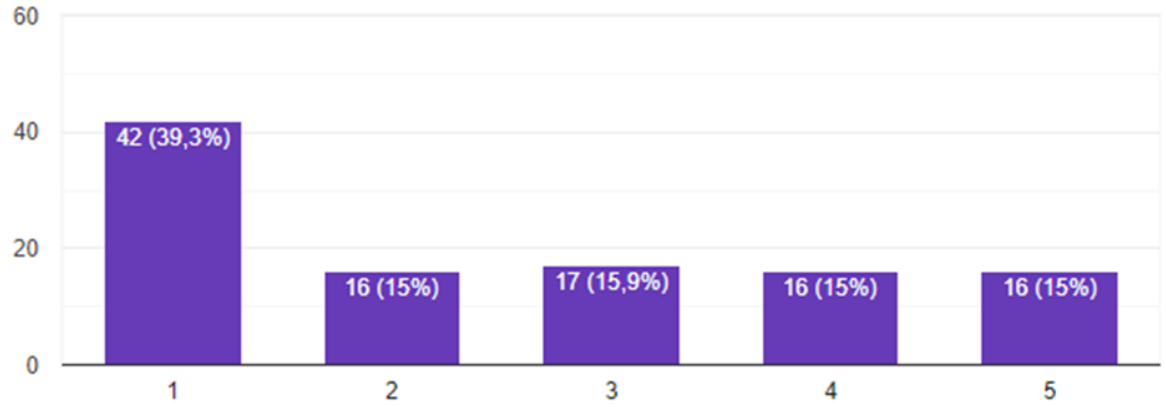

Figure 22: Familiarity with givernment support models for the use of RES

The question examined respondents' familiarity with government support models for the use of renewable energy sources. The largest proportion of respondents indicated a lack of familiarity with existing government support schemes for renewable energy use.

5. CONCLUSIONS

Based on the survey results, it can be concluded that the application of renewable energy sources could contribute to the development of rural areas in the Republic of Serbia. Through the use of renewable energy sources, the population could benefit both in agriculture and in everyday life. The findings indicate that if the state were to provide subsidies, the population would be more inclined to use renewable energy sources for electricity generation, household heating, and the heating of greenhouses. The survey of residents in rural areas further suggests that respondents of different educational levels and age groups do not clearly distinguish between renewable and non-renewable energy sources. Nevertheless, the majority of respondents expressed positive attitudes toward statements highlighting the benefits of using renewable energy sources. These results point to a clear need for increased public education and awareness. A large proportion of respondents also believe that government support is essential in order to enable wider adoption of renewable energy sources.

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