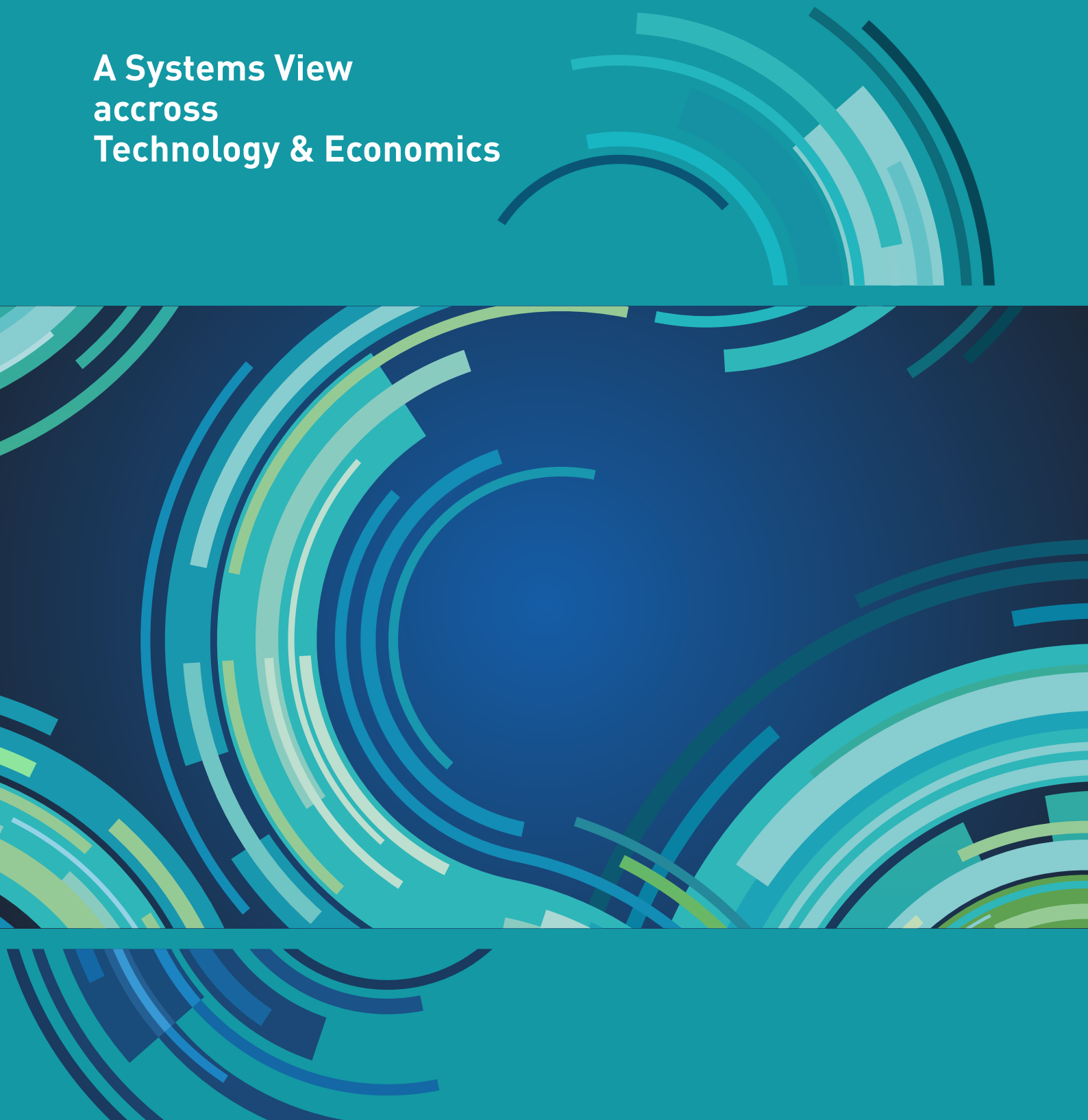


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Business Systems Research

A Systems View
across
Technology & Economics



Impressum

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Business Systems Research Journal (BSR) is an international scientific journal focused on improving the competitiveness of businesses and economic systems. BSR examines a wide variety of decisions, processes, and activities within the actual business setting and the systems approach framework. Theoretical and empirical advances in business systems research are evaluated regularly. Special attention is paid to educational, social, legal, and managerial aspects of business systems research. In this respect, the BSR journal fosters the exchange of ideas, experience, and knowledge between regions with different technological and cultural traditions, in particular in transition countries. Papers submitted for publication should be original theoretical and practical papers. The journal also publishes case studies describing innovative applications and critical reviews of theory.

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A Systematic Review of Green and Digital Transitional Factors in the Fashion Industry

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Abstract

Background: The fashion industry's current manufacturing approach raises various environmental and social concerns, including but not limited to carbon emissions, resource depletion, waste generation, substantial energy consumption, and labour exploitation. Green and digital fashion can minimise these issues. However, fashion's green and digital shifts need more coverage. **Objectives:** This paper aims to observe and explore the key elements of green and digital transitions in the fashion industry. **Methods/Approach:** Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, this systematic review study examined articles on green and digital transformations in the fashion supply chain from 2012 to 2022 in relevant indexation services. The researchers used descriptive and content analysis to explain the results from 46 of the 518 publications that were relevant to their study. **Results:** The study uncovered green transforming factors such as green materials, green energy, cleaner production, and others, as well as digital shifting factors like artificial intelligence, the Internet of Things (IoT), and robotics. **Conclusions:** This study's findings can assist practitioners and policymakers in integrating digital and green technologies into the fashion industry. Moreover, this study identified several research gaps that, if addressed, could have significant practical implications for the future of the fashion industry.

Keywords: Green transition, Digital transition, Fashion industry, Systematic review

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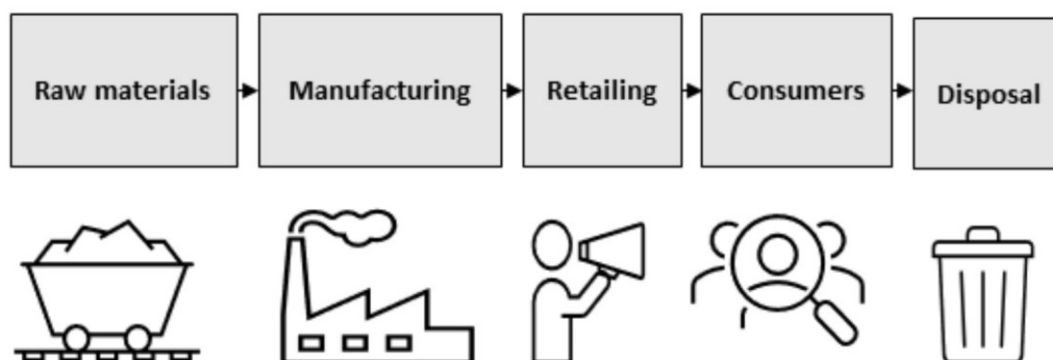
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Introduction

The fashion manufacturing industry is crucial to fostering a country's economic development because it meets basic human needs through clothing production and creates job opportunities (Noor et al., 2022). Across the supply chain, the apparel industry generates income for more than 300 million people and is worth USD 1.3 trillion (Ellen MacArthur Foundation, 2017). However, the fashion supply chain is also the primary source of environmental pollution and carbon emissions due to its high water, energy, chemical, and non-renewable resource consumption (Šajin, 2019; Yu et al., 2021). The conventional fashion supply chain (Figure 1) operates under a linear model known as the "take-make-dispose" paradigm, wherein raw materials are harvested, transformed into useable goods in the factory, shipped to retailers, sold to consumers, and discarded at the end of their lifecycle (Ellen MacArthur Foundation, 2017; Presley & Meade, 2018). The current linear fashion approach generates several ecological and social problems, contributing to 8% of the world's carbon emissions and 20% of wastewater (Brydges, 2021; To et al., 2019). Besides, the industry is often criticised for its unfair treatment of workers and complex supply chain (Presley & Meade, 2018). Therefore, there is a pressing need to switch to a textile system that improves economic, social, and environmental outcomes (Desore & Narula, 2018; Ellen MacArthur Foundation, 2017). The fashion industry has the potential to drastically cut its carbon footprint by shifting to renewable energy and closing the loop on fashion models (Hiller Connell & Kozar, 2017). Closing the loop system is based on circular principles, emphasising maximising the lifespan of products and materials through reuse and the recovery and regeneration of products at the end of their useful lives (Brydges, 2021). Closing the loop fashion approach (Figure 2) is characterised by the utilisation of environmentally friendly materials, as well as sustainable production and retailing practices, promoting sustainable consumption through recycling, reusing, and repurposing (Ellen MacArthur Foundation, 2017; O'Reilly & Kumar, 2016). Adopting digital technologies and a greener approach to business practices can reduce resource consumption and carbon dioxide emissions and promote sustainability (Rosa et al., 2020).

Figure 1
Traditional Fashion Supply Chain



Source: Authors' analysis based on Ellen MacArthur Foundation (2017) and Presley & Meade (2018)

Although some differences exist between the fashion, apparel, and textile industries, this study has employed them interchangeably. The textile business involves several components, such as fibres, yarns, and fabrics, while the apparel industry

focuses explicitly on stitching to produce garments (Majumdar et al., 2020; Nayak et al., 2020). On the other hand, the fashion industry revolves around design and creativity, encompassing both the clothing and footwear sectors (Papahristou & Bilalis, 2017; Peters et al., 2021).

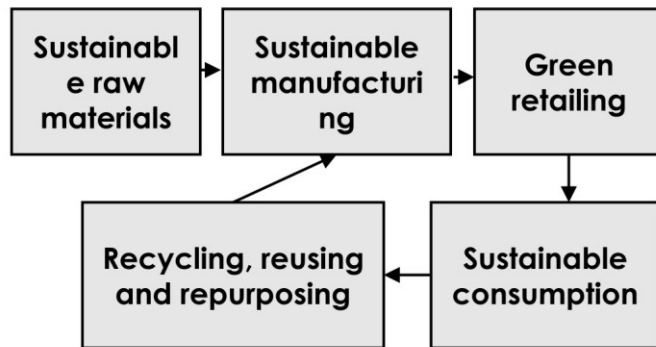
The "green transition" is a shift from excessive energy consumption and greenhouse gas emissions toward a more environmentally friendly economy (Ikram, 2022). It is a transformation from a linear approach to a circular economy model based on the closing-the-loop approach that can minimise resource consumption and promote sustainable development (Michel & Lee, 2017). The circular model incorporates sustainability initiatives at every stage of the economy (Mishra et al., 2020). This includes eco-design, green materials, green manufacturing, and reduction, reuse, and recycling programs. Several global initiatives to fight climate change (Kannan et al., 2022; Ortega-Gras et al., 2021) support the green and digital transition. These include the Paris Agreement, the 2030 Agenda for Sustainable Development, the EU Digital Strategy, and the European Green Deal. A green transition involves adopting sustainable materials, processes, and technologies. Thus, this study implies a green transition in the fashion industry by undertaking a sustainability movement across the fashion supply chain, which can reduce CO₂ emissions, water consumption, and other material consumption.

On the other hand, the digital transition is the implementation of digital tools and technologies in the industrial process to improve efficiency, reduce waste, and make the supply chain more open and transparent. It affects every aspect of business, including organisations, current and prospective business models, business process management, ecological systems, products, and services (Furjan et al., 2020). Emerging digital technologies enable and drive organisations to promote a green business strategy, which increases productivity and profitability (Papahristou & Bilalis, 2017; Wynn & Jones, 2022). Technological applications such as artificial intelligence, blockchain, 3D printing, and cloud computing can enhance fashion sustainability (Casciani et al., 2022; Ortega-Gras et al., 2021). Researchers in earlier studies have pointed out how vital green and circular economies are in the fashion supply chain, where digital technologies help to incorporate green models (Furjan et al., 2020; Rosa et al., 2020; Wynn & Jones, 2022). The COVID-19 pandemic has also drawn attention to the importance of advancing digital technologies in the worldwide fashion supply chain. (Casciani et al., 2022; Khurana, 2022). This study describes the digital transition as integrating intelligent technologies into the operations of the fashion industry to boost operational efficiency and transparency and decrease waste. Digital technologies transform traditional manufacturing operations into intelligent and efficient production systems (Ortega-Gras et al., 2021). Therefore, the digital transition is essential to foster industrial innovation and enhance sustainability in the textile industry.

Overall, the green and digital transition is a long and complicated process (Kazancoglu et al., 2020; Lüthje, 2021; Ortega-Gras et al., 2021). However, fashion enterprises have the potential to enhance their competitiveness, bolster their brand reputation, and foster innovation and growth in a market that is becoming more complex and changing constantly by using green practices and digital technologies (Casciani et al., 2022; Papahristou & Bilalis, 2017; Yu et al., 2021). Greener fashion approaches, such as eco-friendly materials, cleaner production, renewable energies and R principles, reduce waste, energy consumption, and pollution while enhancing financial gains (Ikram, 2022; Zamfir et al., 2022). Additionally, integrating digital technologies such as 3D modelling, blockchain, and virtual and augmented reality in the fashion supply chain can mitigate the wastage of raw materials during

the physical sample process, expedite the manufacturing cycle, foster innovative design approaches, and lower production costs (Bag et al., 2021; Bertola & Teunissen, 2018; Sayem, 2022).

Figure 2
Closing the Loop Fashion Model



Source: Authors' analysis based on Ellen MacArthur Foundation (2017) and O'Reilly & Kumar (2016)

Under these circumstances, the textile manufacturing sector's twin green and digital transitions are crucial to making the industry more sustainable (Tsai, 2018). A green and digital transition can reduce energy and resource use, emissions, and waste in the manufacturing processes of the fashion industry. It can solve problems caused by the garment business. That is why a green and digital transition is necessary to address the environmental and social challenges of the fashion manufacturing industry. Adopting sustainable and digital practices can improve a company's bottom line, CSR, creativity, and public image. Advanced economies and a few emerging economies continue to dominate the shift to green and digital technologies (Bianchini et al., 2022; Nyangchak, 2022). Though developing and underdeveloped countries have less focus on greening and digital technology, there is a rising trend toward adopting green and digital shifts in the textile and apparel industries of India, Bangladesh, Vietnam, and Ethiopia (Khurana, 2022; Nyangchak, 2022). China has taken several initiatives, like environmental regulation, to foster green and digital technologies in the manufacturing sector. A more in-depth understanding of the essential components of green and digital transformation in the fashion sector is becoming increasingly important, considering the pressing need to reduce carbon emissions, energy use, and resource use. The fashion industry is undergoing a green and digital transition simultaneously. Despite extensive research on the multiple factors involved, more systematic reviews with a more comprehensive approach are required to combine this information. A review and synthesis of the most recent scientific studies can help determine green and digital trends in the fashion industry. Therefore, this systematic literature review aims to gain insight into the critical elements of green and digital transitions in the fashion industry from the multidisciplinary literature. The researchers focused on the following research questions while writing this review:

- RQ1. What are the essential components of a green transition in the fashion industry?
- RQ2. Which aspects of the digital transformation of the fashion industry have been highlighted in the existing literature as being particularly crucial?

However, there is a great deal of literature on green and digital transitions, for example, related to fashion circularity (Furferi et al., 2022); green fashion (Andaregie & Astatkie, 2022; Bailey et al., 2022; Brydges, 2021; To et al., 2019; Tsai, 2018; Zhai et al., 2022); technological applications (Lüthje, 2021; Ortega-Gras et al., 2021; Teixeira et al., 2022; Yu et al., 2021); yet researchers still need to explore the significant elements of green and digital transformation in the context of the fashion industry. Literature can be found on various topics and in different fields, such as the cement industry (Zhang et al., 2021), the automobile industry (Lüthje, 2021), the construction industry (Clarke & Sahin-Dikmen, 2020), small and medium-sized enterprises (Šimberová et al., 2022), the manufacturing industry (Sahu et al., 2022), the fashion industry (Brydges & Hracs, 2019; Sun et al., 2021); and several empirical as well as review studies with a variety of research frameworks (Feng et al., 2022; Kannan et al., 2022; Marsiglio & Privileggi, 2021; Wang et al., 2021; Zhai et al., 2022) that focus on policies, driving factors and challenges of green and digital transition. To the best of the researchers' knowledge, there is a minimal systematic literature review (SLR) concerning the elements of green and digital transition in the fashion industry. Therefore, the current study attempts to fill this knowledge gap by synthesising the factors of green and digital transitions in the fashion industry through a systematic literature review.

This literature review contributes in two ways. First, it compiles the rudiments of digital and ecological shifts in the fashion industry. Theoretically, this could help policymakers, practitioners, and stakeholders in the push for a green and digital economy. Second, identifying research gaps may have implications for future research, as new studies may be required to fill the gaps.

The remaining sections of this paper consist of four parts. The research methods section explains this study's methodology and guiding principles. The result section summarises the key findings of the fundamental factors supporting green and digital transformation in the fashion industry. The analysis of the results is presented in the discussion section. In the final section, the study highlights important directions for future research.

Research Methodology

Researchers employed a systematic literature review strategy to collect and analyse studies addressing the digital and ecological shifts in the fashion industry. A systematic literature review helps researchers understand and evaluate the current state of a topic so they can come to clear conclusions about it (Denyer & Tranfield, 2009). This paper presents the outcomes of a systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 framework's recommended three-stage procedure (Kannan et al., 2022).

Literature identification

The authors of this study conducted a thorough literature search, shown in Table 1, for relevant articles published between 2012 and 2022. Since the first digital technologies were introduced to the industry in 2011 (Bertola & Teunissen, 2018; Xu et al., 2021), researchers have focused on that period. This systematic literature review (SLR) was meticulously conducted following rigorous protocols, ensuring the reproducibility of the findings by other scholars. It can be updated with the latest findings on the critical factors of the fashion industry's transition to digital and green technologies. First, the research team decided on keywords and databases to use in their search for a relevant journal. Using the study's prime research question, the team selected the study's keyword set. The researchers used Scopus, Web of Science, ScienceDirect,

and Google Scholar databases. The search strategy was applied in the selected databases, and the employed keywords were "green transition" OR "digital transition" AND "fashion industry" OR "textile industry," resulting in 518 studies. The last search was made on March 18, 2023.

Table 1
The Steps to Finding Literature

Research Protocol	Description of details
Research databases	Scopus, Web of Science, ScienceDirect and Google Scholar
Other sources	Website and Organisation
Search box	Abstracts, titles, and keywords
Keyword used in search advanced search option	("Green Transition" OR "Digital Transition") AND ("Fashion Industry" OR "Textile Industry")

Source: Authors' analysis

A protocol with inclusion and exclusion criteria was made for this study. The research papers analysing green and digital technologies in the fashion supply chain to achieve a sustainable economy were considered for the study. The primary records comprise journal articles, proceeding papers, review articles, data papers, and early access. The researchers chose the studies pertinent to the analysis based on the criteria outlined in Table 2.

Table 2
Inclusion and Exclusion Criteria

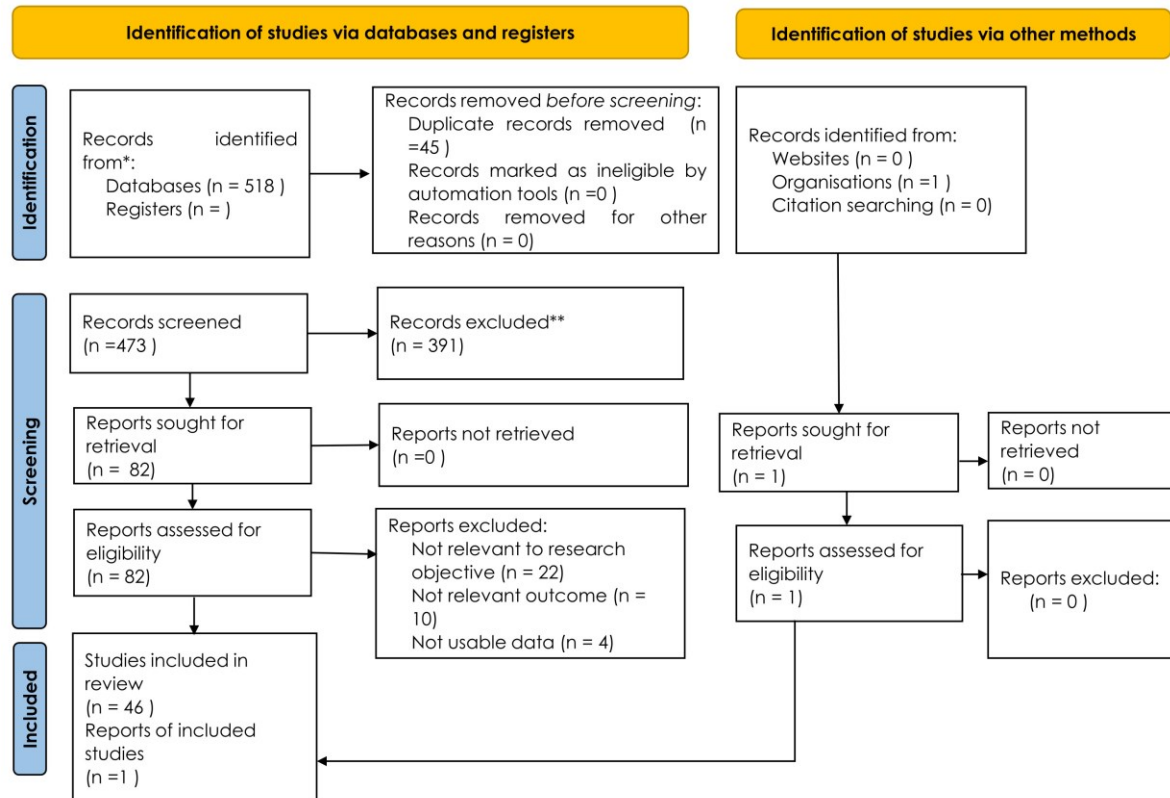
Criteria	Inclusion	Exclusion
Focus	Greening factors and digital technological shifts in textiles	Not related to the green and digital transition in fashion supply chain
Language	English	Other than English
Document Type	Only journal articles and review articles	Other than journal articles and review articles
Time frame	From January 2012 to December 2022	Out of the coverage from January 2012 to December 2022

Source: Authors' analysis

Literature evaluation

To filter out irrelevant articles, we used the method shown in Figure 3. Two researchers read the titles and abstracts of papers to determine if they were relevant to the research objective, and they eliminated 391 of the 473 records that were initially screened. According to this finding, the PRISMA framework's explicit research objective excluded about 82.67% of the records. Therefore, 82 records were chosen to retrieve and assess their suitability. There was also one organisation specifically targeted for retrieval and assessed for viability. The two authors talked over their contrasting opinions and settled on common ground. All studies under consideration reached a consensus.

Figure 3
Literature Review Method



Source: PRISMA 2020 model

Research analysis and interpretation

Researchers used a two-step process to screen and evaluate the studies to reduce the chance of bias. Firstly, greening factors and digital technological application-related literature in the fashion industry were imported into Microsoft Excel for descriptive analysis. The next step was to conduct an in-depth content analysis to map out key factors of green and digital fashions, summarise the state-of-the-art across various elements of greener and digital technological applications, and highlight pressing concerns and promising avenues for future study. At this point, all the information from the literature review has been gathered and written down. Descriptive and content analysis techniques were employed to present and discuss the study results.

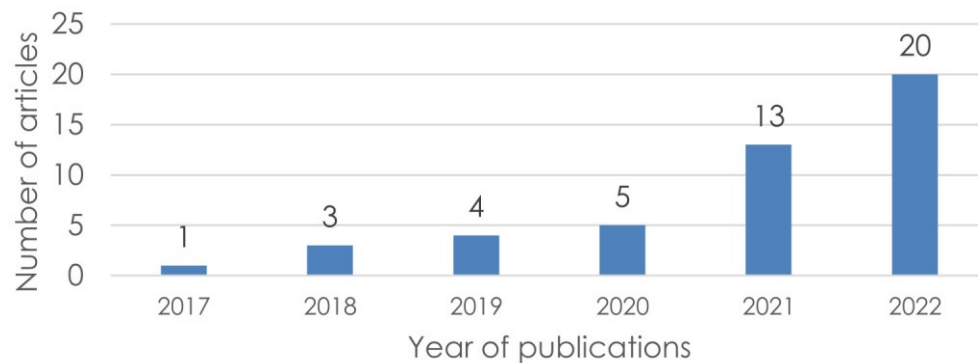
Result

This section presents the results of the systematic review of the crucial elements of the green and digital transition in the fashion industry.

Results from descriptive analysis

To develop a statistical overview of the development and structure of the body of knowledge on greening and digital technological shifting factors in the fashion industry, we sorted 46 reviewed papers according to year, journal, and country of origin.

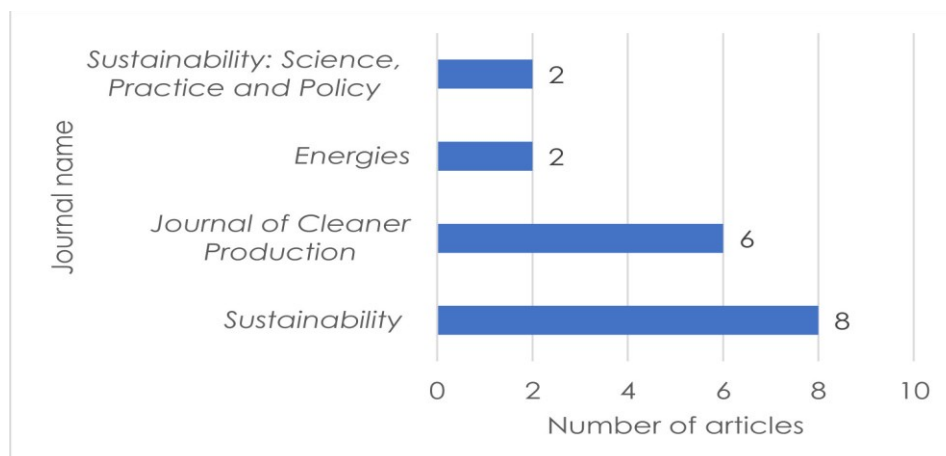
Figure 4
Publication Frequency over the Period



Source: Authors' analysis

Figure 4 shows the annual growth in publications discussing green and digital transitions in the textile and apparel industries from 2017 to 2022. Over the past five years, the percentage of annual publication growth has gone up. Specifically, 2017, 2018, 2019, 2020, 2021, and 2022 growth rates stand at 2.17%, 6.52%, 8.69%, 10.86%, 28.26%, and 43.47%, respectively. The goal was to find examples of how textile and apparel companies use digital and environmentally friendly technologies in the existing body of literature. The first study on green and digital transformational factors in the textile and apparel industry was published in 2017. This field's research grew steadily from 2021 to 2022, peaking in 2022. As shown in Figure 4, the fashion industry has focused primarily on green and digital transitional factors over the past two years. In 2022, there were 20 publications, representing almost half of the total publications during the publication years. The publication pattern reveals that researchers have been increasingly interested in studying the transition to more environmentally friendly and digital textiles in the last two years. However, progress in this area of study still needs to be improved.

Figure 5
Publication from Major Journal

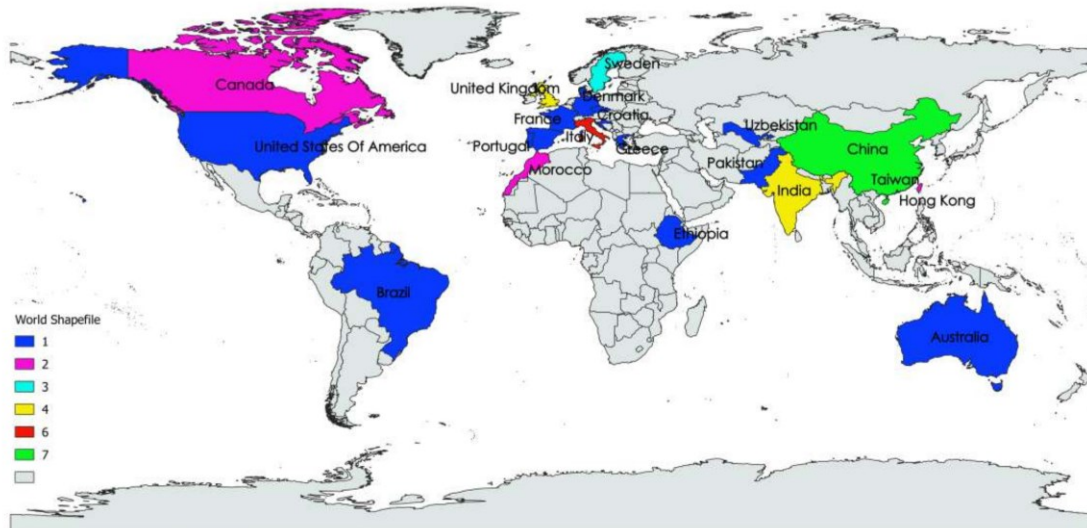


Source: Authors' analysis

Thirty-two journals have published the reviewed papers; Figure 5 presents a ranking of these journals, which have published more than one article. Sustainability, the

Journal of Cleaner Production, Energies, and Sustainability: Science, Practice, and Policy are just a few of the high-quality publications that have published numerous articles. Sustainability and the Journal of Cleaner Production host nearly a third of the reviewed papers.

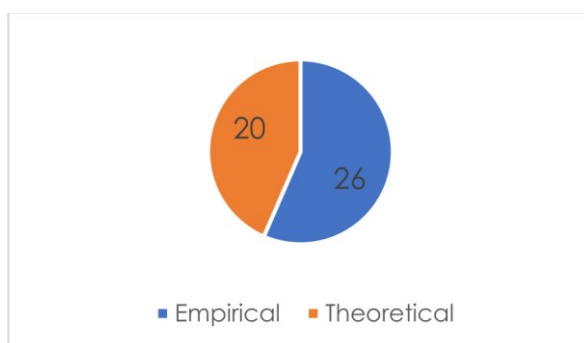
Figure 6
Publication from Different Countries



Source: Authors' analysis

From 2017 to 2022, authors from 23 nations penned works about green and digital transitions in the apparel business. Figure 6 displays the global scope of the reviewed literature by indicating the country of origin for each author. With seven studies, China led the world in publishing studies on using digital and environmentally friendly technologies in the fashion industry. The other considerable research contributions to the green and digital transition in the fashion industry came from Itali (6), the UK (4), India (4), Sweden (2), Morocco (2), Canada (2), Taiwan (2), and Hong Kong (2). The United States, France, Uzbekistan, Germany, Pakistan, Portugal, Denmark, Brazil, the Czech Republic, Ethiopia, Spain, Croatia, Australia, and Greece are just some of the other countries whose authors have contributed to the literature on the green and digital transition in the fashion industry.

Figure 7
Types of publications



Source: Authors' analysis

The data presented in Figure 7 illustrates the distribution of papers according to the types of publications, namely theoretical and empirical. Out of 46 studies, 26 are grounded in empirical research methodologies, encompassing quantitative, qualitative, mixed methods, and case study approaches. On the other hand, 20 papers adopt theoretical approaches, specifically review and conceptual frameworks.

Result from content analysis.

Table 3 and Table 4 below display the identified essential green transitional factors and digital transitional factors, respectively.

Table 3

Identified Essential Factors of Green Transitions.

Factors	Explanation	Reference
Sustainable materials	It refers to natural fibres such as organic cotton, hemp, and bamboo, which are biodegradable and grown using sustainable farming practices.	Sarkar et al., (2020); Rosário & Dias (2022)
Cleaner production	Sustainable production, also called "cleaner production," is a system of processes, products, and services that work together to protect the environment and reduce risks to people and the environment.	Andaregie & Astatkie (2022); De Felice & Petrillo (2021); (Šajn, 2019)
R approach	The R approach stands for "Reduce, Reuse, and Recycle." It entails designing durable products, promoting second-hand fashion, and implementing recycling initiatives and closed-loop supply chains to reduce waste and conserve resources.	Sandvik & Stubbs (2019); Furferi et al., (2022); Mishra et al., (2020); Rosa et al., (2020)
Green product and process innovation	It refers to producing durable and recyclable or repurposable textiles and accessories.	Rosário & Dias (2022); Ikram (2022)
Waste management	It entails cutting down on waste from making and using garments.	Šajn (2019); Yu et al., (2021)
Green energy	Green energy refers to renewable energies such as solar, wind, water, and biomass, which contribute to reducing carbon emissions and other air pollutants associated with energy production. Methods such as optimising procedures and switching to renewable power sources fall under this category of energy conservation measures.	Li et al., (2019); Zamfir et al., (2022); Sarkar et al., (2020)
Green supply chain	It refers to creating and adopting environmentally friendly procedures throughout the supply chain, from the procurement of raw materials to the final disposition of the finished goods.	Coscieme et al., (2022); Li et al., (2019)
Sustainable consumption	It refers to promoting and encouraging consumer behaviour that reduces environmental and social harm by purchasing and using clothing and accessories. This method emphasises waste reduction, resource conservation, and safeguarding human rights through the educated purchase, use, and disposal of clothing and accessories.	Li et al., (2019); Tsai (2018); Cai & Cho (2020)

Source: Authors' analysis

Table 4
Identified Essential Factors of Digital Transitions.

Factors	Explanation	Reference
Internet of Things (IoT)	It refers to integrating networked devices into manufacturing processes, as in the apparel industry.	Lüthje (2021); De Felice & Petrillo (2021); Ortega-Gras et al., (2021); Teixeira et al., (2022)
Artificial intelligence (AI)	It means using algorithms for computer vision, natural language processing, and machine learning to improve supply chain management, customer engagement, and product design, among other things.	Noor et al., (2022); Yu et al., (2021); Casciani et al., (2022); Ortega-Gras et al., (2021)
Robotics	It refers to designing, making, and using robots for industrial tasks like cutting, sewing, and putting things together. It enhances the efficiency of the fashion supply chain by introducing automation.	Bertola & Teunissen (2018); Rosário & Dias (2022)
3D printing	3D printing, also known as additive manufacturing, is a process whereby a digital model is used to create a physical object by adding layers of material.	Bertola & Teunissen (2018); Casciani et al., (2022)
Factors	Explanation	Reference
Blockchain	The blockchain is a transparent and trustworthy digital ledger that can record transactions. It helps monitor textiles throughout their entire lifecycle, from manufacturing to the final disposal.	Ikram (2022); Ortega-Gras et al., (2021)
Augmented reality (AR)	It describes a category of technologies integrating digital data and experiences into the physical world.	Ikram (2022); Sayem (2022); Casciani et al. (2022)
Social media	It is concerned with promoting fashion products and engaging with consumers.	Bailey et al., (2022); Ikram (2022); Zamfir et al., (2022)
Online shopping	It involves using the internet to buy and sell garments and related items.	Ikram (2022); Sayem (2022)

Source: Authors' analysis

The fashion industry is one of the largest polluters in the world, with significant impacts on water, energy, and land resources (Cai & Choi, 2020). In response, there has been an increasing focus on reducing the industry's environmental impact and promoting sustainable fashion. The industry is undergoing a green and digital transition to reduce its environmental impact and promote sustainability (Smouh et al., 2022; To et al., 2019). This transition involves integrating green initiatives and digital technologies into the production and consumption of fashion products.

The systematic literature review results reveal 46 articles, the most important of which identify the essential components of the green and digital transition in the fashion industry shown in Table 3 and suggest avenues for future research. The review of all 46 articles revealed eight green transitional factors, such as sustainable materials, green manufacturing, the circular economy, green product and process innovation, green energy, green building, a green supply chain, and waste

management, as well as eight digital transitional factors, such as the internet of things, robotics, and 3D printing in the fashion industry.

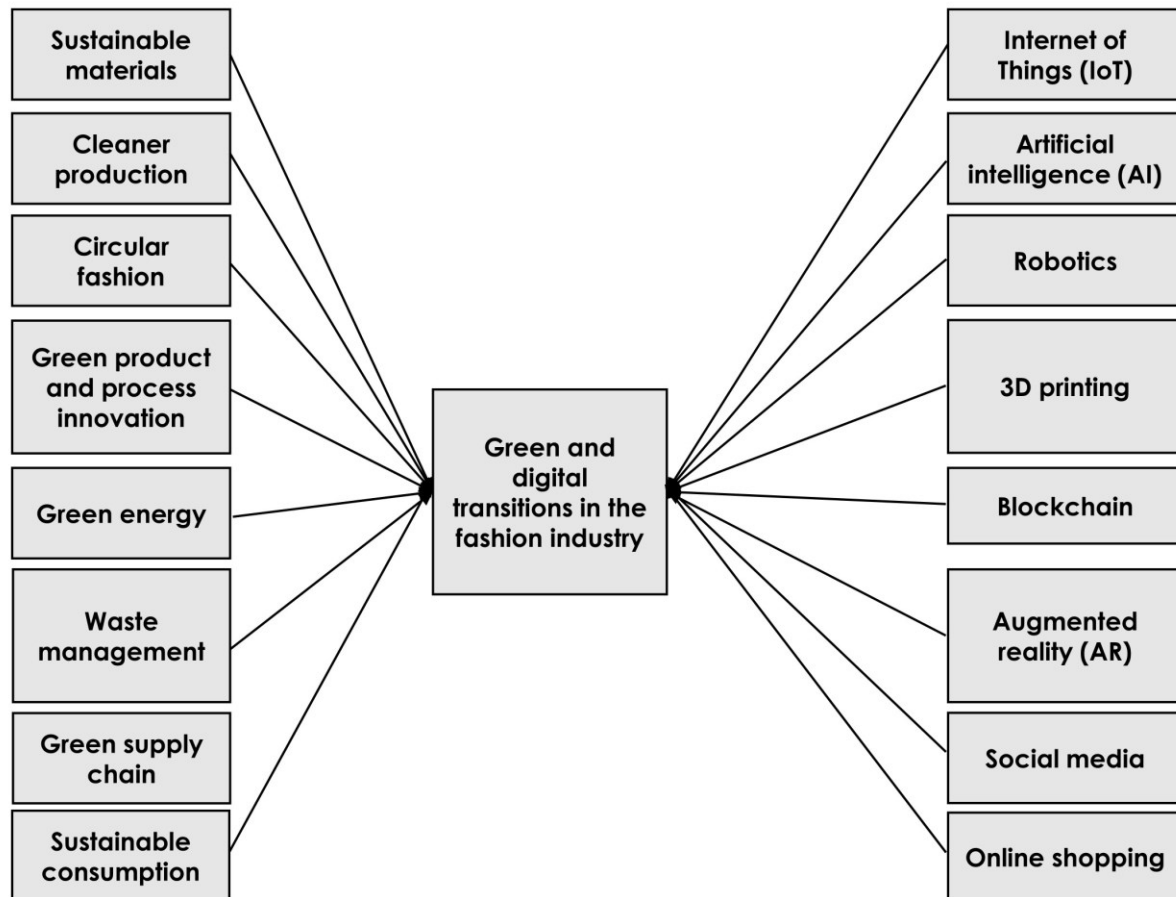
Discussion

The literature review addresses two specific research questions. This section discusses the two research questions presented in the introduction. The findings of this review revealed eight greening factors and eight digital technological applications essential to promoting sustainability in the textile supply chain. It is observed from the literature that the convergence of sustainability and technology has led to a symbiotic relationship between the green and digital transitions in the fashion industry. The fashion industry's future depends on adapting to the shift toward greening and digitisation. The use of technology to drive sustainability is central to both the green and digital transitions, whether it is blockchain to increase supply chain transparency or virtual reality to cut down on waste and enhance product design.

In the literature, every paper combines different parts of green and digital shifts in the fashion industry. Some parts are about making the textile supply chain greener, and others are about digital technologies. Sustainability in the fashion industry includes all phases of the garment life cycle, from raw material extraction to final disposal. Responsible consumption and post-consumer behaviour are also crucial to the fashion industry's supply chain transition to sustainable consumption. However, in light of the research questions, the results of this review can be discussed within a comprehensive factor framework of the green and digital transition, as shown in Figure 7.

85% of the raw materials used to make clothes are cotton and polyester, which are unsuitable for the environment. The fashion industry's greening relies heavily on eco-friendly materials (Sarkar et al., 2020). Sustainable raw materials suit the environment, society, and economy. They focus on protecting people and the planet from extraction to final disposal. Eco-friendly materials allow the fashion industry to reduce waste and produce longer-lasting goods. Some manufacturers may find it more challenging to switch to using sustainable materials due to their scarcity and the higher costs associated with their production (Ikram, 2022; Kannan et al., 2022; Rosário & Dias, 2022).

Figure 8
Green and Digital Fashion Transitions Factors Framework



Source: Authors' analysis

Reducing pollution, boosting energy efficiency, repurposing waste products, and improving waste management are the four cornerstones of sustainable production (Andaregie & Astatkie, 2022). Sustainable production incorporates renewable energy sources like solar and wind power to reduce environmental impact and increase productivity (De Felice & Petrillo, 2021; Madureira et al., 2022). Therefore, environmentally friendly manufacturing processes are necessary for the green fashion industry. A sustainable production process can help reduce the fashion industry's carbon footprint and improve the industry's sustainability (Šajin, 2019). Cleaner production implementation necessitates top-down support and executive guidance. Moreover, alterations to manufacturing procedures can halt ongoing production, wasting time and resources.

The implementation of a circular economy is crucial for the development of green textiles (Sandvik & Stubbs, 2019). The R approach reduces waste and saves resources by establishing a closed-loop system in which products are recycled, reused, or repurposed at the end of their useful lives (Mishra et al., 2020; Sahu et al., 2022). The fashion industry can benefit from this because it can aid in reducing waste and enhancing sustainability (Rosa et al., 2020). However, transitioning from a linear to a circular economy can be difficult because of insufficient supporting infrastructure, standardised procedures, and regulations.

Green product and process design entails making sustainable clothing and accessories for the environment, society, and the bottom line (Andaregie & Astatkie,

2022; Rosário & Dias, 2022). Green product and process initiatives are reshaping the pattern of the textile industry. By focusing on eco-friendly materials, reducing waste, and creating durable, recyclable, and adaptable products, this approach aims to reduce the fashion industry's negative impact on the environment and society (Ikram, 2022).

Green energy is an excellent option for the entire fashion industry, from raw material production to final product distribution. Factories that switch to renewable energy sources can reduce their reliance on fossil fuels, their monthly energy costs, and their adverse environmental effects, among other benefits. In addition, the fashion business can use renewable energy to power the trucks and ships that move their products from one place to another. This can drastically cut carbon emissions, a significant factor in global warming (Feng et al., 2022; Li et al., 2019; Sarkar et al., 2020).

Waste management ensures that all kinds of solid and liquid trash are collected, sorted, and thrown away correctly. The increasing amount of waste produced and its detrimental environmental impacts have become a significant concern for worldwide authorities. The textile and clothing industries' waste management and sustainability challenges have received a significant boost in the age of climate catastrophe (Šajn, 2019; Yu et al., 2021). An effluent treatment plant (ETP) is a system for managing waste that cleans water used in manufacturing and other industrial processes. The purpose of ETP is to clean wastewater of harmful pollutants so that it can be safely released into the environment or reused. ETPs usually use a mix of physical, chemical, and biological processes, such as sedimentation, aeration, and filtration, to clean up wastewater (Shamsi et al., 2022; To et al., 2019).

The green fashion industry demands a green supply chain (Coscieme et al., 2022; Desore & Narula, 2018; Li et al., 2019). Each step in the green supply chain, from production to distribution, contributes to the final product's value to the consumer. Partners in green supply chains cooperate to lessen the environmental impact of industrial processes by recycling more and disposing of less hazardous waste (Andaregie & Astatkie, 2022; Cai & Choi, 2020). Supply chains in the fashion industry are notoriously difficult for businesses to penetrate, making it tough to verify the legitimacy of their raw materials and implement ethical, environmentally friendly manufacturing processes.

Sustainable consumption can be seen in the fashion industry through eco-friendly laundry practices. Consumers can make their clothes less harmful to the environment by washing them less often, washing them in cold water with eco-friendly detergents, and letting them dry in the air instead of using a dryer, which saves energy and extends the life of clothing. Therefore, consumers' habits must shift before sustainable and digital technologies can be widely adopted, and this transition can be slow and unpredictable (Khurana, 2022; Mishra et al., 2020). Sustainable products are often disregarded because consumers are unaware of the fashion industry's adverse effects on the environment and society. Because of this, sustainable production practices may be costly for businesses. In a society where fast fashion and frequent trend shifts are the norms, it can be challenging to persuade consumers to change their consumption habits to be more sustainable and circular (Bailey et al., 2022).

IoT devices can monitor and control various aspects of the manufacturing process, such as energy consumption, resource utilisation, and product quality, to achieve industrial efficiency (De Felice & Petrillo, 2021). Besides, IoT enables fashion companies to collect and analyse real-time data from connected devices, such as smart clothing and accessories (Teixeira et al., 2022). This data can be used to improve sustainability by reducing waste and increasing efficiency. IoT can also help companies improve

customer experiences by providing real-time product information like location and usage (Šimberová et al., 2022).

AI plays a crucial role in the digital transition of the fashion industry by enabling companies to make data-driven decisions, optimise operations, and improve customer experiences (Noor et al., 2022). For example, AI algorithms can analyse consumer data, such as purchase history and social media activity, to help companies better understand their customers' preferences and make more informed decisions about product design and marketing (Yu et al., 2021).

Incorporating robotics into the fashion industry's digitisation process is crucial (Bertola & Teunissen, 2018). It allows businesses to eliminate mundane and potentially dangerous tasks, freeing human resources to focus on those requiring exceptional skill and creativity (Rosário & Dias, 2022). By automating the movement of goods, lowering the need for human intervention, and minimising the possibility of injury, robotics enhances the effectiveness of supply chains (Ortega-Gras et al., 2021).

The fashion industry can save time and money creating physical samples because rapid prototyping with 3D printing technology has made that practice obsolete (Bertola & Teunissen, 2018; Casciani et al., 2022; Papahristou & Bilalis, 2017). 3D printing also allows for the creation of unique and customisable products, giving fashion companies a competitive edge in the market.

Blockchain technology can transform the fashion industry by creating greater transparency, accountability, and sustainability in the supply chain. The entire textile production and disposal process can be tracked in an open and trustworthy manner with the help of blockchain technology (Ikram, 2022; Ortega-Gras et al., 2021). The use of blockchain technology in the apparel industry has the potential to boost its reliability, productivity, and social and environmental impact. The potential for illegal dumping and environmental pollution caused by textile waste can be mitigated if this is done. However, security and privacy are two areas where blockchain can be problematic (Sayem, 2022).

The fashion industry stands to benefit significantly from the revolutionary potential of virtual reality (VR) and augmented reality (AR) (Ikram, 2022). VR transports the user to a simulated setting, while AR enhances the real world with digital data. Both virtual and augmented reality present the fashion industry with promising new ways to improve the shopping experience for its customers and find solutions to some of its most pressing problems (Sayem, 2022).

Digital disruptive technology, such as online shopping, has dramatically altered the apparel business (Bertola & Teunissen, 2018). It has made it easier and more accessible for people to buy clothing, footwear, and accessories while also expanding the market for fashion companies. For instance, Zara's e-commerce platform includes free shipping and returns, personalised products, and online exclusives (Sayem, 2022).

Social media platforms have revolutionised the fashion industry by introducing new channels for consumer interaction, brand promotion, and online sales (Bailey et al., 2022; Zamfir et al., 2022). They have become crucial tools for the fashion industry to remain competitive in the digital age.

However, there are also significant difficulties that the green and digital transition presents for the fashion industry, such as juggling the demands of fast fashion and sustainability or managing data privacy and security in an increasingly digital ecosystem. To successfully navigate these obstacles, fashion companies must cultivate new skills, capabilities, and partnerships that allow them to innovate and adapt to shifting market dynamics. The fashion industry's transition to a greener and more digital future is a massive undertaking with numerous moving parts that must be

carefully planned and executed. By leveraging sustainable practices and digital technologies, fashion companies can increase their competitiveness, enhance their brand image, and drive innovation and expansion in a market that is becoming increasingly complex and dynamic. In short, Table 3 addresses the research questions posed by this systematic literature review.

Conclusion

The study's primary objective was to determine what elements are most important in the green and digital transition in the fashion industry. This systematic review has synthesised diverse literature on the essential elements of green and digital transitions in the fashion industry. Reviewing previous studies has identified green practices, such as eco-friendly materials, green manufacturing, a green supply chain, a circular economy model, and reducing waste, that can help reduce the fashion industry's negative environmental and social impact and increase the profitability and competitiveness of fashion companies. In addition, the study uncovered the presence of digital technologies like AI, the IoT, and robotics in the fashion supply chain to optimise production efficiency, decrease costs, and raise product quality. Therefore, green and digital transitions in the fashion supply chain can promote sustainability by enhancing image and income capacity and lowering costs and pollution. The study results are helpful for managers and academicians in advancing their understanding of green and digital textiles. As part of the overall green and digital transformation, the fashion manufacturing industry must adopt sustainable practices and digital technologies across the entire value chain. Implementing these systems boosts productivity, reduces waste, and reduces environmental pollution. However, they must also overcome the challenges posed by high investment costs, the need for a skilled workforce, and the requirement for significant organisational changes. The first limitation of this study is the selection of keywords used in the literature search. While the search terms employed in the study cover a significant portion of the study field, they can be broader. By incorporating additional keywords such as "apparel industry" and "transformation" into the search terms, future research could enhance the search's comprehensiveness. This study considered only articles and review papers; therefore, books and conference papers still need to be included.

The review identifies eight significant research gaps with theoretical and practical implications. Since the fashion industry has such harmful environmental effects, researchers can concentrate on green and digital transitions. Digital technology and eco-friendly clothing are other areas where they can pursue the investigation. Professionals can use these gaps to plan future research and dive deeper into green and digital technology adoption. First, green and digital transitions are indispensable to addressing the industry's environmental, social, and economic challenges. The convergence of green and digital technologies can boost a business's environmental friendliness, economic viability, social conscience, innovative capacity, and public image. Still, studies have yet to be found in the leather and pharmaceutical sectors. These industries also deal with intricate supply chains and sustainability. Therefore, future research could be considered in the context of green and digital transformations in these industries. Second, empirical research combining expert opinion and survey data on green practices and digital innovation at the enterprise level may be used in future studies, which needs to be included in the current study. Third, since most textiles are produced in developing or least-developed countries, they appear to be more susceptible to the adverse effects of the fashion industry. The environmental benefits of the "twin" transition need to be properly quantified and qualified; therefore, additional study is needed in these areas. Fourth, digital and

green transitions are crucial for attaining net zero emissions, but implementing these transitions is challenging. Thus, future studies could consider critical failure factors of green and digital growth in the fashion industry. Fifth, the present study has yet to provide a green and digital technology assessment framework; future studies could propose such a model to assist in measuring the integration of green and digital technologies in the fashion industry. Sixth, studies can be conducted that compare the green economy in the fashion industry in developed and emerging markets at different stages of development. Seventh, the effects of the fashion industry's green and digital shifts on society are underexplored, but they significantly impact the fashion business and society. Finally, studies concerning the effectiveness of specific digital technologies in improving sustainability and efficiency in the fashion industry, such as blockchain for supply chain management, 3D printing for production, and virtual reality for retail, still need to be included.

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The Digital Transformation of European Union Countries before and during COVID-19

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Abstract

Background: The transformation of business and the economy is a key business problem, and its importance was further heightened during the COVID-19 pandemic, with the increased pressure on enterprises. Hence, the digital readiness of their business will likely determine its future competitiveness in the field. **Objectives:** The paper addresses the issue of digital readiness for business, with the aim of examining similarities and differences in the digital readiness of European Union countries. The main focus is on identifying the changes during the first two years of the pandemic. **Methods/Approach:** We conducted a factor analysis and hierarchical cluster analysis based on selected indicators. The results revealed some significant differences. **Results:** While the countries that lead in digital readiness remained the same, there were relatively large differences in the classification of other EU countries. Some countries, such as Latvia or Slovenia, significantly improved in many aspects of digital readiness during the pandemic. On the other hand, Bulgaria and Romania are still included in the same cluster, representing an overall low digital readiness. **Conclusion:** Enterprises in more developed countries also have a higher level of digital readiness. Although COVID-19 had a positive impact on digital readiness in some less developed countries, the impact is only partial, indicating a need for stronger actions to bridge the digital divide at the EU level. These findings provide a hopeful outlook, suggesting that with the right actions, the digital divide in the EU can be effectively bridged.

Keywords: digital transformation; business digital readiness; digital economy; COVID-19 pandemic.

JEL classification: O33, L21, H12

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Introduction

Digitisation and digitalisation in businesses have been one of the key trends in recent years, with organisations around the world trying to adapt to the new demands of the digital era. Digital transformation includes both digitisation and digitalisation (Verhoef et al., 2021). It represents the use of digital technology that radically improves the performance or reach of enterprises (Westerman et al., 2011). Hence, it is one of the key issues that companies' management should address. The importance of this digital transformation has even further increased during the COVID-19 pandemic, which can be seen as a business emergency that has created the need for organisations to be resilient and versatile (Khalil et al., 2022). Due to the adoption of digital technologies, SMEs can increase their agility and change their business models in weeks, if not days (Tsou & Chen, 2023). The utilisation of digital technologies can increase productivity and profitability, and digitally advanced firms have better chances of surviving any recession (Döhring et al., 2021). However, tolls related to digital transformation, such as big data, e-orders, supplier-customer man-agreement, and e-commerce, were significantly underdeveloped in SMEs in the recent past (OECD, 2021). In our case, the term digital readiness is used as an indicator of the potential success of digital transformation.

The pandemic has affected businesses around the world, forcing them to quickly adapt and implement digital transformation to continue their business and be successful (Qureshi et al., 2020). During the first two years of the pandemic, there was a significant surge in the utilisation of online meetings and organisations across the EU. Employees had to acclimate to a variety of digital platforms for communication and virtual meetings (Khawaja et al., 2023).

Changing customer behaviour, new regulations, and social distancing rules meant unprecedented changes in business for all types of firms in every country. However, differences in levels of digitalisation, as well as different business environments in EU countries, could have a significant impact on the intensity of such a transformation (Khawaja et al., 2023). By comparing the situation before and during the pandemic, our research identifies and explores significant differences in the digital readiness of businesses and its trends in EU countries. Our main aim is to examine differences in the digital transformation of business among EU countries and assess the changes during the COVID-19 pandemic. To fulfil this aim, factor analysis and hierarchical cluster analysis are used on a range of indicators, capturing the dynamic changes in digital readiness during the pandemic. Based on the empirical evidence, clusters of EU countries have been identified, and their characteristics have been compared before and during the pandemic. With an in-depth analysis of selected indicators and their trends, the paper contributes to a deeper understanding of the impact of the pandemic on the digital transformation of business.

In the next section, an overview of the literature related to digital transformation is presented. The focus is on the potential impact of the pandemic. Further sections are devoted to the description of the methodology and data, followed by an explanation of key results and discussion. The final section summarises the findings and conclusions.

Literature review

This section systematises and compares the results of the studies devoted to digital transformation in EU countries. It first focuses on the issue of digital business transformation and potential options for its assessment. Then, the literature review moves on to the effect of the COVID-19 pandemic on businesses' digital readiness.

Digital transformation in the EU countries

Several recent studies have examined the issue of the digital transformation of business in the EU, including those by Wang (2023), Kääriäinen et al. (2021), Borowiecki et al. (2021), Kinnunen et al. (2019), and Bouwman et al. (2019). Most of them analysed digitalisation and digital capital accumulation or examined problems related to digitalisation processes in companies. Our paper builds on the previous research but pays significantly more attention to various indicators of digital readiness in firms. It also classifies EU countries according to digital readiness before and after the pandemic. In some ways, Kozhevina et al. (2017) had previously employed a similar approach. They created the total digital economy index using various metrics that are appropriate, especially for the Russian economy. Our research applies different indicators and factors with a focus on EU countries. The European Commission is annually monitoring digital improvements in EU countries via Digital Economy and Society Index (DESI) reports. The key areas of concern are human capital, connectivity, integration of digital technology, digital public services, and research and development in ICT. Based on the overall results, Denmark, Finland and Sweden are ranked as the three top-performing countries. On the other hand, countries such as Romania, Bulgaria and Greece are usually placed at the end of the ranking. Tomičić Furjan et al. (2020) argue that digital transformation is a very complex problem with many challenges. Our analysis is focused on some specific aspects of digital readiness and digital transformation. With this narrower approach, it is possible to analyse and assess the digital readiness of companies in the EU. A similar strategy has been used, for example, by Hunady et al. (2022), to evaluate the digital readiness in EU countries.

The global trend of digitalisation puts significant pressure on business in the EU. Companies in the EU need to catch up to main global players like China and the US in sales related to information and communication technologies (Schweer et al., 2017). Furthermore, the current state of digital readiness needs to be more distributed among EU countries (Kinnunen et al., 2019). Firms with businesses located in newer member states especially are struggling significantly with digital transformation processes. These processes require some fundamental changes in business models (Bouwman et al. 2019). Companies should redevelop their current strategies and introduce new processes built mostly on emerging digital technologies (Kääriäinen, 2021). This transformation can be affected by many external circumstances, while the pandemic can be considered as one of the most prominent issues. Hence, this problem needs to be examined in more detail.

Over the previous two decades, digitalisation has received some significant attention in economic and business research. However, most of it was consecrated to e-commerce (Zaied, 2012). Due to its convenience for both buyers and sellers, e-commerce fulfils its potential to accelerate the expansion of businesses around the world (Kasemsap, 2018). Despite the indisputable importance of e-commerce, the current digital economy includes a much wider scope of problems. Many emerging digital technologies are becoming essential for increasing business productivity. This includes, for example, the usage of data mining (Topalović & Azzini, 2020) and cloud computing services (Dincă et al., 2019). Moreover, social networks have also become important channels for communication, marketing, and selling. The application of social networks for B2B and B2C communication and e-commerce has been examined, for example, by Ballestar et al. (2019) and Davidaviciene et al. (2017). Big data, cloud, mobile, and social network technologies, especially, have become crucial parts of business infrastructure while improving the financial valuation of the firm (Schwertner, 2017). Big Data contains large datasets retrieved from diverse data

sources and types. The comprehensive usage of such data is enabled only by emerging technology and innovative data management tools. Enterprises using such tools can significantly benefit in several ways, such as process innovation, matching customer skills as well as improved risk and quality management (Urbinati, 2019). Big data analysis is also partly related to cloud computing. This digital solution allows timely, on-demand access to a common pool of important business data and information. Its adoption in the firm can improve internal processes and reduce the overall cost (Schwertner, 2017). The application of the mentioned technologies in firms was used as one of the dimensions of the evaluation of digital readiness. A digital readiness index capturing the usage of selected digital technologies has been previously used to compare the digital readiness of smart ports (Philipp, 2020). Furthermore, Zalite and Zvirbule (2020) also used a similar methodology to examine the digital readiness of higher education institutions in EU countries. The digital readiness of SMEs has also been previously examined in Italy (Pirola, 2019).

The potential effect of a pandemic on digital transformation

The COVID-19 pandemic has precipitated profound transformations in the global economy, acting as a disruptive catalyst for the accelerated adoption of emerging technologies, notably digitalisation. Despite variations in workplace dynamics across professions, industries, and geographical locations, the challenges stemming from the pandemic have demonstrated a remarkable commonality (Sola et al., 2021).

The pandemic may permanently increase the demand for already-existing digital services and pave the way for the development of brand-new ones (Döhring et al., 2021). However, the digital transformation represented a big challenge for the business sector as well as for the government. All organisations, regardless of their size or activities, are significantly affected by the consequences arising from both digital transformation and the COVID-19 pandemic (Burlea-Schiopoiu, 2023). New measures and social distancing policies created a favourable environment for a fundamental transformation to a new digital society (Ganichev & Koshovets, 2021). During the pandemic, digital infrastructure witnessed a “positive demand shock” represented by the shift towards online business and digital society (Banga & Te Velde, 2020).

One of the main pandemic-related phenomena is working from home (Adžić & Al-Mansour, 2021). This previously less common type of work has become dominant in some jobs. Most firms introduced new work-from-home policies and enabled the remote work of their employees through extensive purchases of extra computers, tablets, and cell phones (Kraus et al., 2020). At the same time, this represents one small but important step closer to the digital transformation of companies that did not have such possibilities until then.

Khalil et al. (2022), based on 96 surveyed SMEs, showed that digital technology usage has helped SMEs survive the pandemic. The authors found that digital technologies help businesses in developing countries become more resilient in general. They argue that supporting digital technologies is the main policy solution to the economic problems induced by the pandemic. Insufficient levels of digital readiness led to notably lower productivity among employees during the pandemic (Mustajab et al., 2020).

Additional investment in remote work capabilities and digital technologies enabled firms to maintain at least or even improve productivity. Advanced digital technologies such as those played a key role in recovery from economic problems caused by the pandemic and enabled remote education, employment, and services by reducing exposure to the virus (Al-Sartawi et al., 2021). Burlea-Schiopoiu (2023) found that the crisis caused by the COVID-19 pandemic led to many improvements in digital

capabilities and the development of new digital products. Overall, it notably advanced the digital transformation process. They also argue that pandemics positively influence organisations' implementation of digital transformation strategies.

Our research provides some new empirical evidence on the digital transformation of business in the EU during the pandemic. Moreover, it also shows unique findings on dynamics in the usage of digital technologies and changes in the classification of EU countries into groups based on their level of business digital readiness.

Methodology

Research questions and hypothesis

The paper examines the following research questions (RQ):

- RQ1: What indicators of business digital readiness have been changed the most during the pandemic?
- RQ2: How did the distribution of countries in individual clusters of digital readiness change during the pandemic?
- RQ3: How did the characteristics of each cluster change with respect to digital readiness during the COVID-19 pandemic?
- RQ4: To what extent has the pandemic affected the share of companies implementing measures to enable work from home through digital communication technologies?

Research questions are further followed by research hypotheses, which enable a more detailed examination of these problems. The research hypotheses (H) are stated as follows:

- H1: The digital readiness of companies increased during the EU pandemic.
- H2: The countries that achieved the best digital readiness before the pandemic are still included in the best-performing cluster during the pandemic.
- H3: The characteristics of clusters after the pandemic changed significantly compared to before the COVID-19 outbreak.
- H4: During the pandemic, the share of companies that implemented measures to enable remote work from home through digital communication technologies increased.

Data

The analysis of the examined problem is based on secondary data retrieved from the Eurostat database (Digital Society: E-Business). Data are collected using the annual questionnaire survey, "EU survey on ICT usage and e-commerce in enterprises." Some questions in the questionnaire change every year. Only those indicators that are available for the years 2019 and 2021 have been used in our analysis. Selected indicators refer to digital readiness and the process of digital transformation in firms. The availability of data for both years was also an important criterion when selecting a set of indicators. Indicators are represented by 11 variables, which are described in Table 1.

Table 1

Description of variables used in the cluster analysis (years 2019 and 2021)

Variable	Description (2019 and 2021)
Providing portable devices to employees	Enterprises providing portable devices for mobile connection to the internet for their employees (% of enterprises with 10 or more employees in the economy without financial sector)
Online ordering on the website	Enterprises where the website provides online ordering or reservation or booking, e.g. shopping cart (% of enterprises with 10 or more employees in the economy without fin. sector)
ICT/IT training	Enterprises which are provided training to ICT/IT specialists to develop their ICT skills (% of enterprises with 10 or more employees in the economy without financial sector)
Using ERP software	Enterprises who have ERP software packages to share information between different functional areas (% of enterprises with 10 or more employees in the economy without financial sector)
Using software solutions for CRM	Enterprises using software solutions for Customer Relationship Management (CRM)
Using multimedia content-sharing websites	Enterprises using multimedia content-sharing websites, e.g. YouTube, Flickr, Picasa, SlideShare, etc. (% of enterprises with 10 or more employees in the economy without financial sector)
Using social networks	Enterprises using any social network (% of enterprises with 10 or more employees in the economy without financial sector)
Buying cloud computing services	Enterprises buying cloud computing services used over the internet (% of enterprises with 10 or more employees in the economy without financial sector)
Big data analytics	Enterprises using big data from smart devices or sensors Enterprises analysing big data from smart devices and sensors (% of enterprises with 10 or more employees in the economy without financial sector)
Using industrial robots	Enterprises using industrial robots (% of enterprises with 10 or more employees in the economy without financial sector)
Using service robots	Enterprises using service robots (% of enterprises with 10 or more employees in the economy without financial sector)

Source: Authors based on Eurostat database (EU survey on ICT usage and E-commerce in enterprises).

The set of selected indicators has been classified into three types of measures: essential steps (providing portable devices to employees, online ordering or reservations, and providing ICT training to specialists), slightly advanced digital tools (using ERP software, CRM software, multimedia sharing platforms, and social networks), and advanced tools (cloud computing services, big data analysis, and using industrial or service robots). Basic descriptive statistics for all variables are shown in Table 2.

As can be seen, the mean values for most of the variables are higher in 2021 compared to 2019. Most of the firms included in the survey reported that they are providing portable devices to employees, and more than half of them are also active on social networks. On the contrary, the use of big data analysis and robotics is still rather rare. Interestingly, there was a decrease in the usage of big data analytics from smart devices during the pandemic.

Table 2

Basic descriptive statistics of variables used in the analysis

	Mean (year 2019)	Std. Dev. (year 2019)	Mean (year 2021)	Std. Dev. (year 2021)	Min. (year 2021)	Max. (year 2021)
Providing portable devices (%)	86.1%	8.21	87.78%	6.31	74.00%	99.00%
Online ordering (%)	20.7%	7.52	22.19%	7.01	13.00%	37.00%
ICT/IT training (%)	10.81%	3.7	10.63%	3.56	4.00%	18.00%
Using ERP software (%)	35.74%	9.55	36.81%	10.42	17.00%	57.00%
Using software for CRM (%)	29.89%	10.56	31.41%	11.63	15.00%	54.00%
Multimedia content sharing(%)	22.2%	9.21	28.04%	10.45	11.00%	50.00%
Using social networks (%)	55.33%	14.22	61.15%	13.19	36.00%	84.00%
Cloud computing services(%)	28.52%	14.88	42.81%	17.16	13.00%	75.00%
Big data analytics (%)	4.41%	2.23	3.89%	2.42	1.00%	10.00%
Using industrial robots (%)	4.5%	2.2	5.07%	2.09	1.00%	9.00%
Using service robots (%)	1.93%	0.99	2.15%	0.99	1.00%	5.00%

Source: Authors based on data from the Eurostat database.

Statistical analysis

The variables mentioned capture the share of enterprises using the mentioned tools and are used as inputs into multidimensional statistical analysis. The analysis includes cluster analysis (CA) and principal component analysis (PCA). CA was used to classify countries into clusters with similar overall business digital readiness. Agglomerative hierarchical clustering was used in combination with the Ward linkage method and Euclidean distance calculation. Hierarchical cluster analysis is the method that seeks to construct a hierarchically arranged sequence of partitions for some given object set. The hierarchical clustering task is defined as finding a least-squares approximation to the proximity measure by an ultra-metric structure (Köhn, Hubert, 2009). Ward's method calculates the incremental sum of squares between objects. The pair of clusters is chosen to (locally) minimise the k-means cost of the clustering in the next step (Großwendt et al., 2019). Calinski and Harabasz indexes have been used to choose the optimal number of clusters. The differences in the classification of EU countries in individual clusters in both years have been examined. Moreover, PCA was applied to reduce the dimensions of the examined digital readiness to two principal components. This allows us to show and explain the characteristics of individual clusters while preserving most of their variability. PCA is a multivariate technique that extracts important information from the statistical data to represent it as a set of new orthogonal variables called principal components (Mishra et al., 2017). Clusters' characteristics have been compared mostly by displaying boxplots of both principal components. The main results of our analysis are shown and discussed in the next section of the paper.

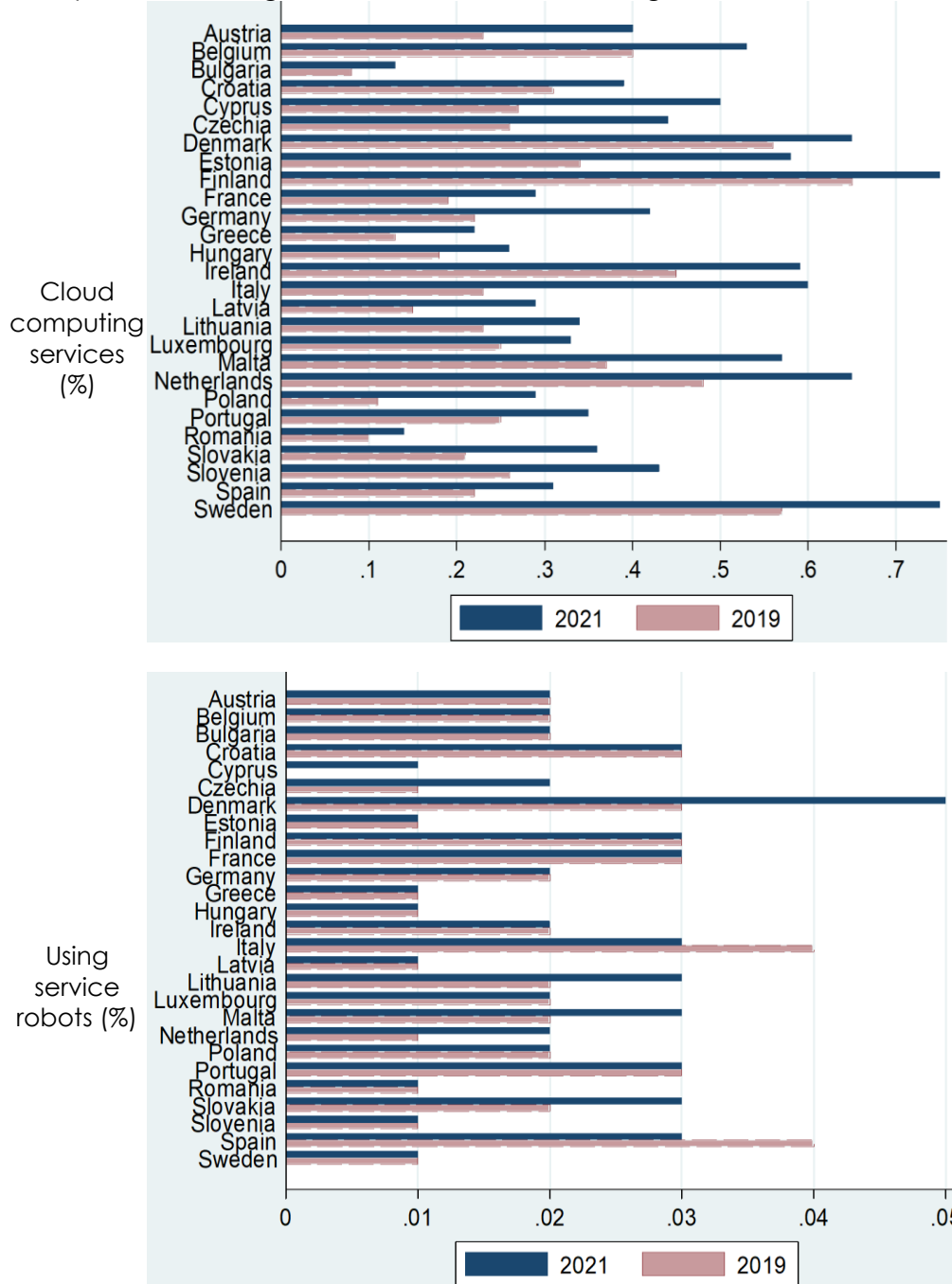
Results

The analysis is focused on investigating the differences in the usage of selected digital tools in EU countries and comparing the situation before and during the pandemic. Firstly, the share of firms using selected advanced technologies has been examined. It can be assumed that their usage is directly affected by the pandemic, i.e., cloud computing services and service robots. Cloud computing services could be used more intensively during the pandemic due to remote work and the necessity of accessing data online. Even though service robots are still relatively new technology, they can be used more frequently due to pandemic social distancing regulations and

potential customers' reluctance to use human-operated services. The results are shown in Figure 1.

Figure 1

Comparison of usage of two selected technologies in firms in EU countries



Source: Authors based on data from the Eurostat database.

There are rather significant differences between EU countries in their usage of cloud computing and service robots. On one hand, there was a significant increase in the usage of cloud computing in all EU countries during the pandemic. On the other hand, there has been no such significant increase in the number of service robots.

Next, the differences in using the other five digital technologies between 2019 and 2021 have been compared. The differences are shown in percentage points in Table

3. The first two tools represent rather basic elements of digital readiness. As expected, the share of portable devices available to employees and online ordering has grown in most countries. The most significant increase in usage of portable devices has been recorded in Latvia, Bulgaria, and Romania. This is mostly due to the rather low levels of these countries before the pandemic. The share of firms with available online ordering grew the most in Romania and Greece. In the case of ERP and CRM software solutions, the results are rather mixed. There was an increase in usage in some countries, but there was also a drop in many countries. This is probably because the use of ERP and CRM solutions is less closely related to pandemic measures. Surprisingly, there has been no significant increase in big data analytics based on data from smart devices in most countries. There has even been a significant drop in usage in Lithuania and Slovenia. Perhaps the business was focused on other issues, and this type of data was less crucial for their business during the pandemic.

Table 3

Changes in the selected indicators between 2019 and 2021 in EU countries

	Providing portable devices to employees (% of firms)	Online ordering on the website (% of firms)	Using software in the company (% of firms)	ERP solutions CRM (% of firms)	Using software for analytics (% of firms)
Belgium			4p.p.	8p.p.	0p.p.
Bulgaria	10p.p.	0p.p.	-1p.p.	0p.p.	0p.p.
Czechia	2p.p.	2p.p.	0p.p.	-3p.p.	-2p.p.
Denmark			0p.p.	7p.p.	2p.p.
Germany	2p.p.		9p.p.	1p.p.	0p.p.
Estonia			-3p.p.	1p.p.	1p.p.
Ireland	0p.p.	-1p.p.	-4p.p.	0p.p.	-2p.p.
Greece	0p.p.	6p.p.	-3p.p.	0p.p.	
Spain	3p.p.	1p.p.	6p.p.	7p.p.	-2p.p.
France	1p.p.	1p.p.	-3p.p.	4p.p.	0p.p.
Croatia	2p.p.	2p.p.	-2p.p.	1p.p.	1p.p.
Italy	2p.p.	4p.p.	-3p.p.	-1p.p.	-1p.p.
Cyprus	3p.p.	3p.p.	1p.p.	6p.p.	0p.p.
Latvia	11p.p.	5p.p.	7p.p.	2p.p.	0p.p.
Lithuania		-3p.p.	-3p.p.	-4p.p.	-3p.p.
Luxembourg	2p.p.	1p.p.	-1p.p.	-2p.p.	-2p.p.
Hungary	4p.p.	0p.p.	7p.p.	3p.p.	1p.p.
Malta	0p.p.	3p.p.	7p.p.	7p.p.	2p.p.
Netherlands	0p.p.	3p.p.	-4p.p.	-4p.p.	-2p.p.
Austria		1p.p.	2p.p.	5p.p.	1p.p.
Poland	1p.p.	0p.p.	3p.p.	1p.p.	0p.p.
Portugal	0p.p.	4p.p.	10p.p.	-3p.p.	-2p.p.
Romania	8p.p.	6p.p.	-6p.p.	-3p.p.	-2p.p.
Slovenia	4p.p.	4p.p.	3p.p.	2p.p.	-4p.p.
Slovakia	3p.p.	1p.p.	0p.p.	0p.p.	-1p.p.
Finland	0p.p.		5p.p.	4p.p.	1p.p.
Sweden		4p.p.	-2p.p.	2p.p.	0p.p.

Note: p.p. – percentage points

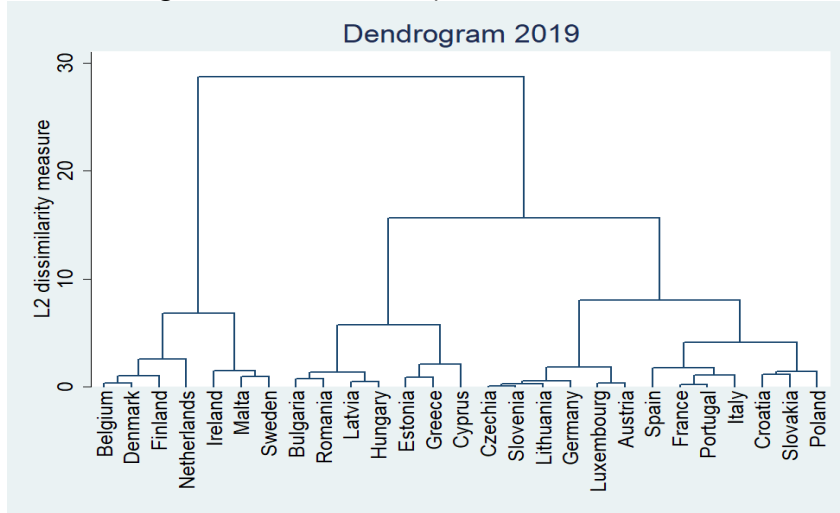
Source: Authors based on data from the Eurostat database.

Cluster analysis was used to group all EU countries into clusters. It is based on the mentioned set of 11 indicators. More specifically, hierarchical clustering with Ward's linkage method was applied. Dendrograms graphically represent the key results. Two

separate cluster analyses were applied to the data from 2019 (Figure 2) and 2021 (Figure 3).

Figure 2

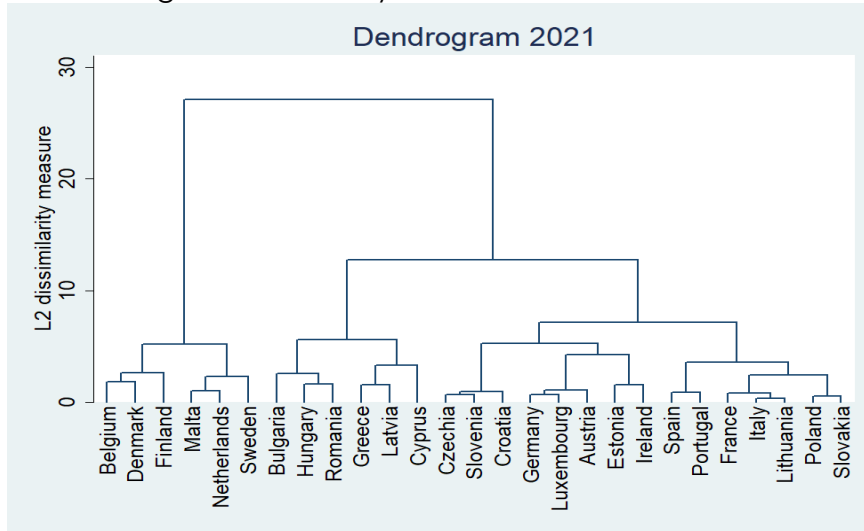
Dendrogram showing the results of the cluster analysis of EU countries based on business digital readiness, the year 2019



Source: Authors based on data from the Eurostat database.

Figure 3

Dendrogram showing the results of the cluster analysis of EU countries based on business digital readiness, year 2021



Source: Authors based on data from the Eurostat database.

Both dendrograms show good separation and relatively even inclusion of countries into each potential cluster. In both cases, there is an evident formation of three top clusters containing many countries on the higher level. However, it is more useful to get more refined results with a higher number of clusters. First, a solution with 10 clusters has been used (Table 4). Based on the results of the Calinski and Harabasz index and in line with our aims, five main clusters at the higher level have been identified. These clusters are further examined (Table 5). When considering the five main clusters, the crucial differences between the years 2019 and 2021 begin to show up. The first cluster is expanded from 4 to 6 countries. Sweden and Malta joined this group of countries

from the previous second cluster, which was formed in 2019. The third cluster before the pandemic was divided into two separate clusters, and Estonia was included in the different clusters. Three countries out of this cluster formed a new second cluster (Romania, Bulgaria, and Hungary), and another three countries (Greece, Latvia, and Cyprus) created a third cluster during the pandemic. The results are rather interesting. Some of the top-performing countries (Clusters I and II) are closer in terms of digital readiness, and low-performing countries (in Cluster III) are starting to differentiate from each other into separate clusters during the pandemic. There are also some minor changes in clusters IV and V. A few countries have been swapped between clusters. However, the core members of these clusters remain the same. Czechia, Germany, Slovenia, Luxembourg, and Austria are still included in Cluster IV. Spain, Portugal, France, Italy, Slovakia, and Poland have formed Cluster V before as well as during the pandemic.

Table 4

Clustering of countries based on their digital readiness in 2019 and 2021; an initial solution with 10 clusters

Cluster	Clustering at a lower level: 10 clusters (More fragmented)	
	2019	2021
I.	Belgium, Denmark, Finland	Belgium, Denmark, Finland
II.	Netherlands	Sweden, Malta, Netherlands
III.	Sweden, Ireland, Malta	Romania, Bulgaria, Hungary
IV.	Romania, Bulgaria, Hungary, Latvia	Greece, Latvia,
V.	Greece, Estonia	Cyprus
VI.	Cyprus	Czechia, Croatia, Slovenia
VII.	Czechia, Germany, Slovenia, Lithuania	Germany, Austria, Luxembourg
VIII.	Luxembourg, Austria	Ireland, Estonia
IX.	Spain, Portugal, France, Italy	Spain, Portugal
X.	Slovakia, Poland, Croatia	France, Italy, Poland, Slovakia, Lithuania

Source: Authors based on data from the Eurostat database

Table 5

Clustering of countries based on their digital readiness in 2019 and 2021; 5 cluster-solution

Cluster	Clustering at a higher level: 5 clusters (Less fragmented)	
	2019	2021
I.	Belgium, Denmark, Finland, Netherlands	Belgium, Denmark, Finland, Sweden, Malta, Netherlands
II.	Sweden, Ireland, Malta	Romania, Bulgaria, Hungary
III.	Romania, Bulgaria, Hungary, Latvia, Estonia, Greece, Cyprus	Greece, Latvia, Cyprus
IV.	Czechia, Germany, Slovenia, Lithuania, Luxembourg, Austria	Czechia, Croatia, Slovenia, Germany, Austria, Luxembourg, Ireland, Estonia
V.	Spain, Portugal, France, Italy, Slovakia, Poland, Croatia	Spain, Portugal, France, Italy, Poland, Slovakia, Lithuania

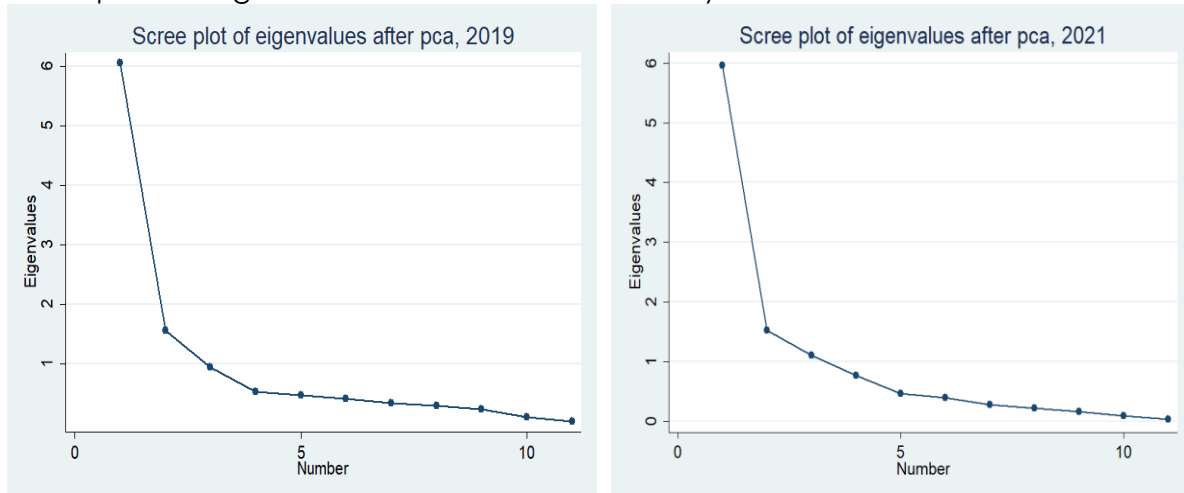
Source: Authors based on data from the Eurostat database

The next part of the analysis describes the individual clusters in more detail. The PCA is used to achieve a more straightforward interpretation of the results. It identifies two

principal components explaining most of the variability in all eleven variables. Two separate PCAs for both years have been applied. Figure 4 shows scree plots representing the decrease in eigenvalues for each number of components resulting from both PCAs. In both cases, two principal components have been used to get results that can be shown in two-dimensional space.

Figure 4

Scree plots of eigenvalues based on the PCA for years 2019 and 2021



Source: Authors based on data from the Eurostat database.

The basic characteristics of both components are shown in Table 6 and Figure 5. Both principal components collectively capture 69% (2019) and 68% (2021) of variability. This means that these components can be used to capture the main essence of overall business digital readiness, as previously explained by eleven variables.

Table 6

Characteristics of the two principal components of digital readiness created by PCA

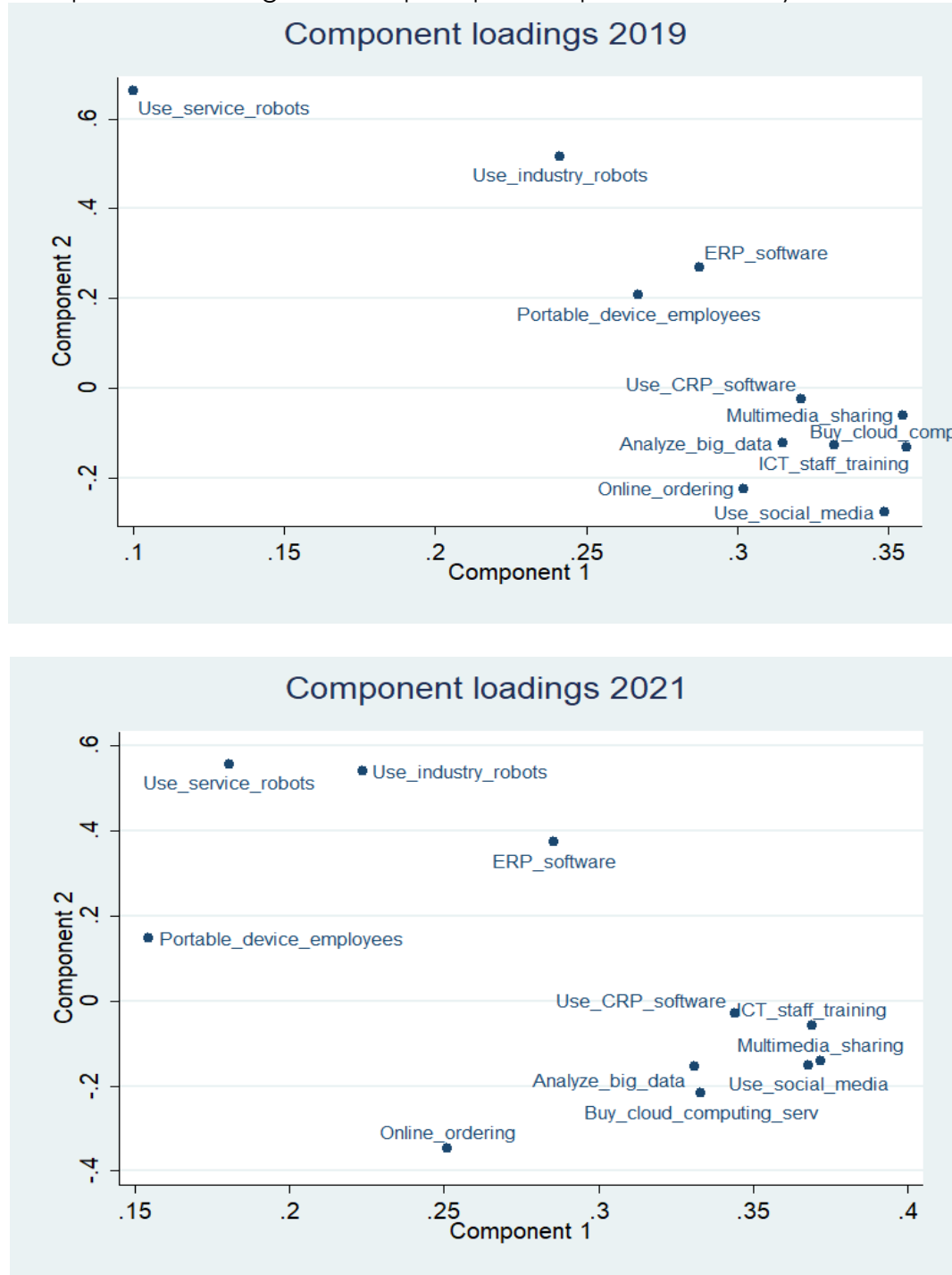
	2019			2021		
	Eigenvalue	Proportion	Cumulative	Eigenvalue	Proportion	Cumulative
Component 1	6.051	0.55	0.55	5.965	0.54	0.54
Component 2	1.563	0.14	0.69	1.52693	0.14	0.68

Source: Authors based on data from the Eurostat database.

More specific component loadings can be seen in Figure 5. Component 2 contains mostly information on the usage of robots in services and industry and, to some extent, also the utilisation of ERP software and portable digital devices for employees. The variables included here mostly express firms' status in automation, robotisation, digital transformation of business processes, and tools for remote work. Hence, this component is focused on processes within the firm and robotisation. Component 1 captures, to the greatest extent, the other 7 variables representing other aspects of business digital readiness, such as the use of digital technology, social media, multimedia sharing, and the possibilities of online ordering. This component is focused on digital transformation with respect to customer and business-to-customer relationships.

Figure 5

Components loadings for both principal components for the years 2019 and 2021



Source: Authors based on data from the Eurostat database.

The distribution of component loadings is similar in both years. Hence, there are two rather distinct principal components depicting slightly different problems related to digital transformation in firms. They also allow us to describe the characteristics of the five main clusters formed by cluster analysis as well as identify the main differences before and during the pandemic. The average scores for both components achieved in each of the clusters have been further investigated. Higher scores mean a better level of business digital readiness in the countries in the cluster. The results are

graphically represented by boxplots, which show median values together with the quartile distribution of values within each cluster (Figure 6).

Figure 6

Boxplots showing the characteristics of five clusters – component scores in 2019 and 2021



Source: Authors based on data from the Eurostat database.

A more detailed explanation of the results is shown in Table 7. Countries classified into the first cluster reach the highest scores with respect to component 1. This means that they are leaders in business digital transformation. This is especially true when considering e-business tools and business-to-customer digitalisation. On the contrary, countries included in the fifth cluster reach the leading position in component 2, which is mostly related to automation, robotisation, and digitalisation of internal processes. The leadership of both clusters in their dominant areas stayed the same before as well as during the pandemic. The problematic cluster is cluster number three. It had the

lowest level of digital readiness before the pandemic. After the pandemic, it split into two clusters. Greece, Latvia, and Cyprus slightly improved their performance and created a new cluster. Moreover, Estonia made it into a significantly better cluster (cluster 4). However, Romania, Bulgaria, and Hungary stay in the cluster with the lowest level of digital readiness.

Table 7

Summary of scores achieved by clusters in relation to both components

	2019	Component 1	Component 2	2021	Component 1	Component 2
I.	Belgium, Denmark, Finland, Netherlands	Very high level with small differences within the cluster	Slightly above the average	Belgium, Denmark, Finland, Sweden, Malta, Netherlands	Very high level	Average level with rather significant differences within the cluster
II.	Sweden, Ireland, Malta	High level	Rather low level	Romania, Bulgaria, Hungary	Very low level	Average
III.	Romania, Bulgaria, Hungary, Latvia, Estonia, Greece, Cyprus	Very low level with rather significant differences within the cluster	Average level	Greece, Latvia, Cyprus	Slightly under the average with rather significant differences within the cluster	Average level
IV.	Czechia, Germany, Slovenia, Lithuania, Luxembourg, Austria	Average level with small differences within the cluster	Average level with small differences within the cluster	Czechia, Croatia, Slovenia, Germany, Austria, Luxembourg, Ireland, Estonia	Average level	Average level
V.	Spain, Portugal, France, Italy, Slovakia, Poland, Croatia	Lower level with rather significant differences within the cluster	High level with rather significant differences within the cluster	Spain, Portugal, France, Italy, Poland, Slovakia, Lithuania	Average level	High level with rather small differences within the cluster

Source: Authors based on data from the Eurostat database.

The last part of our analysis captures the enablers of remote work in more detail. Based on the available data, it examines the measures that companies took to enable remote work during the pandemic. These measures are closely related to the usage of digital tools such as remote access to information, remote meeting software, and ICT systems. The situation was compared among all EU member states (see Table 8). In this case, the data is available only for companies with 10 or more employees. Hence, small enterprises are excluded from this analysis. Firstly, the focus is on the share of companies with the increased share of employees who have remote access to e-mails. On average, almost 33% of enterprises increased the number of these employees, and 13% of enterprises introduced this measure solely due to the

pandemic. The effect of the pandemic on this type of measure was the highest in Malta, Austria, and Cyprus and the lowest in Hungary, Lithuania, and Latvia.

Table 8

The share of remote work-related measures introduced by firms and the effect of the pandemic

	Enterprises that have increased the % of persons employed having remote access to its e-mail (% of enterprises)		Enterprises that have increased the % of persons employed having remote access to the ICT systems of the enterprise other than e-mail (% of enterprises)		Enterprises that have increased the number of remote meetings (e.g. via Skype, Zoom, MS Teams, etc.) (% of enterprises)	
	For any reason	Fully due to Covid	For any reason	Fully due to Covid	For any reason	Fully due to Covid
EU (27)	32.80%	13.00%	32.70%	14.60%	50.1%	30.5%
Belgium	39.70%	13.30%	43.50%	18.10%	67.6%	45.9%
Bulgaria	17.20%	8.60%	14.70%	8.50%	23.3%	13.6%
Denmark	18.60%	NA	23.20%	NA	67.6%	NA
Germany	41.70%	15.10%	38.70%	15.40%	54.1%	30.0%
Italy	30.80%	13.60%	32.60%	16.10%	43.9%	27.1%
Cyprus	35.70%	16.90%	33.10%	16.20%	54.4%	31.4%
Latvia	20.60%	7.70%	19.40%	8.90%	32.6%	19.0%
Lithuania	11.80%	6.10%	11.70%	6.60%	40.6%	23.7%
Luxembourg	33.40%	NA	31.70%	NA	50.9%	NA
Hungary	16.90%	2.60%	16.40%	2.90%	37.0%	18.5%
Malta	55.50%	22.80%	57.60%	27.90%	76.1%	37.6%
Netherlands	42.20%	15.30%	42.40%	17.30%	70.3%	48.1%
Austria	38.20%	20.70%	37.50%	21.90%	56.3%	43.2%
Poland	18.10%	9.90%	20.60%	13.50%	29.4%	22.8%
Portugal	29.80%	9.30%	27.10%	10.50%	47.3%	29.4%
Slovenia	24.20%	6.40%	24.60%	8.00%	48.4%	27.8%
Slovakia	24.60%	8.20%	28.60%	10.90%	41.8%	18.9%
Finland	31.30%	12.00%	31.30%	13.20%	78.7%	48.5%
Sweden	24.60%	8.20%	31.60%	12.30%	71.1%	46.4%

Note: Enterprises with fewer than 10 employees have been excluded from the sample.

Source: Authors based on data from the Eurostat database.

Next, the usage of other remote ICT systems other than email has been examined. The share of firms that adopted this measure is very similar to the previous one. Some enterprises have made this change fully due to COVID-19. More than 57% of enterprises in Malta increased their usage of remote ICT, which had the highest value in the EU. More than a quarter of them did it fully due to COVID-19. In terms of the direct effects of the pandemic, Malta is followed by Austria, Belgium, and the Netherlands. Hungary and Lithuania are again placed on the other side of the ranking.

Finally, the frequency of remote meetings via online team collaboration tools (such as Skype, Zoom, or MS Teams) has been analysed. This is where the most significant changes happened. Moreover, they are largely caused by the pandemic alone. Every second enterprise in the EU has increased the number of online meetings and reported that they increased them fully due to the pandemic.

This time, Finland had the highest increase, followed by Malta, Sweden, and the Netherlands. More than half of the enterprises in Finland, Sweden, and the Netherlands attributed the change to the COVID-19 pandemic. Bulgaria, Poland, Latvia, and Hungary reported a significantly lower increase in online meetings. The most important findings of the paper are briefly summarised in Table 9.

Table 9
Shortened summary of the most significant results

Research questions	Results	Research hypotheses	Results
RQ1	In general, digital readiness of companies increased significantly during the pandemic. However, stagnation (or a slight decrease) in some indicators (big data analytics and ICT trainings) has been also found.	H1	Based on the results, H1 cannot be rejected (can be confirmed).
RQ2	There were some significant changes during the pandemic. However, countries that performed the best before the pandemic remain in the top-performing cluster. Some countries that had recorded unsatisfactory results managed to significantly improve during the pandemic (e.g., Estonia, Latvia, Lithuania). However, the three worst-performing countries (Romania, Bulgaria, and Hungary) are still classified in the same cluster even during the pandemic.	H2	Based on the results, H2 cannot be rejected (can be confirmed). Significant changes in the allocation of countries into the clusters are evident.
RQ3	Some significant difference in cluster characteristics have been found. Most clusters improved in both dimensions (component 1 and component 2) of digital readiness during the pandemic. In most cases, the heterogeneity within individual clusters increased slightly during the pandemic. On the other hand, the difference among the clusters appeared to be smaller during the pandemic.	H3	Based on the results, H3 cannot be rejected (can be confirmed).
RQ4	Significant change towards greater use of digital communication technologies to enable remote work has been found. The most significant change was evident in the case of online meetings via digital platforms. In most cases, this change was implemented exclusively because of the pandemic. The greatest increase in the use of digital technologies to enable work was found in Malta, Austria, Finland, Sweden, and Cyprus.	H4	Based on the results, H4 cannot be rejected. The share of companies that implemented the measures to enable remote work through digital technology significantly increased.

Source: Authors.

The results are presented in relation to the stated research questions and the research hypotheses. All four research questions have been examined in the paper, and our results helped us draw conclusions and test research hypotheses.

Discussion

The processes of digital transformation in business appear to have been accelerated during the COVID-19 pandemic. Our results show important changes in the usage of selected digital technologies and measures adopted to support remote work and the digital transformation. The shift to e-commerce and remote work is evident, which is reflected in the increased usage of cloud computing services, online ordering, and portable devices in most of the EU countries. In these and many other aspects, pandemics really seem to act as disruptive forces that accelerate the adoption of digital transformation, as reported by Döhring et al. (2021). Social distancing policies stimulate the introduction of new technologies, which enables the involvement of businesses in the digital economy, as previously argued by Ganichev and Koshovets (2021). However, several exceptions have been found as well. There has been no significant increase in the use of service robots, and there has been a slight decrease in the application of big data analytics. These technologies are still relatively new and costly. This can be one of the reasons why firms did not invest in them during pandemic times. There are still evident challenges and barriers to the implementation and usage of big data analytics (Kashyap, 2019) and service robotics (Hudson et al., 2017).

The classification of countries into clusters based on their business digital readiness shows similar partners, as reported previously by Kinnunen et al. (2019) or Borowiecki et al. (2020). Our results show rather significant differences in the digital transformation of businesses in EU countries. In general, firms in the eastern and southern parts of the EU are lagging other EU countries. This is in line with some other studies. For example, Hunady et al. (2022) found a significantly lower level of digital readiness for business in newer member states and southern countries of the EU. Even though there are only a very small number of studies devoted to clustering countries based on their digital readiness at the firm level, their results can still be used for comparison with ours.

The pandemic appears to have changed the classification of countries into clusters. The most significant changes have been found in countries with a previously relatively low level of business digital readiness. For example, Estonia makes a significant step forward. It was placed in a much better group during the pandemic than before it. This result is also supported by the findings of Härmand (2021), who argues that Estonia used political momentum during the pandemic to start fundamental changes supporting digital transformation. These changes include legislation for remote notarial transactions, online annual meetings, and digital infrastructure. On the other hand, the countries with lower digital readiness (Romania, Bulgaria, and Hungary) remain in the same cluster even during the pandemic. These countries are usually placed at the end of the digital rankings. Kovács et al. (2023) showed that Hungary, Bulgaria, Romania, and Poland are ranked the lowest based on the degree of integration of digital technologies in the EU. Interestingly, the results indicate that the difference among the clusters appeared to be smaller during the pandemic compared to the situation before. This may be due to public financial and non-financial support as well as demand shocks during the pandemic. The economic reasons for the mentioned development could be further investigated. This research problem could be further examined in future research.

There are several other limitations of our study. First, it would be interesting to compare the results with the new data after the end of the intense pandemic. When these data are available to a sufficient extent, an even more comprehensive comparison will be possible. Moreover, our approach captures only differences while considering two points in time. This is since cluster analysis is usually not suitable for capturing dynamic changes. However, there are some more advanced approaches, such as Kml clustering for longitudinal data developed by Genolini and Falissard

(2011), that are currently used mostly in other fields than economics. This method can capture dynamic trends in digital readiness and perform clustering on panel data. With the application of such methods, it would be possible to further extend our findings in future research.

Our research was also focused on examining the changes in remote work and measures taken by businesses to increase the usage of digital tools enabling remote access. This problem is seen as one of the main pandemic-related phenomena, as reported by Adžić and Al-Mansour (2021). Our results show the positive effect of the COVID-19 pandemic on these types of measures. Firms with ten or more employees considerably increase the share of employees with remote access to e-mail as well as to other ICT systems. More than a third of these changes were caused exclusively by the COVID-19 pandemic. Moreover, every other company in the EU has significantly intensified the remote meeting via digital platforms. More than 30% of all enterprises stated that these measures have been fully adopted due to the pandemic. These results are fully in line with Kraus et al. (2020). They found that most firms introduced new work-from-home policies and enabled remote work during the pandemic.

Conclusion

The paper brings some new findings on digital transformation in business during the pandemic. These findings are based on empirical evidence from EU countries. They confirm the fact that most companies have increased their pace of digital transformation in general. This is especially true for customer-focused digital tools and enablers of e-business. On the other hand, in some technologies, such as big data analysis and the implementation of service robots, signs of stagnation or even a decline have been found. The countries have been classified based on their digital readiness for business into rather homogenous groups. This classification was provided before and during the pandemic. Some significant differences between both periods have been found. Belgium, Denmark, Finland, Sweden, Malta, and the Netherlands form a cluster of countries with the highest overall digital readiness. This is especially true in the case of customer-oriented digital tools. On the other hand, countries like Spain, Portugal, France, Italy, Poland, Slovakia, and Lithuania seem to be dominant in the robotisation and digitalisation of internal business processes. Some significant shifts between clusters have been found. Estonia, Malta, and Sweden are the three countries with the most significant improvements. The original cluster of countries with the lowest level of digital readiness has been split into more clusters. However, the worst-performing countries (Bulgaria, Romania, and Hungary) remain to be included in the same cluster. The EU policies to support digital transformation should be primarily focused on these countries to fill the gap. Even though the worst-performing countries are still significantly struggling to improve, our results also suggest that the differences among clusters tend to shrink slightly during the COVID-19 pandemic.

The paper also examines the response of companies to the pandemic in the form of remote work-related measures. In this area, companies in Malta, Finland, Sweden, and the Netherlands did the most during the pandemic. Every second firm in the EU has increased the number of online meetings, and more than half of them introduced this measure only due to the pandemic. Similarly, more than 13% of firms adopted new measures for employees' remote access to email and other ICT systems exclusively due to the pandemic.

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Using CNNs for Photovoltaic Panel Defect Detection via Infrared Thermography to Support Industry 4.0

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Abstract

Background: This study demonstrates how convolutional neural networks (CNNs), supported by open-source software and guided by corporate social responsibility (CSR), can enhance photovoltaic (PV) panel maintenance. Connecting industrial informatics with sustainable practices underscores the potential for more efficient and responsible energy systems within Industry 4.0. The rapid expansion of solar power necessitates effective maintenance and inspection of PV panels to ensure optimal performance and longevity. CNNs have emerged as potent tools for detecting defects in PV panels through infrared thermography (IRT). **Objectives:** The review aims to evaluate CNNs' effectiveness in detecting PV panel defects, align their capabilities with the IEC TS 62446-3:2017 standard, and assess their economic benefits. **Methods/Approach:** A systematic review of literature focused on studies using CNNs and IRT for PV panel defect detection. The analysis compared performance metrics, economic benefits, and alignment with industry standards. **Results:** CNN models demonstrated high accuracy in defect detection, with most achieving above 90%. Integrating UAVs for image acquisition significantly reduced inspection times and costs. **Conclusions:** CNNs are highly effective in detecting PV panel defects, offering substantial economic benefits and potential for industry-wide standardisation. Further research is needed to enhance model robustness across diverse conditions and PV technologies.

Keywords: Convolutional Neural Networks; Photovoltaic Panels; Defect Detection; Infrared Thermography; Solar Energy

JEL classification: Q42, Q55, Q56

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Introduction

Industry 4.0 has introduced transformative technologies such as artificial neural networks, which play a critical role in predictive maintenance across various sectors (Pejić Bach et al., 2023a). By aligning these technologies with corporate social responsibility (CSR) principles, businesses can enhance both efficiency and sustainability (Barić, 2022). The growing field of industrial informatics, as highlighted by Pejić Bach et al. (2023b), underscores the increasing importance of data-driven technologies in modern industry. Specifically, the role of open-source software in predictive maintenance is emphasised as a cost-effective solution that enhances the accessibility and implementation of advanced technologies like neural networks (Pejić Bach et al., 2023a, 2023b). These insights have motivated the authors to conduct a systematic review to assess the effectiveness of convolutional neural networks (CNNs) in PV panel defect detection, along with evaluating their economic benefits and alignment with industry standards.

In the photovoltaic (PV) industry, CNNs are becoming increasingly important for the defect detection process, thanks to their superior capabilities over traditional techniques. CNNs are a type of deep learning algorithm designed to process structured grid data like images. They learn spatial hierarchies of features through layers of convolutional filters, making them particularly effective for image classification and pattern recognition tasks. A significant advantage of CNNs is their ability to autonomously learn and identify patterns in images, enabling them to accurately detect and categorise defects in images of PV panels (Hassan & Dhimish, 2023). Recent advancements in CNN architectures, such as ResNet, Inception, and EfficientNet, have significantly enhanced their performance and efficiency, making them essential tools for many high-tech applications. These advanced models can learn intricate features and patterns in large datasets, leading to breakthroughs in object detection, segmentation, and image classification (Taye, 2023). Input data for these CNN models in the PV industry are usually images of PV panels, which can be obtained using various imaging techniques such as electroluminescence (EL) images, infrared (IR) thermography of PV panels, fluorescence images, photoluminescence images, etc. (Ahmed et al., 2021). This review will focus on IR thermography images as input for CNN models. Infrared thermography (IRT) measures the infrared radiation emitted from a surface. Thermal imaging cameras capture this radiation and generate images or videos that depict temperature variations. These images, known as thermograms, use colours to illustrate thermal patterns, making them easy to interpret. IRT is a highly effective method because defective PV modules typically show irregularities in their temperature distribution (Lofstad-Lie et al., 2022). IRT of photovoltaic (PV) panels is extensively utilised in the literature due to its rapid execution, cost-effectiveness, suitability for large-scale outdoor applications, ease of use, and high accuracy (Ahmed et al., 2021). These characteristics are particularly beneficial in the PV industry, where numerous panels require frequent and thorough inspection (Hassan & Dhimish, 2023; Jia et al., 2024).

The economic benefits of using convolutional neural networks (CNNs) for automatic defect detection in IR images of PV panels in their operational phase are significant. Reviewing images manually by the human eye is labour-intensive and time-consuming, causing high inspection costs and longer times for generating final reports. Fast detection of abnormalities is crucial for the preservation of the longevity of PV panels and maximising energy production. By employing CNNs, the PV industry can reduce these opportunity costs, increase inspection accuracy and eliminate human bias in the defect identification process. CNNs enhance the inspection process by quickly and accurately identifying defects, ensuring that PV panels operate efficiently

and reliably for their expected lifespan, thus supporting the industry's growth and sustainability (Hussain et al., 2023; Wang et al., 2022). Inspection times for PV panels can be further reduced by utilising unmanned aerial vehicles (UAVs) equipped with IR cameras. UAVs can quickly scan large solar installations, capturing high-resolution IR images that are essential for identifying defects. Research indicates that UAVs can speed up the inspection process by approximately 85%, significantly reducing the time required to conduct thorough inspections of extensive PV arrays (Zefri et al., 2018). Another research done by Huerta Herraiz, Pliego Marugán, and García Márquez (2020) claims a 97% average increase in inspection efficiency using UAVs as opposed to manual inspection and also pinpoints the ease of locating the defects utilising GPS metadata from the UAV. As seen in the work of Nooralishahi et al. (2021), the utilisation of UAVs can enable simultaneous acquisition of IR and standard Red, Green, and Blue (RGB) images. This can enhance the detection rate of defects and enable better determination of root-cause problems.

By enabling sophisticated defect detection, CNNs help maintain the reliability and efficiency of PV systems, thereby supporting the sustainable growth of solar energy worldwide. As solar installations continue to rise, especially in leading markets like China and Europe (SolarPower Europe [SPE], 2024), the implementation of effective inspection methods becomes increasingly vital to uphold the integrity and performance of these renewable energy assets. Connecting this advanced defect detection and classification technology with industry standards is crucial for consistent and reliable PV panel maintenance. The International Electrotechnical Commission (IEC) standard IEC TS 62446-3:2017 outlines guidelines for the use of IR thermography in inspecting PV panels, detailing specific abnormalities (defects) and their corresponding patterns (IEC, 2020). The abnormalities listed by IEC (2020) are Modules in an open circuit, Modules in a short circuit, Substring in a short circuit, Substrings in an open circuit, Single cells with differences in temperature, Module with cells shaded by dirt, Broken glass – crack, Transfer resistance, and Heated module junction box. The effectiveness of CNNs in identifying these patterns, as described in the IEC standard, will be a key focus of this review. They layout 12 classes, but some of them were merged in this list as they are the same defects, just on different PV panel technology.

The purpose of this paper is to evaluate the effectiveness of different CNNs for defect detection in PV panels using IRT images, align their capabilities with the IEC TS 62446-3:2017 standard (International Electrotechnical Commission [IEC], 2020) and assess their economic benefits. This review synthesises existing research on the application of CNNs for PV panel defect detection, providing insights into their performance metrics, economic advantages pinpointed in the papers analysed, and potential for industry-wide standardisation. A systematic review of the literature focusing on studies utilising CNNs and IRT for PV panel defect detection was conducted, and the data were analysed to compare performance metrics and list economic benefits. Current state-of-the-art CNN models have demonstrated significant potential in accurately detecting various abnormalities listed in the IEC standards, as seen in the works of Fonseca Alves, Deus Júnior, Marra, and Lemos (2021) and Bommers et al. (2021) as most of their model output classes are the same as in IEC standard. This leads to the central research questions of this review:

1. RQ1. Can CNNs identify all defect patterns proposed in the IEC standard?
2. RQ2. Can they achieve an acceptable detection rate, effectively replacing human inspection and speeding up the process, thereby providing economic benefits?

To address these questions, we propose the following research hypotheses:

1. H1: Convolutional neural networks (CNNs) can accurately identify all defect patterns listed in the IEC TS 62446-3:2017 standard for PV panel inspection.
2. H2: CNNs can achieve a detection rate that meets or exceeds the accuracy of human inspectors, thus validating their effectiveness in identifying PV panel defects.
3. H3: The implementation of CNNs in defect detection will significantly reduce inspection time and costs, providing substantial economic benefits compared to traditional manual inspection methods.

This review paper aims to make several theoretical contributions to the field of solar energy and photovoltaic system maintenance through the application of convolutional neural networks (CNNs). Firstly, the review will provide a comprehensive analysis of CNN's effectiveness. Synthesising existing research on the application of CNNs for defect detection in PV panels will offer a thorough understanding of how well these networks perform in identifying various defects as per the IEC standards because many of the recent works detect only 2-3 defect classes (Bakır et al., 2023; Cipriani et al., 2020; Hwang et al., 2021; Manno et al., 2021). This critical evaluation of different CNN models' performance metrics will highlight their strengths and limitations, contributing valuable insights into their practical applications. Secondly, the paper will evaluate the economic and operational benefits of adopting CNN-based defect detection in the PV industry. It will discuss cost savings, reduced inspection times, and the elimination of human error, providing a theoretical framework for understanding the broader impact of CNN technology on the sustainability and scalability of solar energy systems. This analysis will offer a new perspective on the economic implications of technological advancements in the PV sector.

Additionally, by aligning the defect detection capabilities of CNNs with the IEC TS 62446-3:2017 standard (IEC, 2020), the review will bridge the gap between advanced technological solutions and industry requirements. This alignment will offer a theoretical basis for standardising the use of CNNs in PV panel maintenance, promoting consistency and reliability across the industry. Such a connection between technology and industry standards is critical for the practical implementation of new inspection methods. These theoretical contributions aim to advance the understanding of how CNNs can revolutionise the inspection and maintenance of photovoltaic systems, supporting the sustainable growth of solar energy on a global scale. By providing a thorough and critical examination of the existing research, this review will serve as a valuable resource for researchers, industry professionals, and policymakers in the field of renewable energy.

The structure of the paper is designed to provide a comprehensive review of the use of convolutional neural networks (CNNs) for defect detection in photovoltaic (PV) panels using infrared thermography (IRT). Following the introduction, the paper is divided into several sections that each address critical aspects of the research. The Background section outlines the rapid growth of solar power and highlights the importance of maintaining PV panel efficiency and longevity through advanced inspection techniques. Next, the Methodology section details the systematic approach taken to gather, analyse, and synthesise relevant literature, including the criteria for selecting studies and the methods for data analysis and synthesis. The Results section presents a comparative analysis of key studies, highlighting their findings on the effectiveness of various CNN models in detecting PV panel defects. The Discussion section delves into the implications of these findings, addressing the research questions regarding CNN's capabilities and their economic benefits. It also identifies limitations in current research and suggests directions for future studies. Finally, the Conclusion summarises the key insights from the review and underscores

the potential of CNN-based defect detection methods to enhance the reliability and efficiency of PV systems, supporting the sustainable growth of solar energy.

The remainder of this paper is structured as follows: The Background section discusses the significance and growth of the photovoltaic (PV) industry and the need for effective maintenance and inspection of PV panels. The Methodology section outlines the systematic approach used for the literature review, including the literature search strategy, inclusion and exclusion criteria, and data analysis techniques. In the Literature Review section, we summarise and compare key studies on the application of CNNs for defect detection in PV panels using infrared thermography. The Results section presents a comparative analysis of the performance metrics, economic benefits, and alignment with industry standards from the reviewed studies. The Discussion section addresses the central research questions, evaluates the strengths and limitations of the reviewed studies, and suggests future research directions. Finally, the Conclusion provides a summary of the key findings and theoretical contributions of this review, emphasising the practical implications for the PV industry.

Background

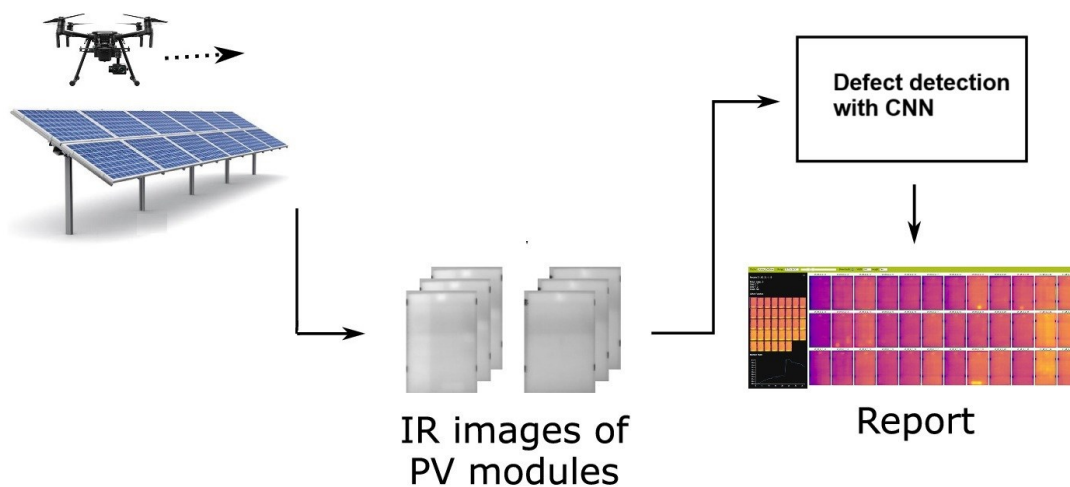
The rapid growth of solar power on a global scale has been nothing short of remarkable. In 2023, the world saw an unprecedented addition of 447 gigawatts (GW) of new photovoltaic (PV) capacity, a staggering 87% increase from the previous year (SolarPower Europe, 2024). This surge underscores solar energy's critical role in the global energy transition, highlighting its potential to meet increasing energy demands while mitigating climate change and aligning with the goals of the Paris Agreement (United Nations Framework Convention on Climate Change [UNFCCC], 2023) and the latest commitments outlined at COP28 (UNFCCC, 2023). COP28, held in Dubai, United Arab Emirates, marked several significant milestones in global climate action. One of the key outcomes was the agreement to triple renewable energy capacity and double the global rate of energy efficiency by 2030, according to UNFCCC (2023). This commitment is crucial for limiting global warming to 1.5 °C above pre-industrial levels, a core objective of the Paris Agreement (UNFCCC, 2015). PV accounted for a dominant 78% of the 576 GW of new renewable capacity added globally, reaffirming its leadership in the renewable energy sector. Europe, in particular, has been a significant contributor to this growth of renewable energy capacity, installing a record 70.1 GW of new solar capacity in 2023, marking a substantial 51% year-on-year increase (SolarPower Europe, 2024). This growth trajectory is set to continue, driven by robust policy frameworks, technological advancements, and strong market demand (SolarPower Europe, 2023).

Recent years have witnessed substantial progress in the photovoltaic sector, characterised by significant reductions in the cost of solar panels and notable improvements in their efficiency. The cost of polycrystalline silicon modules, for instance, has decreased by approximately 68% from \$0.67 per watt in the first quarter of 2014 to \$0.214 per watt in the second quarter of 2019, according to Abou Jieb and Hossain (2022). Concurrently, the efficiency of PV modules has also seen remarkable enhancement. At present, the efficiency of single-junction solar PV cells ranges from 15% to 28%, with a maximum theoretical efficiency of 33.16% (National Renewable Energy Laboratory, 2019, as cited in Abou Jieb and Hossain, 2022). Continuous research and development efforts have led to the creation of high-efficiency modules, such as those produced by Hanwha Q Cells, which have set records with module efficiencies of up to 20.4%, as stated by Abou Jieb and Hossain (2022). This trend of increasing efficiency and decreasing costs is pivotal for making solar energy more accessible and competitive with conventional energy sources.

However, the expansion of solar power also brings to light the importance of maintaining the efficiency and longevity of PV systems. As noted by Sharma and Chandel (2013), electrical energy generated using PV technology can only be economical if the PV modules operate reliably for 25–30 years under field conditions. Proper inspection and maintenance are essential to ensure that PV panels operate at their peak performance, minimising downtime and maximising energy output. This is where advanced technologies, particularly convolutional neural networks (CNNs), come into play. Convolutional neural networks (CNNs) are a class of deep learning algorithms that have revolutionised image and video recognition tasks. These networks are designed to automatically and adaptively learn spatial hierarchies of features from input images through layers of convolutions, pooling, and fully connected layers. The convolutional layers apply filters to the input to create feature maps, which are then down-sampled by pooling layers to reduce spatial dimensions. Finally, fully connected layers perform classification based on the extracted features. This architecture allows CNNs to excel in tasks requiring a high-level understanding of image content, making them indispensable in a field such as computer vision (Alzubaidi et al., 2021; Taye, 2023). CNNs are not limited to photovoltaic inspections; their applications span across various domains, including medical imaging, autonomous driving, and facial recognition. For instance, in medical imaging, CNNs assist in diagnosing diseases by analysing X-rays, MRIs, and CT scans with remarkable accuracy (Taye, 2023).

Figure 1

Inspection phases with UAV / IR / CNN technology in PV systems



Source: Authors' adaption of Bommès et al. (2021) figure

Figure 1 illustrates the inspection phases of photovoltaic (PV) systems utilising UAV (Unmanned Aerial Vehicle), infrared (IR) imaging, and convolutional neural network (CNN) technology. This comprehensive approach involves multiple stages where UAVs capture aerial images, IR sensors detect thermal anomalies, and CNN algorithms analyse the data to identify potential issues in the PV systems.

Literature Review

The intersection of CSR and industrial strategy has been increasingly recognised as vital for achieving long-term sustainability in Industry 4.0. Barić (2022) argues that integrating CSR into core business operations not only fulfils ethical obligations but also provides a strategic advantage, particularly in industries closely tied to environmental

impacts, such as solar energy. This perspective underlines the importance of responsible practices in the deployment of technologies like CNNs for PV panel maintenance.

Pejić Bach et al. (2023a) highlight the rapid growth of industrial informatics as a crucial area of research, emphasising how data-driven approaches are transforming industrial processes. The integration of predictive analytics, especially in maintenance operations, allows companies to pre-emptively address issues, thereby reducing downtime and costs. This research supports the need for advanced technologies like CNNs to be incorporated into routine maintenance strategies to enhance their effectiveness.

The use of open-source software in predictive maintenance is highlighted by Pejić Bach et al. (2023b), who emphasise its benefits across various industries. By leveraging tools like R, companies can implement sophisticated maintenance systems without the financial burden of proprietary software. This accessibility is particularly crucial in the context of Industry 4.0, where cost-effective solutions are needed to democratise the use of advanced technologies like CNNs.

Developing a computer vision tool that integrates CNNs and IRT, Bommès et al. (2021) focused on detecting, mapping, and classifying faults in PV modules. The tool, combined with unmanned aerial vehicles (UAVs), enables rapid data acquisition and high accuracy in identifying various fault types, significantly reducing maintenance costs and improving the reliability of PV systems. This study concentrated on ten classes of defects: Module open-circuit, module short-circuit, substring open-circuit, substring short-circuit, module potential-induced degradation (PID), multiple hot cells, single hot cell, warm cell(s), diode overheated and hot spot. This research is closest to the IEC classification mentioned before. They have used the ResNet-50 CNN model and achieved test accuracy of more than 90%.

Research conducted under Algerian climatic conditions by Kellil, Aissat and Mellit (2023) focused on fault diagnosis of PV modules using a fine-tuned VGG-16 model and deep neural networks. The study achieved remarkable accuracy rates of 99.91% for fault detection and 99.80% for diagnosing five defect types, including bypass diode failure, shading effect, short-circuit, dust deposit, and partially covered PV module. The use of infrared thermographic images underlines the effectiveness of the VGG-16 model in diverse environmental conditions.

In 2021, Hwang et al. proposed a hybrid detection scheme utilising custom CNN architecture and the XGBoost algorithm to enhance the detection of malfunctioning PV modules. By using infrared images captured by UAVs, the study demonstrated high detection accuracy and efficiency, particularly in large-scale or remote solar power plants. The hybrid scheme's integration of multiple machine learning methods provided robust fault detection capabilities, predicting three classes of defects: hot spots, PID (Potential Induced Degradation), and open circuits (Hwang et al., 2021). Their best classification model based solely on image detection had 99% accuracy, while the hybrid model upped it to 99.2%. Hybrid models combine CNNs with other machine learning algorithms, such as XGBoost or support vector machines (SVMs), to enhance performance. These models leverage the strengths of each component, improving accuracy and reducing false positives in defect detection tasks.

Implementing UAV-based infrared thermography to detect faults in PV systems, Manno et al. (2021) highlighted significant efficiency gains and cost reductions in maintenance processes. The integration of UAVs allowed for rapid and precise inspection of extensive solar installations, emphasising the practicality of combining UAV technology with advanced image processing techniques for PV system monitoring. This study focused on only 1 class of defect: hotspot. The main reason it

was chosen for review is because it compares ground-based and UAV acquisition methods. The conclusion was that the UAV acquisition method allows a considerable reduction in inspection time. The architecture they used was VGG-16, and they achieved 98% classification accuracy.

Moreover, Benghanem et al. (2023) introduced a method using CNNs to analyse and classify defects in PV modules under various environmental conditions. Their approach highlighted the importance of adapting inspection techniques to different climatic settings to maintain high detection accuracy and efficiency. This study identified seven defect types: covered PV module, cracked PV module, degradation, diode overheating, dirty PV module, sand accumulated on PV module, and short-circuited PV module. Their best model, which they call CNN-ML, achieved 94% accuracy over these 7 defects. That model is a hybrid model consisting of a custom CNN and support vector machines (SVM) model.

Mellit (2022) introduced an embedded system for fault detection and diagnosis in PV modules using thermographic images and deep convolutional neural networks. The study developed a binary classifier for fault detection and a multiclass classifier for diagnosing four types of defects: partial shading effect, dust deposit on PV modules surface, short-circuited PV module, and bypass diode failure. The system was embedded in a low-cost microprocessor for real-time application, demonstrating high feasibility and accuracy. Final accuracy for defect classification was 95.55%.

In their study, Fonseca Alves et al. (2021) explore the development of an automatic fault classification system for photovoltaic (PV) modules using convolutional neural networks (CNNs) and infrared thermography. The researchers aimed to classify up to eleven different defect types in PV modules, including cell, cell-multi, cracking, hotspot, hot-spot-multi, shadowing, diode, diode-multi, vegetation, soiling, and offline module. They utilised data augmentation techniques to improve the performance of their CNN model on an unbalanced dataset, achieving a testing accuracy of 92.5% for anomaly detection and 78.85% for classifying eight selected defect classes. Data augmentation involves techniques used to increase the diversity of a training dataset without collecting new data. This can include transformations like rotations, translations, and flips, which help improve the robustness and performance of CNN models by simulating various real-world scenarios.

Methodology

In this review article, the methodology section outlines the systematic approach taken to gather, analyse, and synthesise information regarding the use of convolutional neural networks (CNNs) for defect detection in infrared (IR) images of photovoltaic (PV) panels. The methodology ensures a comprehensive and unbiased review of the existing literature and identifies gaps and trends in the research landscape. The methodology section provides a structured approach to reviewing the use of CNNs for defect detection in PV panels, ensuring a comprehensive understanding of current capabilities, challenges, and prospects. This systematic review aims to contribute valuable insights for researchers, industry professionals, and policymakers in advancing the sustainable growth of solar energy through innovative inspection technologies. The steps undertaken are laid out in the subheadings of this section.

Literature search strategy

A thorough literature search was conducted across multiple academic databases, including ScienceDirect, Google Scholar, Wiley Online Library, and SpringerLink. The search focused on articles published between 2010 and 2024 to ensure the inclusion of both foundational studies and the latest advancements in the field. Key search

terms included combinations of the following keywords: "Convolutional Neural Networks," "CNN," "PV panel defect detection," "infrared thermography," "solar energy," "photovoltaic inspection," and "deep learning."

Inclusion and Exclusion Criteria

Specific inclusion and exclusion criteria were established for the inclusion and exclusion of the papers. The inclusion criteria were:

- Peer-reviewed journal articles and conference papers
- Studies focusing on CNN applications for defect detection in PV panels
- Research utilising infrared thermography for PV panel inspection
- Articles published in English.

The exclusion criteria were:

- Non-peer-reviewed articles, such as preprints, thesis papers, and technical reports
- Studies not involving CNNs or IR imaging in the context of PV panels
- Articles with insufficient methodological details or experimental data.

Data analysis and synthesis

Relevant data were gathered from the selected articles, focusing on the following aspects:

- Study Objectives and Scope: The primary goals and coverage of each study
- CNN Architectures Used: Specific CNN models (e.g., ResNet, EfficientNet) employed in the defect detection process
- Performance Metrics: The main metric for comparison will be the accuracy of classification.
- Applications and Results: Key findings, applications in the PV industry, and practical outcomes of each study.

The gathered data were organised into tables to facilitate a clear comparison of different studies and highlight the performance and applicability of various CNN models.

Analysis of CNN Effectiveness

The review critically analysed the effectiveness of CNNs in identifying the defect patterns specified by the International Electrotechnical Commission (IEC) standard IEC TS 62446-3:2017 (IEC, 2020). This involved:

1. Mapping Defect Types: Comparing the identified defect types in the reviewed studies with the IEC standards
2. Detection Rates: Evaluating the detection rates achieved by CNN models and their potential to replace human inspection
3. Economic Benefits: Assessing the economic implications of using CNNs, including inspection speed, cost savings, and reduction in human error.

Technological Integration and Future Directions

The review also explored the integration of UAVs equipped with IR cameras in the inspection process, considering their impact on efficiency and accuracy as several reviewed studies have employed UAVs as their channel of acquisition of IR images (Grimaccia, Leva, Dolara, & Aghaei, 2017; Huerta Herraiz et al., 2020; Hwang et al., 2021; Kirsten Vidal de Oliveira, Aghaei, & R  ther, 2020; Masita, Hasan, & Shongwe, 2022; Zefri, Sebari, Hajji, & Aniba, 2022). Additionally, future research directions were identified based on current gaps and limitations in the literature.

Quality Assessment and Bias Mitigation

To ensure the reliability of the review, a quality assessment of the selected studies was conducted using standardised tools like the Critical Appraisal Skills Programme (CASP) checklist (Critical Appraisal Skills Programme, 2018). Efforts were made to mitigate bias by including studies from diverse geographical regions and research groups and by considering both positive and negative findings.

Seven research studies were chosen for results synthesis as they have passed the inclusion and exclusion criteria out of 23 research found in the literature search. These studies were selected based on their relevance to the application of convolutional neural networks (CNNs) and infrared thermography (IRT) for the detection and classification of defects in photovoltaic (PV) modules. The selected research collectively demonstrates the significant advancements in automated PV system inspection and maintenance technologies. These advancements are critical for enhancing the efficiency, accuracy, and economic viability of solar energy systems, contributing to their sustainable growth and reliability. Each of the studies will be briefly described in a paragraph, and the final results of all studies will be presented in a tabular form afterwards.

In this study, we conducted a review of seven key research articles that focus on the application of convolutional neural networks (CNNs) and Infrared Thermography (IRT) for detecting and classifying defects in photovoltaic (PV) modules. The results from these studies are compared in the form of a table in the Results section to highlight defect classes recognised, compatibility with IEC classification, and respective accuracies.

Compatibility with the IEC standard (IEC, 2020) was evaluated based on the defect class names and examples provided in the respective articles, as well as the reviewer's domain knowledge. Although the accuracies are not directly comparable due to the differing number of classes each study predicted, they present a clear picture of the performance of individual models. This comparative analysis demonstrates the effectiveness of CNNs in identifying various defect types in PV modules, thereby enhancing their maintenance and operational efficiency.

Results

The integration of convolutional neural networks (CNNs) with infrared thermography (IRT) has shown significant advancements in the inspection and maintenance of photovoltaic (PV) panels.

These advancements, detailed in the reviewed studies summarised in Table 1, are crucial for the PV industry as they not only enhance the efficiency and accuracy of defect detection but also reduce the associated costs and time required for maintenance. The use of CNNs allows for the automated identification of defects, which is essential for the rapid and accurate inspection of large-scale PV installations, as reflected in the objectives and scopes of the analysed research.

Table 1
Analysed Papers

Authors, year	Paper title	Objectives and scopes
Bommes et al. (2021)	Computer vision tool for detection mapping and fault classification of photovoltaics modules in aerial IR videos	Develop a semi-automatic tool for extracting PV modules from thermographic UAV videos and classifying anomalies with ResNet-50 CNN, achieving over 90% accuracy for automated PV plant inspection.

Kellil et al. (2023)	Fault diagnosis of PV modules using deep neural networks and infrared images under Algerian climatic conditions	Address fault diagnosis in PV modules using VGG-16 CNN with thermographic images, achieving high accuracy in diverse conditions with binary and multiclass classification.
Hwang et al. (2021)	Detection of Malfunctioning Photovoltaic Modules Based on Machine Learning Algorithms	Propose a hybrid detection scheme combining CNN and XGBoost to enhance the detection of malfunctioning PV modules, achieving high detection accuracy with infrared thermography.
Manno et al. (2021)	Deep learning strategies for automatic fault diagnosis in photovoltaic systems by thermographic images	Develop a system for automatic classification of thermographic images using CNNs, achieving high accuracy for remote and ground-based inspections to maintain PV system efficiency.
Benghanem et al. (2023)	Embedded Hybrid Model (CNN-ML) for Fault Diagnosis of Photovoltaic Modules Using Thermographic Images	Develop a hybrid CNN-ML model for real-time fault diagnosis of PV modules, optimising and implementing it in a microprocessor with a user-friendly interface for diverse climatic conditions.
Mellit (2022)	An embedded solution for fault detection and diagnosis of photovoltaic modules using thermographic images and deep convolutional neural networks	Introduce an embedded system for real-time fault detection and diagnosis of PV modules using DCNN, focusing on common defects and optimised for low-cost microprocessor deployment.
Fonseca Alves et al. (2021)	Automatic fault classification in photovoltaic modules using Convolutional Neural Networks	Investigate the use of CNNs with data augmentation for classifying up to eleven defect types in PV modules through thermographic images.

Source: Authors' work

Overall, the reviewed studies, as summarised in Table 2, demonstrate the potential of CNNs to improve the inspection and maintenance of PV panels significantly. The high accuracy rates achieved by various CNN models indicate that these technologies can effectively identify a wide range of defects, ensuring that PV systems operate at their optimal efficiency. As the demand for solar energy continues to rise, the adoption of advanced inspection techniques like CNNs and IRT will be essential for maintaining the performance and reliability of PV installations worldwide.

Table 2
Findings in analysed papers

Authors, year	Findings of own research	Relation to existing findings in the literature
Bommes et al. (2021)	High accuracy (>90%) in classifying PV module anomalies using ResNet-50 CNN.	Confirms the effectiveness of CNNs for defect detection, extending it to large-scale PV plants with UAV integration.
Kellil et al. (2023)	Achieved 99.91% accuracy in fault detection and 99.80% in fault diagnosis using VGG-16 CNN.	Supports prior work on the high accuracy of CNNs in diverse environmental conditions, enhancing fault diagnosis precision.

Hwang et al. (2021)	High detection accuracy with a hybrid CNN and XGBoost scheme.	Aligns with previous studies on hybrid models, improving detection accuracy, particularly in large-scale settings.
Manno et al. (2021)	99% accuracy in fault classification using CNNs for UAV-acquired images.	Validates the use of UAV and CNN combinations for efficient PV module inspection, consistent with other research.
Benghanem et al. (2023)	Effective real-time fault diagnosis using a hybrid CNN-ML model.	Builds on existing literature by demonstrating practical embedded solutions for real-time applications in varied climates.
Mellit (2022)	Feasibility of real-time fault detection using DCNN, optimised for low-cost microprocessors.	Reinforces the potential for cost-effective, real-time PV module inspection using embedded DCNN systems.
Fonseca Alves et al. (2021)	92.5% accuracy for anomaly detection and 78.85% for defect classification with data augmentation in CNNs.	Extends current knowledge by addressing classification challenges in unbalanced datasets with data augmentation.

Source: Authors' work

Infrared thermography (IRT) is a widely used technique in PV panel inspection due to its ability to detect thermal anomalies that indicate potential defects. By capturing temperature variations on the surface of PV panels, IRT provides a visual representation of the panel's thermal profile, making it easier to identify areas that may require further inspection or maintenance. The CNN architectures used and their respective classification accuracies, as listed in Table 3, demonstrate the effectiveness of these models in quickly and accurately classifying different types of defects based on the thermal patterns observed. Classification accuracy is a metric used to evaluate the performance of a classification model by measuring the proportion of correct predictions out of the total predictions made. In PV panel inspection using infrared thermography (IRT) and convolutional neural networks (CNNs), "detection" and "classification" are often synonymous. This is because the main goal is to identify and categorise defects, as knowing the type of defect informs the necessary remedial action. GPS tracks the panel's location, making the exact location of the defect on the panel less critical. IRT highlights temperature variations, and CNNs classify these thermal patterns to determine defect types. Therefore, detection inherently includes classification, ensuring efficient maintenance and repair of the panels.

Table 3
CNN Architectures and classification accuracy in analysed papers

Authors, year	CNN Architecture Used	Classification accuracy score of the best model
Bommes et al. (2021)	ResNet-50	90.91%
Kellil et al. (2023)	VGG-16	99.80%
Hwang et al. (2021)	Custom CNN + XGBoost	99.00%
Manno et al. (2021)	VGG-16	98.00%
Benghanem et al. (2023)	Custom CNN + SVM	94.00%
Mellit (2022)	Custom CNN	95.55%
Fonseca Alves et al. (2021)	Custom CNN	78.85% (for 8 classes)

Source: Authors' work

Table 4

Key Findings, Applications, and Outcomes in Analysed Paper

Study	Key findings	Applications in the PV industry	Practical outcomes of each study
Bommes et al. (2021)	High accuracy in classifying PV module anomalies using ResNet-50 CNN, achieving over 90% test accuracy.	UAV-based thermographic inspection for large-scale PV plants.	Significant reduction in inspection time and costs, improved scalability for multi-gigawatt plants.
Kellil et al. (2023)	High fault detection and diagnosis accuracy using VGG-16 CNN, achieving 99.91% and 99.80%, respectively.	Fault detection and diagnosis in PV modules under diverse environmental conditions.	Enhanced accuracy and reliability in PV module performance, minimised energy production losses.
Hwang et al. (2021)	High detection accuracy with a hybrid scheme combining CNN and XGBoost, achieving better accuracy and low time consumption.	Maintenance of large-scale or remote solar power plants.	Reduced maintenance time and costs, timely replacement of malfunctioning PV cells.
Manno et al. (2021)	High accuracy in fault classification using CNN with various pre-processing techniques, achieving 99% accuracy for UAV-acquired images.	Automatic classification of thermographic images for remote failure detection.	Improved fault detection efficiency, a practical tool for both UAV and ground-based inspections.
Benghane m et al. (2023)	Effective hybrid CNN-ML model for real-time fault diagnosis, optimised and implemented in a microprocessor.	Real-time fault diagnosis of PV modules with a user-friendly interface.	Feasibility of embedded solutions for diverse climatic conditions enhanced PV module analysis and maintenance.
Mellit (2022)	Feasibility of real-time fault detection and diagnosis using DCNN, optimised for low-cost microprocessor deployment.	Embedded systems for real-time fault detection and diagnosis in PV modules.	Cost-effective maintenance solution with acceptable accuracy real-time notifications for PV module state.
Fonseca Alves et al. (2021)	Effective use of CNNs with data augmentation for classifying multiple defect types, achieving 92.5% accuracy for anomaly detection.	Automated fault classification in large-scale PV plants.	Improved inspection efficiency and reduced labour costs, a practical tool for diverse defect classification.

Source: Authors' work

Manual inspection methods are not only time-consuming and labour-intensive but also prone to human error. As highlighted in Table 4, CNNs offer a high degree of accuracy and consistency in defect detection, thereby reducing the likelihood of missed defects and subsequent panel failures. Additionally, the use of unmanned aerial vehicles (UAVs) equipped with infrared cameras can further expedite the inspection process, allowing for the rapid assessment of large PV installations with minimal human intervention. This combination of UAVs and CNNs represents a

significant leap forward in the field of PV panel maintenance, as reflected in the practical outcomes of the reviewed studies.

Moreover, aligning the defect detection capabilities of CNNs with the IEC TS 62446-3:2017 standard is crucial for ensuring consistent and reliable PV panel maintenance across the industry. Table 5 presents the defect types recognised by each study and compares them to the IEC standard, providing a benchmark for evaluating the performance of CNN models. By adhering to these standards, the PV industry can ensure that the inspection methods used are not only effective but also compliant with established guidelines, thereby enhancing the overall reliability and longevity of PV systems.

Table 5
Defect types and comparison to IEC

Study	Defect types classes names	Number of defect classes recognised	Defect classes comparable to IEC standard (IEC, 2020)
Bommes et al. (2021)	Module open-circuit, module short-circuit, substring open-circuit, substring short-circuit, module PID, multiple hot cells, single hot cell, warm cell(s), diode overheated, hot spot	10	6/9
Kellil et al. (2023)	Bypass diode failure, shading effect, short-circuit, dust deposit, partially covered PV module	5	3/9
Hwang et al. (2021)	Hot spots, PID, open circuits	3	1/9
Manno et al. (2021)	Hotspot	1	0/9
Benghane m et al. (2023)	Covered PV module, cracked PV module, degradation, diode overheating, dirty PV module, sand accumulation, short-circuited PV module	7	4/9
Mellit (2022)	Partial shading effect, dust deposit on PV module surface, short-circuited PV module, bypass diode failure	4	3/9
Fonseca Alves et al. (2021)	Cell, cell-Multi, cracking, hotspot, hot-spot-multi, shadowing, diode, diode-multi, vegetation, soiling, offline module	11	6/9

Source: Authors' work

The results from the reviewed studies indicate that no single research comprehensively covered all the IEC classes for PV panel defects. However, by combining the defect classes identified in different studies, it is possible to cover all IEC-determined classes, suggesting a potential for developing a model in line with the IEC standard. Most of the reviewed models, except the one by Fonseca Alves et al. (2021), achieved accuracies above 90%, showcasing the efficacy of CNNs in PV panel defect detection. This high accuracy rate suggests that CNNs can potentially surpass human capabilities in detecting PV panel defects, aligning well with the research questions on the feasibility of CNNs in maintaining PV system reliability and efficiency by identifying defect patterns as per IEC standards and surpassing the human eye in detection rate.

The reviewed studies highlight several economic benefits. The economic benefits of using CNN-based defect detection methods in PV panels are substantial. The key advantages include significant reductions in maintenance and inspection costs, increased accuracy in defect detection, and consequentially minimised energy production losses. The use of UAVs combined with CNNs allows for rapid and precise inspections, particularly in large-scale installations, further reducing costs associated with manual labour. The adoption of low-cost microprocessors for real-time fault detection and diagnosis also contributes to overall cost savings, making these advanced technological solutions both efficient and economical for the PV industry. Table 6 summarises these benefits in the 7 papers reviewed.

Table 6

Summary of economic benefits pinpointed in articles

Study	Economic Benefits
Bommes et al. (2021)	Significant reduction in maintenance costs and improvement in PV system reliability through rapid data acquisition and accurate fault detection using UAVs.
Kellil et al. (2023)	Enhanced accuracy of fault detection leads to minimised energy production losses and reduced costs associated with manual inspections and maintenance.
Hwang et al. (2021)	High detection accuracy and efficiency, especially in large-scale or remote solar power plants, resulting in reduced maintenance time and costs.
Manno et al. (2021)	Significant efficiency gains and cost reductions in maintenance processes through rapid and precise inspection using UAVs.
Benghanem et al. (2023)	Reduced operational costs through effective fault diagnosis under various environmental conditions, ensuring optimal performance of PV modules.
Mellit (2022)	Cost savings through the use of a low-cost microprocessor for real-time fault detection and diagnosis, reducing the need for extensive human intervention.
Fonseca Alves et al. (2021)	Economic benefits from automated classification of defects, though less accurate than other models, still provide substantial improvements over manual inspection methods, reducing labour costs and increasing inspection efficiency.

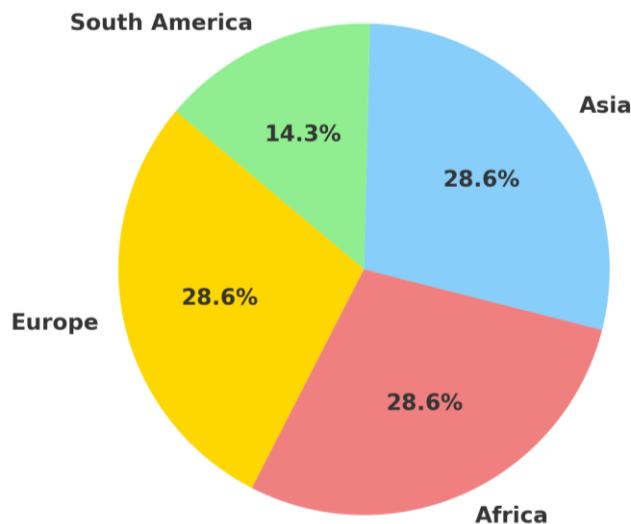
Source: Authors' work

The global nature of the reviewed studies is evident from the wide range of authors' home countries, which include Germany, Algeria, Taiwan, Italy, Saudi Arabia, and Brazil. This geographical diversity is crucial for ensuring that the findings and methodologies are robust and applicable across different climatic and environmental conditions. Research conducted across various continents helps mitigate biases that may arise from studying PV panel defect detection in a single environmental context. Different regions present unique climatic and operational challenges that can affect the performance and reliability of CNN models. For example, studies from Algeria and Saudi Arabia provide insights into PV panel defect detection under harsh desert climates, while research from Germany and Italy offers perspectives from more temperate climates.

Additionally, incorporating data from multiple continents strengthens the generalizability and applicability of the research findings. The varied climatic conditions and operational settings represented in the studies contribute to developing universally applicable CNN models for PV panel defect detection,

enhancing their reliability and effectiveness worldwide. The distribution of reviewed studies across different continents is illustrated in Figure 2. By presenting these visualisations and analyses, we emphasise the global scope and relevance of the reviewed research, providing a strong foundation for the broader applicability of the findings. This comprehensive approach ensures that the inspection methods developed are not only technically sound but also environmentally resilient, catering to the diverse needs of the global solar energy industry.

Figure 2
Distribution of Studies by Continent



Source: Authors' work

The importance of this geographical diversity cannot be overstated. Research conducted across various continents helps mitigate biases that may arise from studying PV panel defect detection in a single environmental context. Different regions present unique climatic and operational challenges that can affect the performance and reliability of CNN models. For example, studies from Algeria and Saudi Arabia provide insights into PV panel defect detection under harsh desert climates, while research from Germany and Italy offers perspectives from more temperate climates. This diversity ensures that the findings and methodologies are robust and applicable across a wide range of environmental conditions.

Additionally, incorporating data from multiple continents strengthens the generalizability and applicability of the research findings. It highlights the widespread interest and relevance of CNN-based defect detection methods in the global push for more efficient and reliable solar energy systems. The varied climatic conditions and operational settings represented in the studies contribute to developing universally applicable CNN models for PV panel defect detection, enhancing their reliability and effectiveness worldwide.

Conclusion and discussion

Summary of research

This research has successfully addressed the primary research questions, providing substantial insights into the application of convolutional neural networks (CNNs) for defect detection in photovoltaic (PV) panels using infrared (IR) thermography. The

analysis of seven key studies reveals significant advancements in automated PV system inspection and maintenance technologies, demonstrating that CNNs can effectively identify various defect types in PV modules, thus enhancing maintenance and operational efficiency.

Can CNNs identify all defect patterns proposed in the IEC standard? The first hypothesis suggested that CNNs could accurately identify all defect patterns listed in the IEC TS 62446-3:2017 standard. Reviewed studies demonstrated high accuracy rates above 90% for several defect classes, supporting this claim partially. However, no single study covered all the IEC-defined defect types comprehensively. This indicates that while CNNs are effective, further refinement is needed to align with the IEC standard fully. Combining the defect classes identified across different studies suggests the potential for developing a comprehensive model in line with the IEC standard.

Can CNNs achieve an acceptable detection rate, effectively replacing human inspection and speeding up the process, thereby providing economic benefits? It was proposed that CNNs could achieve a detection rate that meets or exceeds the accuracy of human inspectors. The high accuracy rates achieved by most reviewed models (above 90%) showcase the efficacy of CNNs in defect detection, suggesting that CNNs can surpass human capabilities in detecting PV panel defects. Combining that with the high inference times of humans answers our question. Models can classify hundreds of pictures in a matter of seconds, while humans need hours for manual inspection of a hundred images. The economic benefits of using CNN-based defect detection methods in PV panels are substantial. The key advantages include significant reductions in maintenance and inspection costs, increased accuracy in defect detection, and minimised energy production losses. The use of UAVs combined with CNNs allows for rapid and precise inspections, particularly in large-scale installations, further reducing costs associated with manual labour. Studies reviewed highlighted substantial reductions in inspection times, especially when UAVs were used, and significant cost savings compared to manual inspections. This efficiency gain confirms the predicted economic benefits. However, further research is needed to quantify these benefits across different scales of PV installations.

Theoretical Contributions

This review paper makes several theoretical contributions to the field of solar energy and photovoltaic (PV) system maintenance through the application of convolutional neural networks (CNNs).

Firstly, it offers a comprehensive analysis of CNN effectiveness by synthesising existing research on the application of CNNs for defect detection in PV panels. The review provides a thorough understanding of how well these networks perform in identifying various defects according to IEC standards. By critically evaluating different CNN models' performance metrics, the paper highlights their strengths and limitations, offering valuable insights into their practical applications. For instance, models like ResNet-50 and VGG-16 have demonstrated high accuracy rates in defect detection, showcasing the potential of CNNs in this domain.

Secondly, the paper evaluates the economic and operational benefits of adopting CNN-based defect detection in the PV industry. It discusses cost savings, reduced inspection times, and the elimination of human error, providing a theoretical framework for understanding the broader impact of CNN technology on the sustainability and scalability of solar energy systems. This analysis offers a new perspective on the economic implications of technological advancements in the PV

sector, highlighting how CNNs can reduce maintenance costs and enhance the reliability of PV systems.

Thirdly, by aligning the defect detection capabilities of CNNs with the IEC TS 62446-3:2017 standard, the review bridges the gap between advanced technological solutions and industry requirements. This alignment offers a theoretical basis for standardising the use of CNNs in PV panel maintenance, promoting consistency and reliability across the industry. Such a connection between technology and industry standards is critical for the practical implementation of new inspection methods, ensuring that CNN-based solutions are widely adopted and trusted within the PV industry.

Lastly, these theoretical contributions aim to advance the understanding of how CNNs can revolutionise the inspection and maintenance of photovoltaic systems, supporting the sustainable growth of solar energy on a global scale. By providing a thorough and critical examination of the existing research, this review serves as a valuable resource for researchers, industry professionals, and policymakers in the field of renewable energy. It underscores the potential of CNNs to enhance the efficiency, accuracy, and economic viability of solar energy systems, thereby contributing to their sustainable expansion and reliability.

The application of convolutional neural networks in photovoltaic panel defect detection represents a significant technological advancement with substantial theoretical and practical implications. This review highlights the effectiveness, economic benefits, and alignment with industry standards of CNN-based defect detection methods, offering valuable insights for future research and practical implementation in the PV industry.

Concluding remarks

This review paper makes several contributions to the field of photovoltaic (PV) system maintenance and solar energy sustainability through the application of convolutional neural networks (CNNs). By synthesising existing research, this study provides a comprehensive understanding of the efficacy, economic benefits, and practical applications of CNNs in detecting defects in PV panels.

The review partially supports the first hypothesis, indicating that CNNs are highly accurate in identifying many IEC-defined defect patterns, though not all. Future work should aim to develop more comprehensive models that cover all defect types specified by the IEC standard to ensure complete alignment.

The paper concludes that CNNs are highly effective in identifying various defect types in PV panels, often surpassing traditional inspection methods in accuracy and efficiency and strongly supporting our second hypothesis. Models such as ResNet-50 and VGG-16 have demonstrated significant potential in real-world applications, achieving high accuracy rates in defect detection. This finding underscores the viability of CNN-based approaches in enhancing the reliability and longevity of PV systems.

Secondly, the review highlights the substantial economic benefits associated with adopting CNN-based defect detection methods. The integration of UAVs and CNNs not only reduces inspection times and costs but also minimises human error, leading to more reliable maintenance processes. All of this validates our third hypothesis. These economic advantages are crucial for the sustainable growth of the solar energy sector, making advanced inspection technologies more accessible and cost-effective.

This study has demonstrated the significant potential of CNNs in enhancing PV panel maintenance, particularly when integrated with open-source software solutions

and guided by CSR principles. The broader trend of data-driven technologies transforming industry processes aligns with the findings of this review, highlighting the growing importance of industrial informatics. The accessibility and economic viability of adopting advanced technologies like CNNs, especially within the framework of Industry 4.0, are underscored by the emphasis on predictive maintenance and the use of open-source tools. All the CNN architectures discussed in this review, along with other algorithms like XGBoost, are open source, making them readily accessible for implementation without the high costs associated with proprietary software. This availability allows for widespread adoption of these advanced techniques, even by smaller enterprises, contributing to the democratisation of technology in industrial applications.

Furthermore, the strategic integration of CSR into technological innovations reinforces the importance of responsible practices in achieving sustainable business operations. By aligning CNN applications with CSR, businesses can enhance their operational efficiency while also contributing to broader sustainability goals. This review suggests that the convergence of artificial neural networks, open-source software, and CSR can lead to more resilient and sustainable energy systems, paving the way for future advancements in the industry.

In reflecting on these contributions, this study emphasises the need for continued research and development in CNN technologies to further improve their performance and integration with industry standards. Future research should focus on optimising CNN architectures and exploring new applications to ensure that PV systems can operate at their peak efficiency, supporting the global transition to renewable energy.

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Simulation and Optimisation of Business Process Management: Case Study of IT Company

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Abstract

Background: In managing business processes of complex hierarchical systems, primary attention is given to analysing, accelerating, and optimising the basic processes typical for any company. **Objectives:** The goal of this work is to prove that while managing business processes, it is crucial to consider the peculiarities of the external and internal environment to determine the effects of individual triggers. **Method:** An example of business process analysis was provided regarding the peculiarities of managing IT service companies operating in a dynamic environment of rapid technological changes. The business processes analysis of IT service companies in Ukraine was conducted. Business process groups characterised by low use of labour and financial resources and excessive and high levels of risk management were determined. **Results:** An algorithm for optimising the IT company's business processes was developed. Simulation and optimisation models for managing IT company business processes were developed using scenario modelling and simulation techniques. **Conclusion:** Based on these models, a predictive evaluation of management impacts on business processes was conducted, representing individual clusters according to defined management strategies.

Keywords: business process; cluster; management simulation model; business process activities

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Introduction

The article studies the peculiarities of modern concepts and ideas regarding managing the development of complex systems. These represent a complete object consisting of functionally diverse but connected by functional subordination to achieve the set goals. Similar management objectives are widespread at this stage of the development of economic systems. These can be corporations, multidisciplinary enterprises, and even organisations that provide regional interaction within one country.

The needs of the modern dynamic market require reviewing the life cycle of products and services while maintaining the quality of the final product (Stark, 2022). That causes a contradiction in the management of the company's development because it forces the companies to make radical changes to the strategic development plans of enterprises (Kopei et al., 2023). The management concept relies on the company management paradigm as a framework, which can be adapted, in this case, to meet the specific needs of project management in response to changing circumstances (Soleymani, 2020). Nevertheless, the newer information, knowledge and skills become available to the enterprise, the more demands society has for the final product, and vice versa. Such a situation begins to make adjustments to management processes, and an unchanged management paradigm, i.e., the use of old methods and models in new fast-moving conditions, can lead not only to a significant lag in competition but also to the complete collapse of the business.

Most modern organisations are hierarchical systems operating in conditions where information is the central resource, and the economy has a network structure. The organisation's external environment acts as a broadcaster of information that has a targeted impact on forming the final product. It orients the organisation to change or improve its management structure into a group of interconnected blocks that aim to implement a single strategy in modern informatisation conditions (Webler, 2022). On the one hand, such "blocks" are easier to manage and have sufficient flexibility. On the other hand, this causes additional informational noise, which can hinder the timely detection of any problematic moment. At the same time, flexibility advantages can become an obstacle in coordinating resources, but they allow single-out individual management processes and exert a targeted influence on them.

The abovementioned is especially typical for companies working in the field of information technologies (IT). The IT industry generally finds it difficult to harmonise with the classical management paradigm based on the rational production organisation to obtain the maximum additional value. The "maintenance-development" cycle does not coincide with the life cycle of IT companies' products and services since they are oriented to the "innovation-development" cycle. In this case, the "maintenance" step is replaced by an innovative step, which does not simply save the work result but updates it and brings it to the level of obtaining a new version or a significantly new product according to the efficiency criterion (Guo et al., 2020). Each step is a separate business process (BP) (Mahdiraji et al., 2020) because the product is being refined and value is added.

An essential ability of modern organisations is a flexible and effective response to unexpected events (Röglinger et al., 2022). Critical events can be caused by a lack of resources, including financial (Goel et al., 2021) or human (Lee et al., 2019), which in turn can be caused by an incorrect distribution or sales management approach (Kajba et al., 2022). Researching this aspect in the example of IT companies in China (Illumdeen, 2022) revealed a positive and significant relationship between marketing turbulence, flexibility and innovation potential. Technology innovations can soften the impact of marketing turbulence by changing how companies' function. This shift often

requires companies to focus on product promotion and sales to drive innovation.

The above can be studied as an example of a modern direction in IT service companies as blockchain platforms. For example, the Ethereum and Caterpillar platforms allow individuals to handle their business processes independently without relying on a central authority for transactions. Such functions are basic blocks for performing joint business processes between the parties. A blend of trusted Business Process Management Systems (BPMS) that rely on the widely used Business Process Model and Notation (BPMN) standard is utilised to minimise errors, which in turn increase organisational performance (Suša Vugec et al., 2020; Slavec et al., 2023; Dwivedi et al., 2021). This approach enables the creation of convenient abstractions, which, in turn, facilitates the quick development of process-oriented software programs (López-Pintado et al., 2019). Something similar applies to the management processes regarding the Internet of Things (IoT). The IoT-based business model improves overall capabilities but has several challenges regarding the accuracy of business asset information and difficulty in requirements analysis. All this leads to the need to manage a large volume of data. It is common practice to break down extensive processes into smaller sub-processes to increase efficiency and prioritise the most critical aspects of a business. This helps to minimise any potential issues that may arise (Shoukry et al., 2021).

The study aims to present the methodological foundations of creating a paradigm for managing the development of an organisation as a complex hierarchical system operating in a rapidly changing external environment.

Throughout the study, we examine the peculiarities of structural changes in business process management as they undergo optimisation. The given optimisation model allows considering a separate BP through subsidiary processes. On this basis, a simulation modelling method is proposed, which allows considering the future consequences of decision-making at the current moment within the limits of business processes at all levels. The article reveals the necessity of studying the complex properties and business process optimisation of a complex hierarchical system through their detailing. This enables the identification of the optimisation model's variables and their use as controlling influences in managing individual triggers.

The article is structured in the following way. Section 2 provides the aim formalisation, criteria and limitations in managing a complex system, which allows the writing down the structure of each BP according to the function of efficiency and details of business processes in a complex hierarchical system concerning IT service companies, as the object of research. Section 3 presents the simulation results with the development of optimisation model flow charts. Section 4 describes the obtained results and measures that can be offered to companies with a complex hierarchical management system to optimise individual BPs. Section 5 presents the conclusions of the work.

Methods

Formalisation of the aim, criteria, and limitations

A system is a set of means that create a specific structure to achieve a particular goal efficiently. By formalising a complex hierarchical system of organisation according to the above definition, it is possible to operate with three categories: element, relation, and property. The complete specification of these categories will determine the organisation system through its development.

The representation of M elements, the relations between them R , will determine the universe of system properties P :

$$P = M \times R \quad (1)$$

and the Cartesian product

$$S = M \times R \times P \quad (2)$$

Determine the set of objects and their inherent phenomena concerning the complex hierarchical system S . It follows from the expression (2) that a specific complex hierarchical system of the organisation will be uniquely determined only in the case when given subsets of the elements of $M = \{m_1, \dots, m_i\}$, relations between them $R = \{r_1, \dots, r_j\}$ and properties $P = \{p_1, \dots, p_k\}$. At the same time, the specified sets are finite and can be described informatively when the level of detail of the system elements is determined.

A system with properties P can be obtained in development management only if the set S is not empty. That is, for equation (1), the universe of the system will include

$$P \subset M \times R \quad (3)$$

which indicates the existence of such a subset of elements M and relations between them R on which the development of this complex system is possible. A hierarchical system may contain several specified subsets, which indicates a multi-vector paradigm for developing such systems. Nonetheless, the general concepts (1) - (3) enable us to consider this process discretely, by separate vectors.

Mathematical representation of a complex hierarchical system

Consider the set S as a complex hierarchical system consisting of nodes that interact with each other but are, to a certain extent, independent. In the general cycle of goods or services production, they can create delays, change, or recover. In the specified system, some triggers of these processes can occur randomly. Perturbations in such a system are insignificant to a certain extent. The system is deterministic if the parameters are unchanged (Xing et al., 2019). However, disturbances that will lead to a change in parameters can cause not only the stoppage of a separate node but also problems in managing the entire system (Chueshov & Schmalfuß, 2020).

Consider a random process in some system node. Assume that this process occurs in a discrete phase space:

$$\mathcal{E} = \{0, 1, 2, \dots\} \quad (4)$$

A number of time points of the system transition from one state to another is also discrete:

$$T = \{0, 1, 2, \dots\} \quad (5)$$

Consider the process specified at the node through a random variable corresponding to the number of the state where the system is at the moment of time ℓ . Denote through $E_{i\ell}$ the state of this node is summarised because, at the moment of time ℓ the system is in a state of impact i to the specified separate node:

$$E_{i\ell} \propto (\xi_\ell = i) \quad (6)$$

A complete theoretical-probabilistic description of the system evolution control development consists in determining the probability that for arbitrary time sets $\ell_1, \ell_2, \dots, \ell_k$ ($\ell_1 < \ell_2 < \dots < \ell_k$) for separate nodes of the system and the effects on these nodes from the side of the system $i_1, i_2, \dots, i_k$ the occurrence takes place:

$$E_{\ell_1 \ell_2 \dots \ell_k, i_1, i_2, \dots, i_k} = E_{\ell_1 i_1} \cap E_{\ell_2 i_2} \cap \dots \cap E_{\ell_k i_k} = \bigcap_{t=1}^k E_{\ell_t i_t} \quad (7)$$

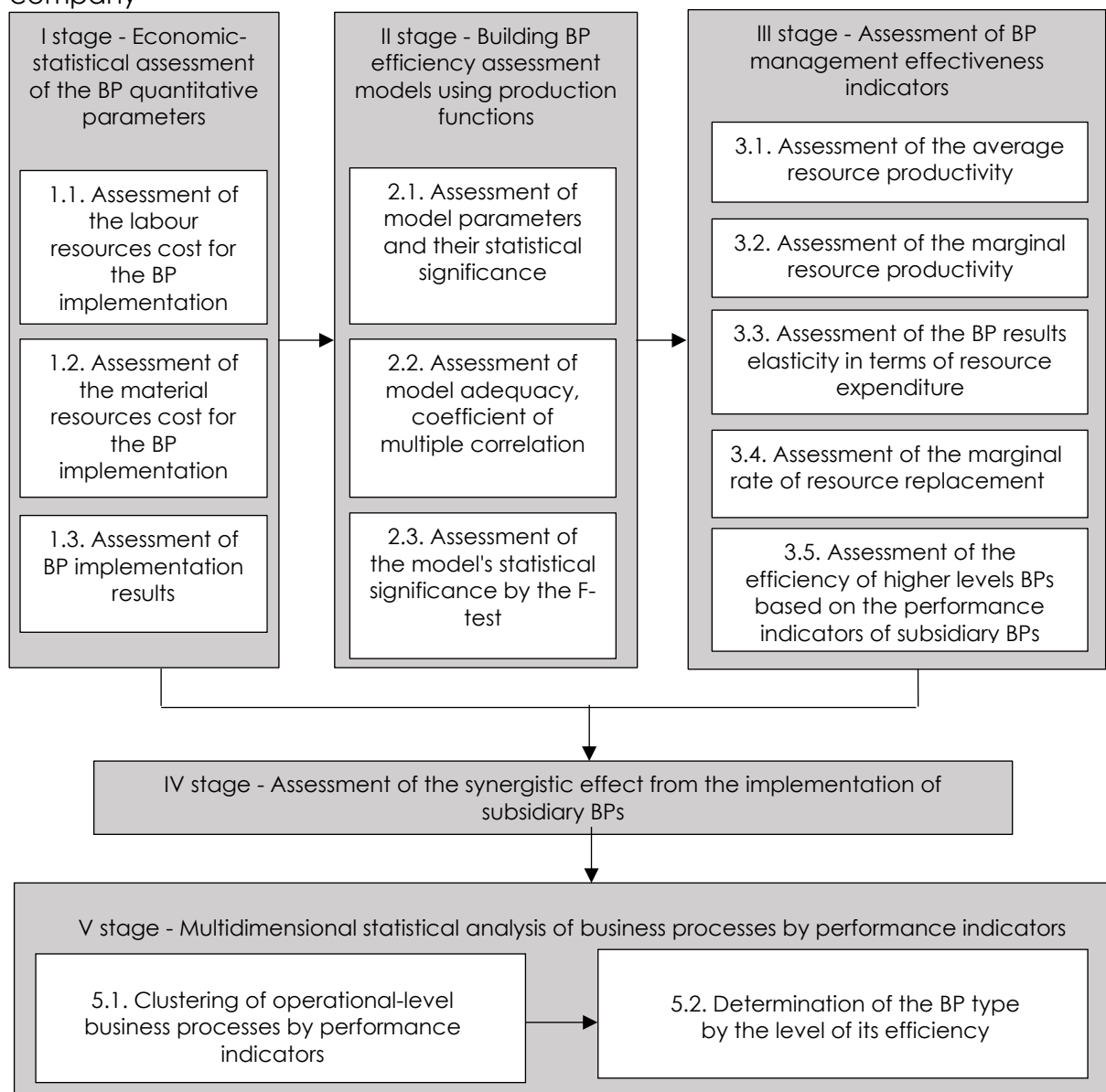
Thus, at a given k moments of time, the S system exerts a specific management influence on separate nodes, which generally forms a paradigm for developing the entire hierarchy of individual organisational elements. The probability of the event (7) can be calculated through the conditional probability system. At the same time, there is a class of random processes for which the necessary description can be obtained more simply. For example, this is a class of Markov-chain probability distribution (Munkhammar & Widén, 2018), which can be considered flexible models of individual business processes with varying management models depending on the situation.

depends on the efficacy of each subsidiary BP. That is, the BPMS centre's effectiveness in the IT service company is determined by considering the effectiveness of all other system elements: the purpose of the BPMS operation is to achieve the maximum level of strategic BP efficiency. Therefore, the effectiveness of the IT service company's entire BPMS begins with the efficacy of the lowest-level activities and business processes. Considering the accepted hierarchical structure of the BPMS, the lowest level of consideration is BP's operational level.

It is proposed that the effectiveness of the operational-level BP be evaluated concerning the amount of labour and material resources spent on the business process. Figure 1 displays the general mechanism for assessing the efficiency of business processes in the IT service company.

Figure 1

Mechanism for assessing the efficiency of business processes in the IT service company



Source: Authors' work

Ten leading IT service companies in Ukraine were reviewed using the specified mechanism (Figure 1) and considering approach (8). According to the State Statistics Service of Ukraine, their list and performance indicators for 2022 are shown in Table 1.

Table 1

List of leading IT service companies in Ukraine

Company name	Net income in 2022, million USD
EPAM Systems	625.0
GlobalLogic Ukraine	356.0
Luxoft Solutions	184.0
Ciklum	149.0
Intellias Institute of Information Technologies	126.0
Infopulse Ukraine	104.0
LOHIKA LTD LLC	93.0
Sigma Software	61.0
Grid Dynamics Ukraine	51.0
Astound Commerce	46.0

Source: According to data from the State Statistical Service of Ukraine (n.d.)

To better understand the impact of business processes and resource allocation for each of the companies mentioned above, one can analyse them using the concept of production function. This helps to establish a clear relationship between input resources and output results (Sickles & Zelenyuk, 2019). Considering the rapidity of technology development in the IT industry, especially in the provision of service services, the Cobb-Douglas production function in the form of J. Tinbergen (Wang et al., 2021) should be chosen as a modelling tool in the study (Wang et al., 2021), which takes into account the impact of technological progress (Biddle, 2020).

Result dependence characterisation of processes and resources for an IT service company

In general, the mathematical model of the Tinbergen production function (Wang et al., 2021) can be represented by the expression:

$$Y = A \cdot e^{\rho \cdot t} \cdot L^{\alpha} \cdot K^{\beta} \quad (12)$$

where:

α, β – output elasticity by factors;

$A \cdot e^{\rho \cdot t}$ – the level of technical progress at $A < 0$;

$\rho > 0$ – means the rate of technological development.

The study used time expenditure (zp) and capital expenditure (zm) as production factors for BP's activities (actions) to build a dependency model. The result factor is the value of the integral assessment of the satisfaction level with the BP e_{ijk}^t results. Considering the above, the research used a general mathematical model for assessing the effectiveness of BP in the following form:

$$e_{ijk}^t = A \cdot e^{\rho \cdot t} \cdot zp^{\alpha} \cdot zm^{\beta} \quad (13)$$

For the study, the effectiveness of BP was assessed using the Statistica software package in the Non-Linear Estimation module for a generalised complex hierarchical system of an IT service company. Table 2 summarises the results of building the obtained mathematical models into production functions.

Table 2

Results of modelling assessment of operational level BP efficiency

BP designation	BPs name	A model for assessing the BP effectiveness	d	R	F	p-value
A1	Marketing					
A1.1	Market research	$e_{11}^t = 0.024 \cdot e^{0.85 \cdot t} \cdot zp_{11}^{0.087} \cdot zm_{11}^{0.891}$	0.77	0.877	964.8	0.0031
A1.2	Lead generation					
A1.2.1	Lead generation via company email	$e_{121}^t = 0.19 \cdot e^{1.13 \cdot t} \cdot zp_{121}^{0.097} \cdot zm_{121}^{0.107}$	0.97	0.985	9666.67	0.00
A1.2.2	Lead generation via conferences	$e_{122}^t = 0.215 \cdot e^{0.93 \cdot t} \cdot zp_{122}^{0.104} \cdot zm_{122}^{0.091}$	0.87	0.933	764.78	0.012
A1.2.3	Lead generation via the website					
A1.2.3.1	Promotion through search engines	$e_{1231}^t = 0.233 \cdot e^{0.83 \cdot t} \cdot zp_{1231}^{0.084} \cdot zm_{1231}^{0.102}$	0.911	0.954	126.23	0.008
A1.2.3.2	Promotion via social networks	$e_{1232}^t = 0.385 \cdot e^{0.5 \cdot t} \cdot zp_{1232}^{0.12} \cdot zm_{1232}^{0.039}$	0.76	0.872	274.7	0.047
A1.2.4	Lead generation through a partner program	$e_{124}^t = 0.27 \cdot e^{0.71 \cdot t} \cdot zp_{124}^{0.14} \cdot zm_{124}^{0.062}$	0.81	0.904	113.82	0.038
A1.3	Increasing brand awareness					
A1.3.1	Content distribution through thematic resources	$e_{131}^t = 0.25 \cdot e^{0.97 \cdot t} \cdot zp_{131}^{0.112} \cdot zm_{131}^{0.07}$	0.788	0.887	347.21	0.005
A1.3.2	Content distribution to leads (potential customers)	$e_{132}^t = 0.097 \cdot e^{0.56 \cdot t} \cdot zp_{132}^{0.082} \cdot zm_{132}^{0.522}$	0.825	0.908	965.83	0.027
A1.3.3	Mailing to existing contacts	$e_{133}^t = 0.47 \cdot e^{0.347 \cdot t} \cdot zp_{133}^{0.21} \cdot zm_{133}^{0.074}$	0.76	0.87	77.6	0.022
A1.4.	Content development	$e_{141}^t = 0.089 \cdot e^{0.745 \cdot t} \cdot zp_{141}^{0.354} \cdot zm_{141}^{0.479}$	0.79	0.889	105.33	0.047
A2	Sales					
A2.1	Customer engagement					
A2.1.1	Customer engagement through a tender	$e_{211}^t = 0.065 \cdot e^{1.03 \cdot t} \cdot zp_{211}^{0.107} \cdot zm_{211}^{0.604}$	0.81	0.9	119.36	0.029
A2.1.2	Customer engagement through open vacancies	$e_{212}^t = 0.128 \cdot e^{0.43 \cdot t} \cdot zp_{212}^{0.04} \cdot zm_{212}^{0.642}$	0.837	0.915	143.78	0.028
A2.2	Contract signing	$e_{22}^t = 0.116 \cdot e^{0.453 \cdot t} \cdot zp_{22}^{0.63} \cdot zm_{22}^{0.17}$	0.78	0.887	99.27	0.047
A2.2.1	Signing a support contract	$e_{221}^t = 0.186 \cdot e^{0.453 \cdot t} \cdot zp_{221}^{0.53} \cdot zm_{221}^{0.24}$	0.91	0.954	283.11	0.019
A2.3	Preparation of the project start	$e_{23}^t = 0.426 \cdot e^{0.16 \cdot t} \cdot zp_{23}^{0.24} \cdot zm_{23}^{0.23}$	0.94	0.97	438.67	0.009
A3	Negotiations					
A3.1	Pre-Sale	$e_{31}^t = 0.355 \cdot e^{0.312 \cdot t} \cdot zp_{31}^{0.48} \cdot zm_{31}^{0.123}$	0.74	0.86	79.69	0.048
A3.2	Elaboration phase	$e_{32}^t = 0.274 \cdot e^{0.184 \cdot t} \cdot zp_{32}^{0.19} \cdot zm_{32}^{0.25}$	0.757	0.87	87.22	0.042
A3.3	Upsales	$e_{33}^t = 0.155 \cdot e^{0.113 \cdot t} \cdot zp_{33}^{0.41} \cdot zm_{33}^{0.42}$	0.803	0.896	114.13	0.033
A4	Project implementation					
A4.1	Project development	$e_{41}^t = 0.268 \cdot e^{0.77 \cdot t} \cdot zp_{41}^{0.104} \cdot zm_{41}^{0.094}$	0.92	0.959	322	0.007
A4.2	Monitoring					
A4.2.1	Questionnaire PMO	$e_{421}^t = 0.54 \cdot e^{0.233 \cdot t} \cdot zp_{421}^{0.18} \cdot zm_{421}^{0.054}$	0.72	0.849	61.7	0.049
A4.2.2	Project Statuses	$e_{422}^t = 0.145 \cdot e^{0.253 \cdot t} \cdot zp_{422}^{0.187} \cdot zm_{422}^{0.46}$	0.879	0.943	194.18	0.027
A4.2.3	Status - meeting	$e_{423}^t = 0.179 \cdot e^{0.173 \cdot t} \cdot zp_{423}^{0.23} \cdot zm_{423}^{0.411}$	0.69	0.831	62.32	0.047
A4.2.4	Delivery status-meeting	$e_{424}^t = 0.384 \cdot e^{0.03 \cdot t} \cdot zp_{424}^{0.14} \cdot zm_{424}^{0.2}$	0.71	0.84	68.55	0.042
A4.2.5	Process adjustment	$e_{425}^t = 0.14 \cdot e^{0.57 \cdot t} \cdot zp_{425}^{0.081} \cdot zm_{425}^{0.322}$	0.95	0.975	532.22	0.007
A4.3	Support	$e_{43}^t = 0.486 \cdot e^{0.032 \cdot t} \cdot zp_{43}^{0.18} \cdot zm_{43}^{0.12}$	0.88	0.938	205.33	0.036

Source: Authors' work

High-quality indicators characterise the resulting models. The evaluation criteria are the determination coefficient, the coefficient of multiple correlation, the F-test and its

p -value significance level. The coefficient of determination for the built models exceeds 0.7, characterising a high level of model adequacy. The coefficient of multiple correlation is high and close to 1, which indicates a strong influence of model factors on the resulting indicator. The value of Fisher's criteria in the models is high and exceeds critical levels, which is confirmed by the low level of the p -value criterion. Thus, we can conclude that the built models are of high quality, which makes it possible to use them for further BP optimisation. A simulation modelling approach based on an aggregated model of dynamic processes, characteristic of all reviewed IT service companies, was applied for optimisation.

Results

Basic model

If models (8) – (10) are considered, then within the functional structure, the efficiency function of each BP will have the form:

$$e_{ijk}^t(A_{ijk}^t) = f(zp_{ijk}^t(\bullet), zm_{ijk}^t(\bullet), s_{ijk}^t(\bullet)) \quad (14)$$

where the model (11) can be represented as

$$f(zp_{ijk}^t(\bullet), zm_{ijk}^t(\bullet)) = A \cdot e^{\rho \cdot t} \cdot zp_{ijk}^{\alpha} \cdot zm_{ijk}^{\beta} \quad (15)$$

at which $s_{ijk}^t(A_{ijk}^t)$ – will act as additional financing for a separate business process of the company at the t – time point to increase its efficiency.

Then:

$$\sum_i \sum_j \sum_k s_{ijk}^t(A_{ijk}^t) \leq \Delta_{ZM}^t \quad (16)$$

In this case $\Delta_{ZM}^t = ZM^t - \sum_i \sum_j \sum_k zm_{ijk}^t(A_{ijk}^t) > 0$ – the foundation surplus funds can be directed to additional financing in implementing low-performing subsidiary BPs.

The business processes group efficiency (or the entire system of company business processes) can be calculated as the arithmetic mean of the business processes efficiencies that make it up:

$$E_q = \frac{\sum_{i=1}^{n_q} e_i^t(A_{ijk}^t)}{n_q} \quad (17)$$

where:

q – group number;

n_q – number of BPs of this group.

Moreover, considering the specifics of the IT service companies functioning (Ilmudeen, 2022), concepts (1) – (3) and model (11), the task of the BPMS effective functioning will be to achieve the maximum level of BPMS effectiveness containing N processes:

$$E_N = \frac{\sum_{i=1}^N e_i^t(A_{ijk}^t)}{N} \rightarrow \max \quad (18)$$

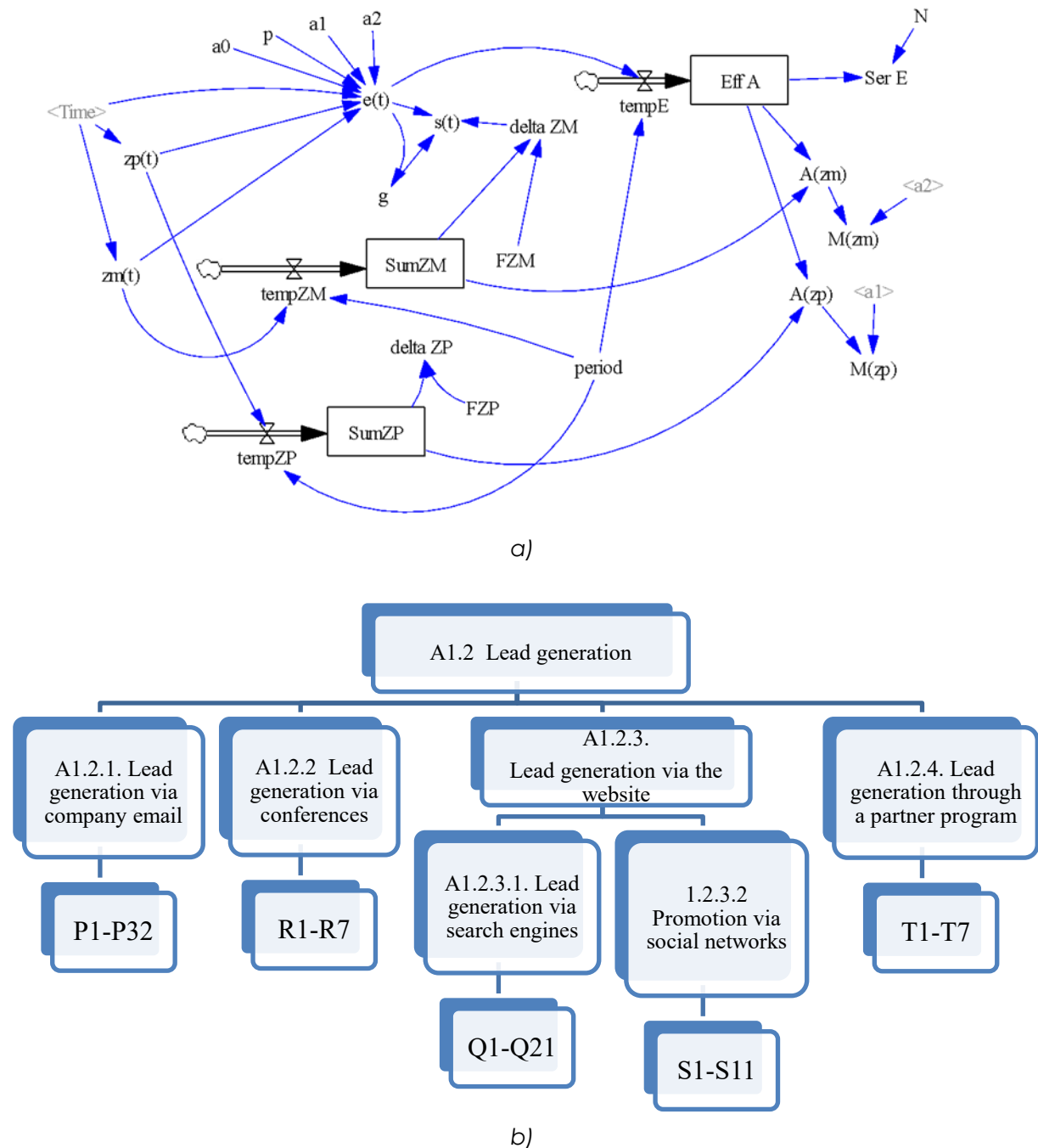
where the constraints system will be represented by labour and financial resources:

$$\begin{aligned} \sum_i \sum_j \sum_k zp_{ijk}^t(A_{ijk}^t) &\leq ZP^t \\ \sum_i \sum_j \sum_k zm_{ijk}^t(A_{ijk}^t) &\leq ZM^t \\ \Delta_{ZM}^t &= ZM^t - \sum_i \sum_j \sum_k zm_{ijk}^t(A_{ijk}^t) \end{aligned}$$

The system dynamics method was used to build the model, following the approach detailed in Palm's work (2021). Considering the correlations (12) - (16) given above, the basic model of an IT company's business process management can be presented as a flow diagram (Figure 2).

Figure 2

Flow diagram of the basic model IT company's business process management (a) and structure of BP "Lead generation" (b)



Source: Authors' work

The head of the Marketing Department (), Operating Director (), Commercial Director (), Researcher (), Analyst (), SEO (Outsourcer) (), and Sales Manager (USA) () perform BP activities.

The presented model included several variables reflecting the peculiarities of BP in IT companies (Schweikl & Obermaier, 2020), which are listed in Table 3.

Table 3

Variables of the basic model of IT company business process management

Variable designation	Variable type	Variable name	Calculation method/formula
Time	Time component	Moment of time	One month with a daily saving of results
zp(t)	Controlled variable	Time spent on the activity	Depends on activity, output data
zm(t)	Controlled variable	Current expenditure of funds for performance of activity per unit of time	It depends on the qualification of the activity performer
a0	Constant	Parameters of the Activity Efficiency Evaluation Model	Defined for each BP
p	Constant		
a1	Constant		
a2	Constant		
e(t)	Computed variable	activity effectiveness	Determined by the formula (13)
s(t)	Computed variable	additional financing of the activity at t -time to increase its efficiency	$s(t) = \Delta ZM \cdot g$
g	Controlled variable	the share of funds of the saved fund, which must be directed to increase the efficiency of the business process	It depends on the BP efficiency level and its priority
SumZP	Level	The total time spent on performing process activities	TempZM amount for the entire period
SumZM	Level	The total cost of financial resources for the performing process activities	TempZM amount for the entire period
tempZM	The tempo of filling the level	Expenditure of funds for activity at the current moment	Is equal to the current expenditure of funds per unit of time $zm(t)$
tempZP	The tempo of filling the level	Time spent on the activity at the current moment	Is equal to the current time spent on the activity $zp(t)$
EffA	Level	Effectiveness of the entire VR	TempZM amount for the whole period
tempE	The tempo of filling the level	Value of BP efficiency at the current moment	Is equal to the current performance efficiency of the activity $e(t)$
FZP	Controlled variable	The fund of time for the BP implementation	Depends on BP, limitations
delta ZP	Computed variable	Saving time for BP implementation	$\Delta ZP = FZP - SumZP$
FZM	Controlled variable	Fund of financial resources for the BP implementation	Depends on BP, limitations
delta ZM	Computed variable	Fund economy the of financial resources by process	$\Delta ZM = FZM - SumZM$
period	Controlled variable	The periodicity of activity performance	Depends on activity, output data
Ser E	Computed variable	Average efficiency of BP	$Ser E = EffA / N$
A(zp)	Computed variable	The average productivity of the performer's labour unit	$A(zp) = EffA / SumZP$
M(zp)	Computed variable	Marginal productivity of the performer's labour unit	$M(zp) = A(zp) \cdot a1$
A(zm)	Computed variable	Average productivity of financial resources unit	$A(zm) = EffA / SumZM$
M(zm)	Computed variable	Marginal productivity of the performer's labour unit	$M(zm) = A(zm) \cdot a1$
N	Constant	Number of BP activities	Depends on activity, output data

Source: Authors' work

The base model will be expanded according to the number of BP activities chosen by the modelling objects for each BP. A more detailed analysis is carried out for these objects by separating individual resulting clusters.

Business processes for the representation of individual clusters

In analysing ten leading IT service companies of Ukraine, followed by generalisation through a flow chart of the primary business process management model, BP clusters were identified according to resource utilisation efficiency. The processes of these clusters (Table 4) require changes in management methods.

Table 4

Characteristics of BPs requiring optimisation by clusters

BP group name	Designation and name of the BP representative	Type of BP based on cluster analysis results	BP management strategy
Group 2. Customer engagement processes	A3.1 Pre-sale	high-risk capital management business processes (type IV)	Optimisation of financial resources management
Group 5. Project diagnosis and adjustment processes	A4.2.2 Analysis of the Project Status	business processes of sufficient resource utilisation efficiency (type II)	Maintenance of the BP efficiency level
	A4.2.3 Discussion of the project status	high-risk business processes of personnel management (type III)	Financial, moral and ethical stimulation of employees
Group 10. Customer search processes	All subsidiary BPs A1.2 Lead generation	high-risk business processes of resource management (type V)	Optimisation and restructuring of BP

Source: Authors' work

Process detailing by groups has the following characteristics:

- Group 2, which includes customer engagement processes, is also characterised by indicators of resource efficiency use below the average level. Therefore, the need to optimise high-risk capital management processes (type IV) is confirmed, to which the representative process A3.1 "Pre-sale" belongs
- Group 5, which holds the processes of diagnosis and adjustment of the project, is characterised by efficiency indicators that are below the average level for the structure as a whole, and therefore, its processes require optimisations. This group includes two representative processes. The first, A4.2.2, "Analysis of the project status", represents the cluster of business processes with sufficient resource utilisation efficiency (type II). The second, BP A4.2.3 "Discussion of the project status", is characterised by an increased risk of personnel labour management (type III)
- Group 10, which contains the business customer search processes, has significantly lower performance indicators. Thus, the need to optimise the A1.2 "Lead generation" processes of high-risk resource management of type V within the new structure is confirmed.

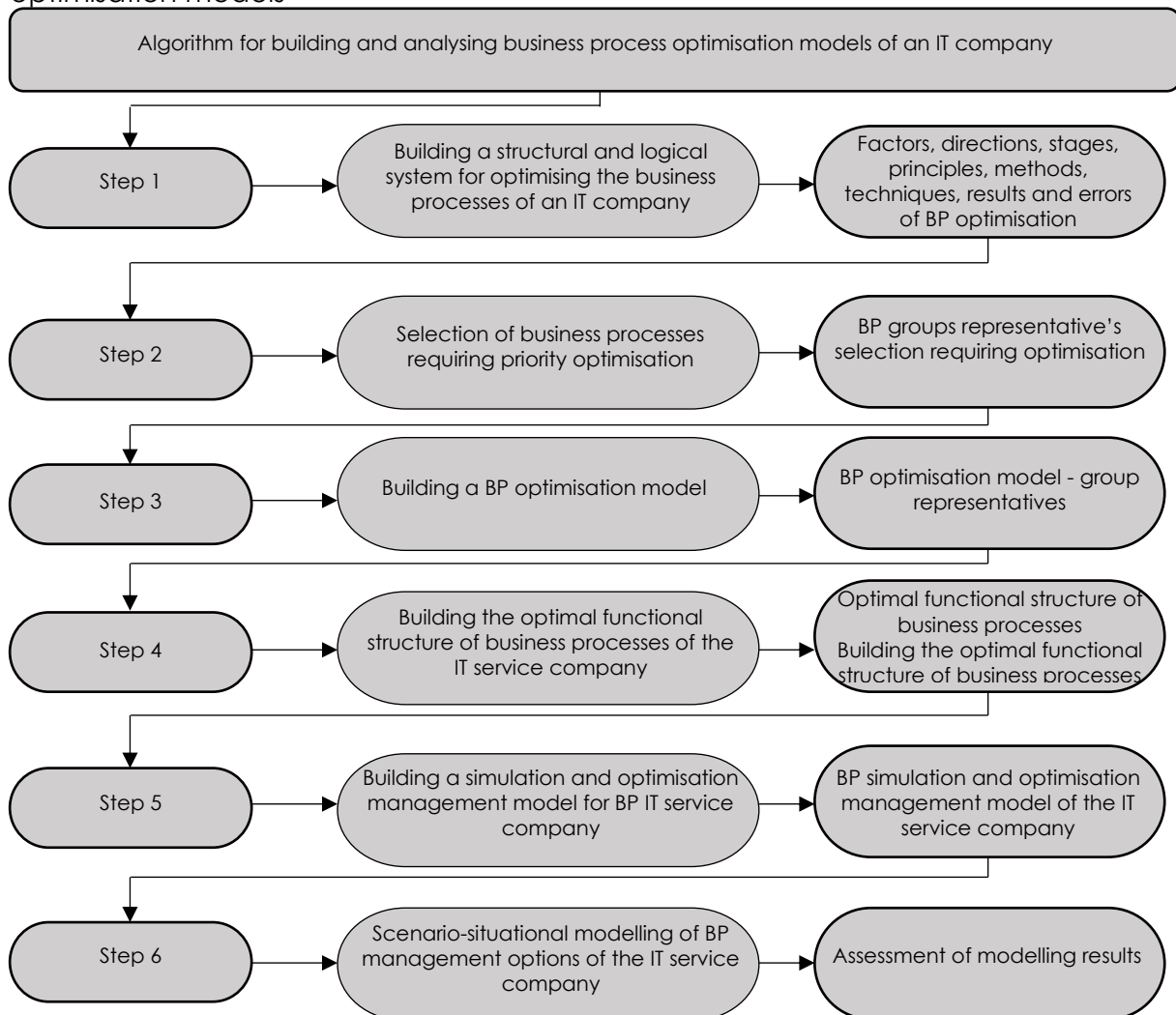
Algorithm for optimisation of IT company's business processes

The defined groups of business processes are characterised by low labour and financial resource use and excessive and high risk in their management. They require BP optimisation and restructuring considering activities, actions, their sequence,

performers, and analysis of financial and information flows to identify redundancy and consider other aspects that directly or indirectly affect the BP implementation. Therefore, based on the activity analysis and features of the BP flow in the researched IT service companies and selected BPs that need optimisation, an algorithm for building and analysing optimisation models of the IT company's business processes was developed (Figure 3).

Figure 3

General algorithm for building and analysing IT company business process optimisation models



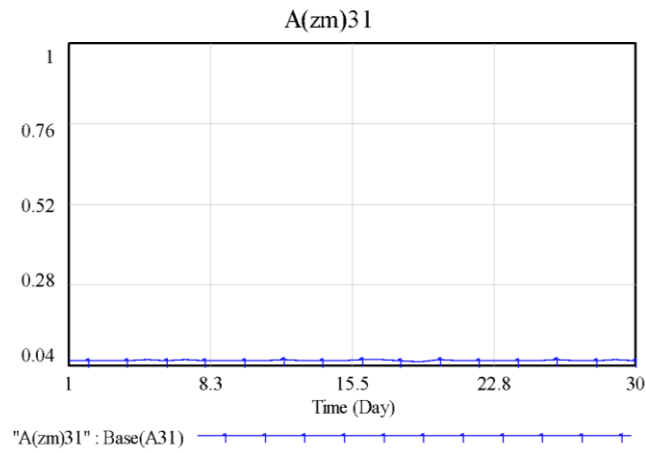
Source: Authors' work

The essence of the given algorithm (Figure 3) is as follows: an analysis is carried out, and a stationary situational model with dynamic feedback on the output vector is built. Implementing the algorithm results in building a BP control model with linear feedback on the state vector. At the same time, a closed system with occurrences of the type (7) receives a BPMS according to model (16), which has a stationary probability distribution of possible control model options for individual BPs, which are representative of clusters where problems are detected.

Implementing a similar algorithm regarding Table 3 confirms the need for further optimisation of BP with high and increased resource management. In particular, the solution will be building simulation and optimisation management models of BP A1.2

Figure 5

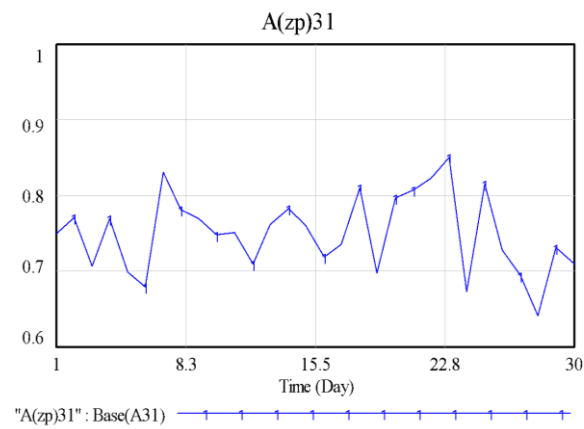
Dynamics of the model values of the financial resources' average productivity by project, unit/conditional units



Source: Authors' work

Figure 6

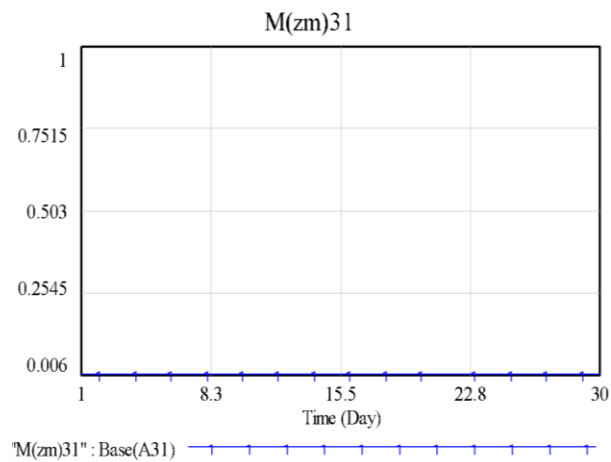
Dynamics of model labour cost values average productivity by project, unit/hour



Source: Authors' work

Figure 7

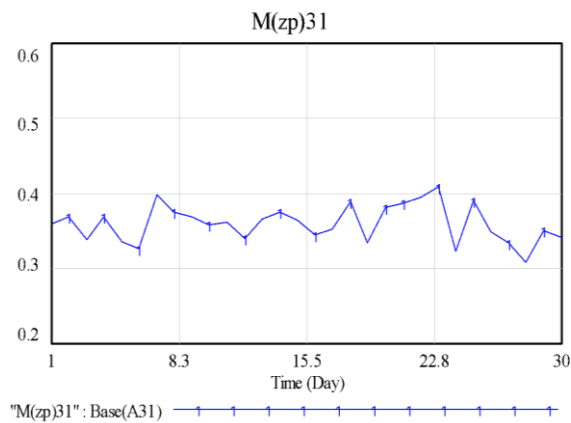
Dynamics of model values of the financial resources' marginal productivity by project, units/conditional units



Source: Authors' work

Figure 8

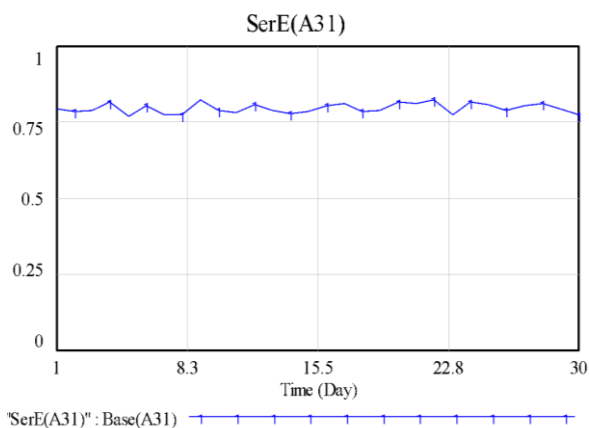
Dynamics of the model values of the financial resources' marginal productivity by project, unit/hour



Source: Authors' work

Figure 9

Dynamics of model values of the efficiency average level of the project A3.1, units



Source: Authors' work

Table 5 presents the assessment of the adequacy of the built simulation model for managing BP A3.1 using indicators of average absolute and average relative modelling error.

Table 5

Assessment of the adequacy of the built simulation model for BP managing A3.1

Indicator	Denotation and obtained model values of the resulting model variables					Average deviation
	A(zp)31	M(zp)31	A(zm)31	M(zm)31	SerE(A31)	
Average model values for the modeling period	0.750	0.360	0.053	0.007	0.795	-
Actual values	0.724	0.348	0.054	0.007	0.79	-
Absolute deviation, units	0.026	-0.012	0.001	0.000	-0.005	0.02
Relative deviation, %	3.52	-3.32	1.06	-6.25	-0.59	-1.12

Source: Authors' work

Thus, the given approach and the developed means of simulation modelling helped predict the results of managerial influences on specific activities of business processes requiring optimisation. The simulation experiments for both business processes were determined as optimal by using the average percentage deviation of the resulting indicators of the built models as a criterion of optimality. These experiments were selected based on their ability to minimise the chosen criterion. The obtained results are shown in Table 6.

Table 6

Results of simulation experiments on business process management A1.2 "Lead generation" and A3.1 "Pre-sale"

Activity designation	Activity characteristics	The purpose of simulating management effects	An experiment with the best results	Predictive value of a variable $e(t)$, %	The average growth rate of the resulting indicators, %	Conclusion about the results of the experiment
A3.1.37	the lowest satisfaction level with the result (60%)	To increase the efficiency of the activity due to the financial stimulation of the performer	Exp(3.1)-3 $g(A3.1.37) \uparrow$ on 15%	72.6	5.55	The goal has been achieved
P11	the lowest satisfaction level with the result (60%)		Exp(A12)-1 $g(P11) \uparrow$ on 5%	62.6	-5.89	The goal was achieved under the condition of excessive additional funding
A3.1.54	the lowest level of resource availability (40%)	To increase the efficiency of the activity by reducing the performing time to increase the performer availability level	Exp(3.1)-4 $zp(t)(A3.1.54) \downarrow$ on 5%	73.8	-0.72	The goal has not been achieved
Q3	the lowest level of resource availability (60%)		Exp(A12)-5 $zp(t)(Q3) \downarrow$ on 10%	74.4	-0.13	The goal has not been achieved
A3.1.57	the lowest level of resource availability (50%) and low satisfaction with the result (70%)	To increase the efficiency of the activity due to the performer's financial stimulation and reduction of the activity performance time to increase the performer availability level	Exp(3.1)-7 $g(A3.1.57) \uparrow$ on 15% $zp(t)(A3.1.57) \downarrow$ on 5%	76.06	2.88	The goal has been achieved
P2	the lowest level of resource availability (40%) and low satisfaction with the result (65%)		Exp(A12)-9 $g(P2) \uparrow$ on 15% $zp(t)(P2) \downarrow$ on 5%	65.37	0.12	The goal was achieved under the condition of excessive additional funding

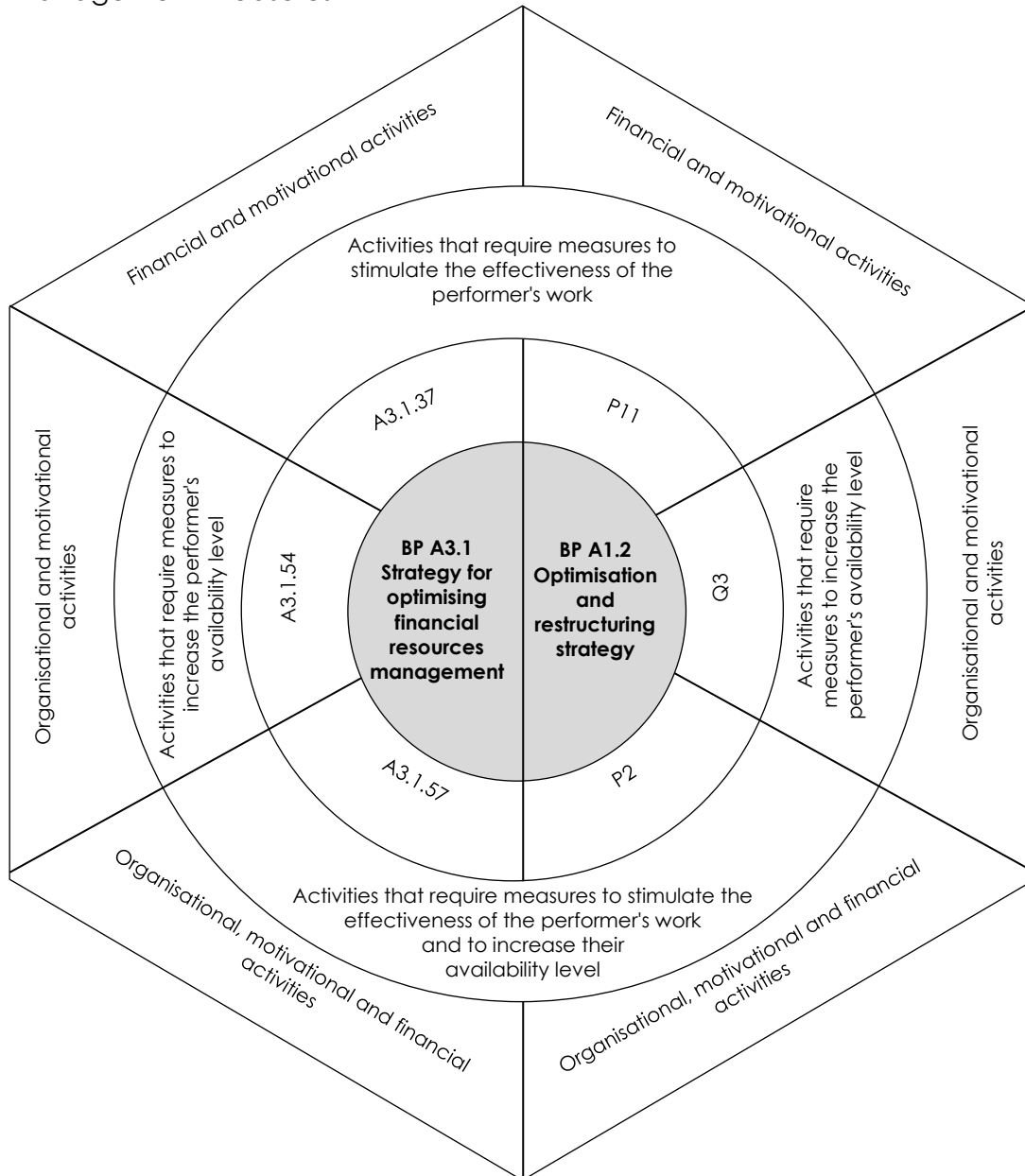
Source: Authors' work

The analysis results of the conducted experiments made it possible to form an optimal subset of management influences for each activity according to its type and the BP optimisation strategy of which it is a part and to build a hexagon to form optimal business process management measures (Figure 10). At the same time, the main emphasis should be placed on improving the strategy of managing financial resources through its optimization and restructuring strategy. It was considered through the prism of optimizing organizational and motivational measures and

increasing the general accessibility level of performers to the relevant BPs necessary for effective management.

Figure 10

Hexagon formation of the IT service company's optimal business process management measures



Source: Authors' work

From the analysis of Table 6 and Figure 10, it can be noted that the simulation experiments, the purpose of which was to reduce the time to perform the activity (A3.1.54 and Q3), did not give positive predictions. That indicates the ineffectiveness of using only moral and psychological encouragement measures to increase the productivity of IT company staff. Predictive evaluations of the solutions proposed for activities P11 and P2 of the business process A1.2 "Lead generation" turned out to be low due to the discrepancy between the growth rates of material incentives and the performer's work, regardless of their position. Predicting the effects on activities A3.1.37 and A3.1.57 gave positive results. The goal of increasing the activity's effectiveness

was achieved, which indicates the reliability and efficiency of the selected management decisions.

Discussion

In the work, the organisation is considered a complex hierarchical system. The basis of the model presented in the paper was the assessment of business processes at different levels. This assessment became the basis for building a hierarchical model with a business process structure. The logical sequence of the assessment is followed: activity (separate for the business process) – business process of the operational level – business process of the tactical level – transition to the business process of the strategic level. That confirms the step-by-step nature of business processes and correlates with the work of Goel et al. (2021). The proven interrelationships between business processes made it possible to build a model of the optimisation mechanism of the company's IT management processes.

The developed model, represented in Figure 4 by the flow diagram of the BP A3.1 management simulation model with the following assessment of adequacy (Table 5), proved the proposed toolkit for managing the development of complex hierarchical systems to have relatively high accuracy. In particular, the given model allows the operation of the business processes of individual functional blocks of the hierarchical system, which is consistent with the conclusions of other researchers (Webler, 2022). However, this model's advantage is precisely the minimisation of information noise since the feedback is carried out according to the state vector, which considers information about the problem cluster.

Such block BP management has an advantage over models (Goel et al., 2021; Lee et al., 2019) when considering critical occurrences associated with the lack of financial resources or critical phenomena in HR management. As confirmed by Figure 10, utilising additional levers on activity, which require measures to stimulate performers' work (A3.1.37 and P11), can reduce the possibility of marketing turbulence. For example, in this case, financial and motivational measures will be optimal, which can include:

- A salary increase is the simplest and most effective way of motivation. It is formed by many factors, such as the enterprise size, the origin of the enterprise's capital, the field of activity, specific knowledge and skills availability, certificates, etc.
- The social package includes health insurance, payment for mobile phone calls, meals, fitness club membership, travel expenses, discounts on the company's goods and services, etc.
- The points accumulation system assigning points to the performer for the period of work in the company for participation in projects and other activities, which are then exchanged for any benefit at their discretion
- The incentives through the choice of equipment for work at their discretion at the company's expense, provided that it then becomes the employee's property.

Nevertheless, analysing the approach (Ilmudeen, 2022) and considering the model (Figure 10), it is necessary to reduce marketing turbulence, namely for IT service companies, to exert some influence on measures to increase the performer's availability level (A3.1.54 and Q3). Organisational and motivational measures will be optimal, including:

- Competent manager - For IT specialists, the leader's professional qualities are of great importance, as is the manager's ability to become an influential motivational factor for employees, especially in the IT industry. The information

technology department is a relatively separate unit; it has its own rules, style of communication, clearly expressed specific interests, etc., so the manager needs to understand this

- Convenient location of the office, the possibility to work at home is a significant factor in reducing the time to complete the task
- Flexible and convenient work schedule - is an important motivating factor for any IT specialist, provides comfort and promotes an individual approach to optimising the employee's working capacity
- IT professionals' team – a way to gain the necessary experience and improve the skills
- Freedom in corporate communication – rejection of standards and regular meetings or brainstorming sessions for all in favour of groups or communities in messengers
- Distribution of tasks according to the employee's qualifications
- Non-financial encouragement of employees (shortened working day, an opportunity to hold a meeting, give a lecture, etc.)
- Promoting the development of time management skills, self-motivation and meeting deadlines among employees.

Considering the proposed management paradigm in terms of efficiency and business importance, as suggested by Shoukry et al. (2021), in addition to the mentioned author, it is possible to emphasise stimulating labour productivity and increasing the performer's availability level (A3.1.57 and P2). In this case, according to the model (Figure 10) and the conducted simulation experiments, organisational, motivational, and financial measures will be optimal:

- Introduction of a changeable bonus component into the salary for projects and non-standard tasks in addition to the mandatory norms
- Social package – payment of specialised IT training, mobile communication, home internet and computer
- Ensuring comfortable conditions at the workplace - the opportunity to have a snack and rest in the office, providing a comfortable microclimate on the premises
- Use of effective work tools (appropriate modern software tools).

When creating a model to optimise an IT company's business processes, it is essential to consider the representatives of BP groups with an increased and excessive resource management risk. This model can determine the optimal number of performers required to ensure the minimum cost of implementation and the necessary level of performance efficiency for the chosen BP activities. Optimising representative processes led to a 3.26% increase in the company's entire BPMS efficiency, which was determined using the econometric models for assessing BP's effectiveness. The obtained simulation calculations were confirmed in practice in a Ukrainian IT service company AltexSoft. For the formed BP groups and the structure as a whole, an efficiency indicator was assessed based on the results of building econometric models, which showed an average increase in BP efficiency by 6%. The advantages of the BP's newly formed functional structure are:

- The implementation of a close connection between the BP of the highest management level and the BP that implements functional management
- Increasing the importance of functional managers
- Reducing the need for performers of a comprehensive profile
- Decreasing the time between decision-making and implementation
- Reducing intermediate links between the manager and the performer solutions

- Lowering the effectiveness dependence of some processes on others due to forming groups united by the type of performed functions.

Conclusions

The work proposed a general algorithm for building and analysing business process optimisation models of the IT company. The study identified groups of business processes that had a significant decrease in the level of utilization of the company's labour and financial resources. Also, these BPs were characterised by a high level of management risk, which had an impact on the management of the company. An IT company's business process management was analysed and optimised using simulation modelling and scenario modelling. That included a predictive assessment of management impacts on business processes to identify the most effective solutions for specific activities within individual clusters based on defined management strategies. The BP's management strategy and specific activity were considered while developing the optimal business process management measures for a service IT company. Based on the obtained results, a hexagon was formulated. It provides a set of measures to choose from, including financial and motivational, organisational, and motivational, or organisational, motivational and financial measures. The results obtained in the study became the basis for the formation of an optimal pool of management influences, considering the type and strategy of BP optimisation for each activity.

The limitation of the presented study is the use of average model values for the simulation period. That relatively generalises the obtained result but simultaneously allows the presentation of the situation in terms of basic processes in relation to any IT company. Thus, the article offers a significant scientific contribution by presenting a comprehensive model that IT companies can utilise to introduce and optimise various BPs. Consequently, critical processes in developing complex hierarchical systems, which arise due to the systemic inconsistency of individual BPs or result from synergistic effects during the optimisation of other BPs, can be promising research on the specified topic.

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The Influence of Consumer Motivation on Engagement with Sports Club Social Media: An Intrinsic and Extrinsic Analysis

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Abstract

Background: Understanding the motivations behind consumer engagement on sports club social media can help clubs and marketers tailor their strategies to better connect with fans, fostering deeper loyalty and more meaningful interactions. By identifying what drives fans to engage—whether it is a genuine love for the brand or the pursuit of rewards—clubs can create more targeted content that not only boosts engagement but also strengthens the overall fan experience and community.

Objectives: This study explores the impact of intrinsic and extrinsic motivation on consumer engagement with sports club social media, utilising the theoretical framework of Uses and Gratifications Theory. **Methods/Approach:** Using structural equation modelling and network analysis, different motivational factors, such as internal and external motivation, were analysed to determine their influence on engagement behaviours. **Results:** The findings reveal that both intrinsic motivations (e.g., personal identity, entertainment, and brand love) and extrinsic motivations (e.g., rewards, empowerment, and social interaction) significantly affect consumer engagement. Intrinsic motivations were strong predictors of high-quality engagement behaviours, including meaningful commenting and active participation in discussions. In contrast, extrinsic motivations, particularly the role of social interaction, were more associated with the frequency of posting and sharing content. **Conclusions:** These results underscore the importance of understanding the diverse motivational drivers behind consumer interactions with sports club social media to enhance fan engagement and loyalty.

Keywords: intrinsic and extrinsic motivations; social media engagement; sports clubs

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Introduction

The role of motivation in shaping consumer behaviour and engagement has been widely explored across various domains, including knowledge transfer within organizations (Gutić Martinčić, 2020), brand promotion in the context of digital transformation (Istrefi-Jahja & Zeqiri, 2021), and social media marketing's influence on purchase intentions in transition economies (Emini & Zeqiri, 2021). Recent studies have also examined how influencer credibility and advertising disclosure impact consumer purchase intentions, particularly among younger generations (Sesar et al., 2022; Sesar et al., 2023). Furthermore, the importance of digital tools and smart technologies in enhancing cultural promotion has been highlighted, emphasizing the need for effective digital strategies in today's marketing landscape (Floričić et al., 2023). The application of brand equity models in higher education marketing has also gained attention, offering insights into the specific challenges of this sector (Vukasović, 2022). Additionally, the intersection of banking quality and reputation in the digital era, particularly through mobile banking, underscores the evolving dynamics of consumer trust and satisfaction (Pejić Bach et al., 2020).

Understanding consumer motivation is essential for marketers aiming to engage their target audience on social media platforms effectively. Emini et al. (2021) emphasises the significance of motivation theory in deciphering consumer behaviours in the digital realm. By delving into the intrinsic and extrinsic factors that drive individuals to interact with sports club social media, this research aims to provide insights into the underlying mechanisms of consumer engagement.

Intrinsic motivation emphasises the inherent value individuals place on certain activities or experiences (Chang et al., 2022). When consumers perceive engagement with sports club social media as fulfilling a personal interest or satisfying a need for connection with like-minded individuals, it reflects intrinsic motivation. On the other hand, extrinsic motivation is driven by external rewards or incentives, such as discounts, prizes, or recognition (Allam et al., 2019). Understanding the interplay between these two types of motivation is crucial for designing effective engagement strategies that resonate with consumers across various functions and activities on social media platforms.

This research seeks to uncover patterns and preferences that influence engagement levels on sports club social media by conducting a comprehensive analysis of consumer motivations. By identifying key drivers of consumer behaviour, marketers can tailor their content, messaging, and promotional efforts to align with the motivations that resonate most strongly with their target audience. Ultimately, this research aims to enhance our understanding of how sports clubs can leverage social media to cultivate meaningful relationships with fans and drive positive outcomes for both the organisation and its supporters.

Theoretical Framework

The theoretical framework for this study draws on three primary theories: motivation theory and uses and gratifications theory. These theories collectively provide a comprehensive understanding of how and why consumers engage with sports club social media, highlighting the roles of intrinsic and extrinsic motivations.

Motivation theory

Motivation theory serves as a foundational framework for understanding human behaviour across various contexts, including consumer engagement on social media platforms. Rooted in psychological principles, motivation theory delves into the

intrinsic and extrinsic factors that drive individuals to take specific actions or pursue certain goals (Le, 2022).

Researchers such as Rode (2016) and Qureshi et al. (2024) have extensively studied these motivational dynamics, highlighting the importance of distinguishing between intrinsic and extrinsic motivations. Intrinsic motivation, characterised by a genuine interest or enjoyment in an activity, is often associated with higher levels of engagement and sustained participation. This intrinsic drive stems from internal factors such as personal satisfaction, curiosity, or a sense of autonomy (Chang et al., 2022). In the realm of sports club social media, individuals may be intrinsically motivated by their passion for the sport, a desire for belongingness within the fan community, or the emotional connection they feel towards the club (Stavros et al., 2014).

Conversely, extrinsic motivation relies on external incentives or rewards to prompt action. While extrinsic rewards like discounts, prizes, or social recognition can initially attract attention and spur engagement, their long-term effectiveness may be limited if they do not align with individuals' intrinsic goals and values (Allam et al., 2019). For instance, sports club social media platforms may offer exclusive access to behind-the-scenes content, VIP experiences, or merchandise discounts to incentivise interaction and participation.

Understanding the interplay between intrinsic and extrinsic motivations is crucial for marketers seeking to optimise consumer engagement strategies on social media. By catering to both types of motivation and aligning content and incentives with individuals' underlying desires and preferences, sports clubs can cultivate a vibrant online community, foster deeper connections with fans, and ultimately drive positive outcomes for their brand.

Moreover, insights from motivation theory can guide the development of tailored communication strategies that resonate more effectively with different segments of the fan base (Aichner, 2019). For example, content that highlights personal stories, achievements, and milestones of players and the club can appeal to intrinsically motivated fans (Ferreira et al., 2022). Meanwhile, time-limited offers, contests, and gamified experiences can attract those driven by extrinsic rewards (Machado et al., 2020).

Additionally, understanding these motivational factors can help create more engaging and interactive social media campaigns that capture attention and encourage active participation and loyalty. By leveraging both intrinsic and extrinsic motivational factors, sports clubs can design social media content that not only engages but also retains fan interest, fostering a stronger, more dedicated community. This comprehensive approach not only enhances immediate engagement metrics but also contributes to long-term brand loyalty and advocacy, ultimately translating to increased support and revenue for the club.

Uses and gratifications theory

Uses and gratifications theory (Katz et al., 1973) offers a foundational framework for understanding how individuals actively select media to satisfy specific needs and desires (Santos et al., 2022). This theoretical approach shifts the focus from the effects of media on audiences to the ways in which individuals utilise media to achieve personal objectives.

The theory identifies several key motivations for media use, including information seeking, personal identity formation, social interaction, and entertainment. Recent research applications of uses and gratifications theory in the context of social media have underscored its relevance in elucidating user engagement behaviours (Bailey et al., 2021). For instance, Zhang and Su (2023) have demonstrated that social media

users primarily engage with platforms for purposes such as social interaction, entertainment, information acquisition, and convenience. These motivations are particularly pertinent in the realm of sports club social media, where fans are drawn to real-time updates, opportunities to connect with fellow supporters, and access to exclusive content. Kharmalki, et al. (2020) have extended the uses and gratifications theory to the domain of sports marketing, revealing that fan engagement with sports clubs' social media channels is driven by needs analogous to those identified in broader social media contexts. Their study highlights that fans are particularly motivated to engage with content that enhances their connection to the club, provides valuable and timely information, and facilitates social interactions with other fans.

The interactive nature of social media platforms allows sports clubs to effectively apply the uses and gratifications theory by tailoring content to meet these specific needs. By providing timely and relevant information, sports clubs can keep fans informed and engaged with the latest news, match updates, and behind-the-scenes insights, thereby fulfilling fans' information-seeking needs and reinforcing their loyalty to the club. In the realm of personal identity and self-expression, sports club social media serves as a vital platform for fans to express their affiliation and passion for the team, fostering a sense of identity and belonging (Chang et al., 2022). This aspect is critical in cultivating a dedicated and emotionally invested fan base. Sharing personal stories and fan-generated content and incorporating interactive features such as polls and Q&As can deepen the personal connection between the club and its supporters. Social interaction is further enhanced through the community-building capabilities of social media. Fans can engage with one another, share their experiences, and celebrate the team's successes together, fulfilling their need for social connection (Vieira & Sousa, 2020). Sports clubs can facilitate these interactions by creating discussion spaces, hosting live events, and actively engaging with fans through comments and messages. Entertainment remains a central driver of engagement on sports club social media platforms. By providing a range of entertaining content, such as highlight reels, player interviews, behind-the-scenes footage, and humorous posts, sports clubs can maintain high levels of fan interest and activity.

The role of convenience in fan interaction with sports clubs on social media is also significant. The ease of accessing content, the ability to engage while on the move, and the immediacy of social media updates contribute to its appeal as a preferred medium for many fans. Sports clubs can leverage this by ensuring their content is mobile-friendly, regularly updated, and easily accessible across various platforms (Vale & Fernandes, 2018). In conclusion, the uses and gratifications theory offers a comprehensive framework for understanding and enhancing fan engagement with sports club social media. By addressing the key motivations of information seeking, personal identity, social interaction, and entertainment, sports clubs can create a dynamic and engaging online presence that resonates with their fan base and fosters a strong, loyal community. This theoretical approach not only aids in optimising current engagement strategies but also provides valuable insights for future developments in digital fan interaction.

Consumer engagement

Consumer engagement encompasses a dynamic and multifaceted relationship between customers and brands, extending beyond transactional interactions to include emotional connections, brand loyalty, and advocacy (Santos et al., 2022). At its core, consumer engagement involves ongoing and meaningful interactions across

various touchpoints and channels, where brands seek to connect with consumers, address their needs, and foster long-term relationships.

Central to consumer engagement is the establishment of a strong emotional connection between customers and the brand (Buzeta et al., 2024). This connection is often forged through positive experiences, shared values, and personalised interactions. Brands that successfully evoke positive emotions and resonate with consumers on a deeper level are more likely to cultivate loyalty and sustained engagement (Bailey et al., 2021).

Consumer engagement is closely intertwined with brand loyalty. Engaged consumers exhibit a higher propensity for repeat purchases, show a preference for the brand over competitors, and actively advocate for it within their social circles. Strategies such as loyalty programs, exclusive offers, and personalised rewards can serve to incentivise and reinforce this loyalty, further enhancing engagement (Vieira & Sousa, 2020). Engaged customers often transition into brand advocates, actively promoting the brand and sharing their positive experiences with others. Word-of-mouth recommendations and user-generated content generated by engaged customers significantly influence brand perceptions and attract new customers. Brands can nurture advocacy by fostering a sense of community among their consumers, encouraging interaction, and facilitating opportunities for them to share their experiences (William et al., 2020).

Consumer engagement and social media

Incorporating digital technologies into customer engagement strategies has increased brands' opportunities to engage with their audiences (Schwarz et al., 2022). Social media platforms, customer relationship management (CRM) systems, and data analytics tools allow for highly personalised and timely interactions, enhancing the overall customer experience. These technologies enable brands to gather insights into customer preferences and behaviours, facilitating the development of targeted engagement strategies that resonate more deeply with individual customers.

Moreover, the shift towards a customer-centric approach in business practices underscores the importance of viewing engagement as a continuous process rather than a series of isolated events. This perspective encourages brands to adopt a holistic view of the customer journey, recognising the interconnectedness of various touchpoints and the cumulative impact they have on customer perceptions and loyalty. By maintaining consistent and meaningful engagement across all stages of the customer lifecycle, brands can build stronger, more resilient relationships with their customers (Bailey et al., 2021).

In conclusion, customer engagement is a critical driver of success in today's competitive marketplace, serving as a cornerstone for building enduring relationships with customers, driving business growth, and fostering brand advocacy. By understanding the underlying motivations and behaviours that drive engagement and by leveraging both academic insights and practical tools, brands can create more effective strategies that enhance customer satisfaction, loyalty, and advocacy. This, in turn, contributes to sustained competitive advantage and long-term business success.

Hypothesis development

By integrating motivation theory and uses and gratification theory, we can better understand the multifaceted nature of consumer engagement with sports club social media. Intrinsic and extrinsic motivations drive fans' initial and sustained engagement, while social identity reinforces their connection to the club and other fans. The uses

and gratifications theory helps explain the specific needs and desires that social media fulfils for these consumers.

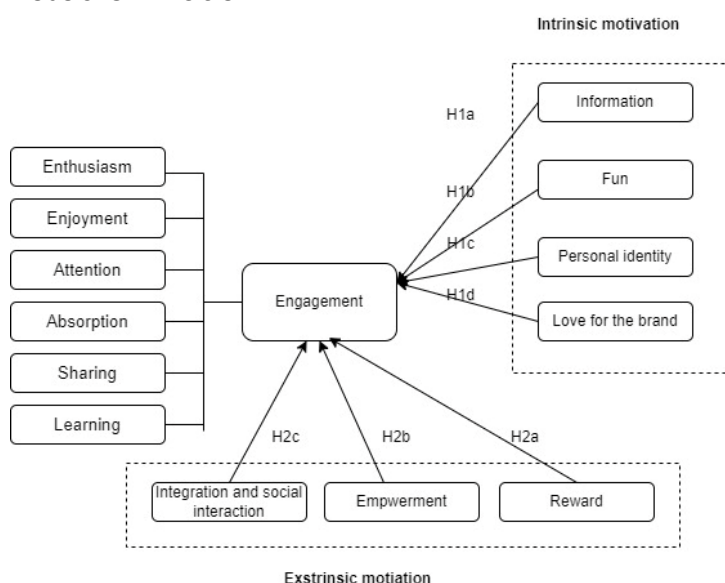
This comprehensive framework allows us to hypothesise that both intrinsic and extrinsic motivations significantly influence consumer engagement with sports club social media. Specifically, it is expected that:

- Intrinsic motivations (e.g., enjoyment, personal identity) will be strongly associated with higher levels of engagement, particularly in terms of active participation and content creation.
- Extrinsic motivations (e.g., rewards, exclusive content) will also positively impact engagement, especially in terms of content consumption and sharing.

This theoretical framework provides the basis for an empirical investigation, as depicted in Figure 1, delving into the motivational factors influencing consumer engagement with sports club social media, leading to the following hypothesis:

- H1. Intrinsic consumer motivation has a positive impact on consumer engagement on the social media of a sports club.
 - H1a. Information as a motivation has a positive impact on consumer engagement on the social media of a sports club
 - H1b. Fun as a motivation has a positive impact on consumer engagement on the social media of a sports club
 - H1c. Personal identity as a motivation has a positive impact on consumer engagement on the social media of a sports club
 - H1d. Love for the brand as a motivation has a positive impact on consumer engagement on the social media of a sports club
- H2. Extrinsic consumer motivation has a positive impact on consumer engagement on the social media of a sports club.
 - H2a. Reward as a motivation has a positive impact on consumer engagement on the social media of a sports club
 - H2b. Empowerment as a motivation has a positive impact on consumer engagement on the social media of a sports club
 - H2c. Integration and social interaction as a motivation have a positive impact on consumer engagement on the social media of a sports club

Figure 1
Research model



Source: Authors' work

Methodology

Sample and Data Collection

Data for this study were collected from a sample of sports club social media users. Participants were asked to complete a survey that measured their motivations for engaging with sports club social media and their levels of engagement. The research sample includes 322 respondents (research participants) who follow sports clubs in the fields of basketball, football, and handball on social networks. Considering the gender of the respondents, the research sample included 52% of male respondents and 48% of female respondents. The largest share of respondents, 67% of them, resides in the City of Zagreb.

Measurement

A motive scale consisting of 15 items to examine intrinsic motivation and 12 items to investigate extrinsic motivation was tested according to the model by Vale and Fernandes (2018) adapted for this research (Table 1). Intrinsic motivation integrates four dimensions: information, entertainment, personal identity, and brand love. Extrinsic motivation contains three dimensions: reward, empowerment, integration, and social interaction (Table 2). Finally, Table 3 presents the engagement motivation research instrument, which was developed based on Dessart, Veloutsou, and Morgan-Thomas (2016). A Likert scale with seven levels (determined by a scale from "1 - strongly disagree" to "7 - strongly agree") was used for measurement.

Table 1

Research instrument for intrinsic motivation

Variable	Code	Research items
Information	INF1	I follow a sports club on social media because I want to know what others think about the sports club.
	INF2	On the sports club's social networks, they can get information about the club's success.
	INF3	They can get information about player profiles on the sports club's social networks.
	INF4	On the sports club's social networks, they can get information about the schedule of the next matches.
	INF5	The information posted on the sports club's social networks helped me form my opinion about the sports club.
Fun	FUN1	I follow the sports club on social networks for fun.
	FUN2	The social network of the sports club is a place to escape from everyday life.
	FUN3	The social network of the sports club arouses my emotions and feelings.
	FUN4	The social network of the sports club relaxes me.
Personal identity	PER1	I follow the sports club's social networks because I want to express my personality.
	PER2	I follow the sports club's social networks because they give me confidence.
	PER3	I follow the sports club's social networks because I want to impress others with my knowledge of the sports club.
Love for the brand	LOV1	I follow the sports club's social networks because I am delighted with the sports club.
	LOV2	I associate the sports club with some important events in my life.
	LOV3	I participate in the sports club's social networks because I care about the sports club.
	LOV4	I identify with the sports club.

Source: Vale and Fernandes (2018)

Table 2

Research instrument for extrinsic motivation

Variable	Code	Research items
Reward	REV1	When I want to buy a ticket for a match, I use the club community on social networks to find a cheaper price and a discount.
	REV2	I am motivated to participate in social sports networks because that way, I can get discounts and prizes.
	REV3	I follow the sports club's social networks because I can get the information I want instantly.
	REV4	I follow the social networks of the sports club because I want to get better service from the club.
Empowerment	EMP1	I follow the sports club's social networks because I want to influence its activities and work.
	EMP2	I follow the sports club's social networks because I want to influence other people.
	EMP3	I feel good when other members of the sports club's social networks share my comments and ideas.
	EMP4	When the members of the sports club's social network comment positively on my post, I am happy to participate in the social network's activities.
Integration and soc. Inter.	INT1	I look forward to discussing and sharing information with other sports club followers on social networks.
	INT2	I follow the sports club's social networks because they make me more connected to the sports club.
	INT3	I follow the sports club's social media because I feel less alone.
	INT4	I follow the sports club's social networks because that is how I feel connected to the sports club.

Source: Vale and Fernandes (2018)

Table 3

Research instrument for engagement

Variable	Code	Research items
Enthusiasm	ENT1	I am delighted with the sports club I follow on social networks.
	ENT2	I am interested in everything related to the sports clubs I follow on social networks.
	ENT3	The sports club I follow on social media is interesting.
Enjoyment	ENJ1	Socialising and interacting with the sports club on social media makes me happy.
	ENJ2	I feel energetic in contact with the sports clubs I follow on social networks.
	ENJ3	Interaction with a sports club on social networks is like a reward for me.
Attention	ATT1	I spend a lot of time thinking about the sports clubs I follow on social media.
	ATT2	I always find time to think about the sports club.
Absorption	ABS1	I forget about everything around me when I interact with a sports club on social media.
	ABS2	Time flies when I interact with a sports club on social media.
	ABS3	I get carried away when I interact with a sports club on social media.
	ABS4	I am reluctant to stop interacting with the sports club on social networks.
Sharing	SHA1	I share my ideas on the sports club's social networks.
	SHA2	I share interesting things on the sports club's social networks.
	SHA3	I help a sports club on social media.

Learning	LEARN1	I ask questions on the sports club's social networks.
	LEARN2	I am looking for ideas or information on the social network of the sports club.
	LEARN3	I am looking for help on the social network of the sports club.
Approval	APP1	I actively support the sports club on the social network.
	APP2	I try to get other people interested in the sports club I support.
	APP3	I actively defend the sports club on the social network against its critics.
	APP4	I say positive things about the sports club to other people.

Source: Dessart, Veloutsou & Morgan-Thomas (2016)

Statistical analysis

The statistical analysis in this paper focused on understanding the relationship between consumer motivations and engagement with sports clubs' social media platforms. A key component of the analysis was the use of network analysis, which provided a visual and quantitative assessment of the structure and density of the relationships among the engagement and motivation variables. This analysis helped identify the most influential factors within the network, revealing that variables like enjoyment and empowerment played central roles in driving engagement, while others like information seeking and rewards were less central.

Structural equation modelling (SEM) was employed to explore these relationships further. Engagement was conceptualised as a second-order latent variable composed of multiple first-order factors such as enthusiasm, enjoyment, attention, absorption, sharing, learning, and active participation. The SEM analysis involved estimating factor loadings to determine how each of these first-order factors contributed to the overall engagement construct. The model's fit was evaluated using several fit indices, including CFI, TLI, RMSEA, and SRMR, all of which indicated an excellent fit to the data. Statistical analysis has been conducted using JASP ver 19.01, deploying lavaan R module for structural equation modelling (Rosseel, 2012).

Results

Descriptive analysis

Table 4 presents the descriptive statistics of the average values of the research items. The descriptive statistics reveal important insights into consumer engagement and motivation on sports club social media. Among the engagement variables, enthusiasm (ENT) and enjoyment (ENJ) stand out with higher mean scores of 4.541 and 4.526, respectively. This indicates that users generally feel a moderate to high level of enthusiasm and enjoyment in their interactions with the sports club's social media. On the other hand, variables such as attention (ATT), absorption (ABS), and sharing (SHA) have lower mean scores of 2.974, 2.840, and 2.794, respectively, suggesting these aspects of engagement are less pronounced among users.

Regarding intrinsic motivation, information seeking (INF) has the highest mean score of 5.429, indicating that users predominantly engage with sports club social media to obtain information. Brand love (LOV) also has a relatively high mean of 4.609, reflecting a strong emotional connection with the sports club. However, personal identity (PER), with a mean of 3.243, suggests that fewer users engage with the intent of expressing their identity.

Extrinsic motivation's mean scores are generally lower than those of intrinsic motivation. Rewards (REV) have a mean of 4.013, indicating that while external incentives like discounts and prizes are motivating, they are less impactful than intrinsic

factors. Empowerment (EMP) and integration and social interaction (INT) have lower mean scores of 3.491 and 3.430, respectively, suggesting these extrinsic motivations play a smaller role in driving user engagement.

Table 4.

Descriptive Statistics	Valid	Mean	Std. Deviation
Engagement			
ENT	322	4.541	1.472
ENJ	322	4.526	1.522
ATT	322	2.974	1.779
ABS	322	2.840	1.722
SHA	322	2.794	1.645
LEARN	322	3.278	1.631
APP	322	3.584	1.677
Intrinsic motivation			
INF	322	5.429	0.967
FUN	322	4.333	1.297
PER	322	3.243	1.562
LOV	322	4.609	1.369
Extrinsic motivation			
REV	322	4.013	1.465
EMP	322	3.491	1.523
INT	322	3.430	1.288

Source: Authors' work

Table 5 presents the correlation analysis of the average variables of engagement and intrinsic and extrinsic motivation. The overall correlation analysis demonstrates a high level of interconnectedness among the various motivational and engagement variables, with most relationships showing statistically significant correlations. This indicates that both intrinsic and extrinsic motivations are closely tied to different aspects of engagement on sports club social media. Correlations are also presented in the heatmap depicted in Figure 1.

Table 5
Correlation analysis

Variable	ENT	ENJ	ATT	ABS	SHA	LEARN	APP	INF	FUN	PER	LOV	REV	EMP	INT
ENT	1.00													
ENJ	0.77	1.00												
ATT	0.63	0.72	1.00											
ABS	0.58	0.65	0.81	1.00										
SHA	0.57	0.59	0.69	0.71	1.00									
LEARN	0.55	0.57	0.61	0.56	0.76	1.00								
APP	0.62	0.64	0.65	0.63	0.76	0.77	1.00							
INF	0.37	0.46	0.23	0.21	0.23	0.21	0.25	1.00						
FUN	0.37	0.52	0.42	0.36	0.34	0.29	0.34	0.44	1.00					
PER	0.46	0.58	0.59	0.54	0.47	0.41	0.46	0.34	0.65	1.00				
LOV	0.66	0.66	0.54	0.48	0.46	0.49	0.56	0.37	0.45	0.52	1.00			
REV	0.44	0.53	0.40	0.41	0.49	0.44	0.42	0.40	0.38	0.47	0.49	1.00		
EMP	0.57	0.62	0.61	0.54	0.63	0.63	0.61	0.29	0.43	0.57	0.61	0.56	1.00	
INT	0.56	0.64	0.55	0.55	0.55	0.47	0.52	0.33	0.51	0.67	0.57	0.54	0.67	1.00

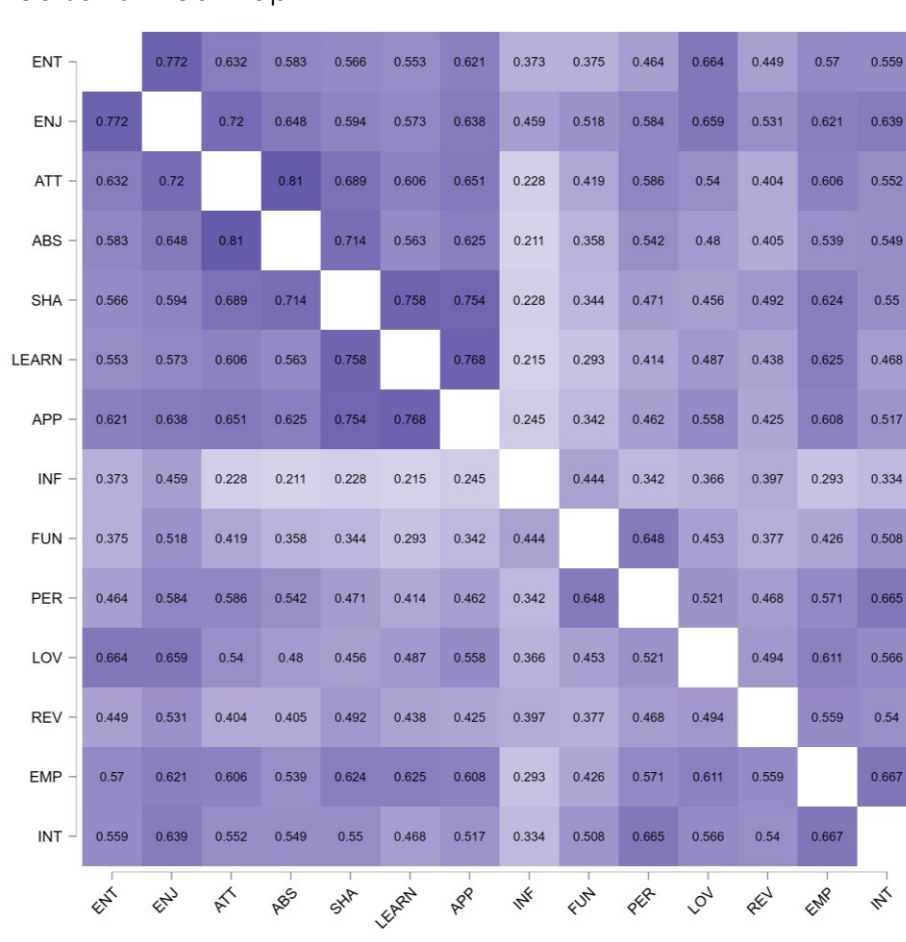
Source: Authors' work

When examining the correlations between the engagement variables from Table 3 and the intrinsic motivation variables from Table 1, several strong relationships emerge. For instance, enthusiasm (ENT) and brand love (LOV) show a strong correlation ($r = 0.664$, $p < .001$), suggesting that intrinsic factors like a deep emotional connection with

the brand significantly enhance engagement behaviours such as enthusiasm. Similarly, enjoyment (ENJ) correlates highly with personal identity (PER) ($r = 0.584$, $p < .001$), indicating that individuals who express their identity through sports clubs tend to enjoy their social media interactions more.

The correlations between the engagement variables from Table 3 and the extrinsic motivation variables from Table 2 reveal moderate to strong relationships. However, they tend to be slightly lower than those with intrinsic motivations. For example, sharing (SHA) correlates with rewards (REV) at $r = 0.492$ ($p < .001$), indicating that external incentives encourage users to share content, though not as strongly as intrinsic motivations. Additionally, absorption (ABS) shows a moderate correlation with empowerment (EMP) ($r = 0.539$, $p < .001$), suggesting that feeling empowered can significantly contribute to deeper engagement, such as getting absorbed in the content.

Figure 1
Pearson's r heatmap



Source: Authors' work

Network analysis

The network analysis summarised in Table 6 provides an overview of the structure and density of the connections among the variables under study. With 14 nodes and 56 non-zero edges out of a possible 91, the network has a sparsity of 0.385. This indicates that while there is a moderate level of connectivity among the variables, a significant portion of potential connections remains unobserved, suggesting that only certain relationships are strongly represented in the data.

Table 6
Summary of network analysis

Number of nodes	Number of non-zero edges	Sparsity
14	56 / 91	0.385

Source: Authors' work

Table 7 presents the centrality measures for each variable, offering insights into their roles within the network. Enjoyment (ENJ) emerges as the most central variable, with the highest closeness (1.758) and strength (2.119) measures, indicating its pivotal role in connecting other variables and exerting a strong influence within the network. Empowerment (EMP) also shows high centrality, particularly in-betweenness (1.596), suggesting it acts as a key bridge between other variables.

Conversely, variables like Information Seeking (INF) and Rewards (REV) exhibit low centrality across multiple measures, including negative strength and expected influence, indicating their relatively peripheral roles in the network. These variables are less connected and exert less influence on other variables. Similarly, Fun (FUN) and Brand Love (LOV) show low centrality, suggesting these motivations, while important, are less integral to the overall structure of engagement in this context.

Overall, the centrality measures suggest that Enjoyment (ENJ) and Empowerment (EMP) are critical drivers within the network, acting as key influencers of engagement. In contrast, extrinsic motivators such as Rewards (REV) and Information Seeking (INF), despite their importance, appear to play more peripheral roles. These insights can guide the focus of engagement strategies, emphasising the importance of enhancing enjoyment and empowerment to foster deeper and more meaningful user engagement.

Table 7
Centrality measures per variable

Variable	Betweenness	Closeness	Strength	Expected influence
ENT	-0.216	0.703	-0.249	-0.126
ENJ	1.394	1.758	2.119	2.072
ATT	0.791	0.827	1.205	0.627
ABS	0.187	0.319	-0.086	-0.113
SHA	-0.014	-0.347	0.773	0.822
LEARN	0.388	-0.137	-0.250	-0.127
APP	-1.222	-0.867	0.269	0.355
INF	-0.417	-0.776	-1.729	-2.234
FUN	-1.222	-1.282	-0.966	-0.791
PER	0.589	-0.099	0.300	0.383
LOV	-1.423	-0.800	-0.498	-0.358
REV	-1.222	-1.526	-1.361	-1.158
EMP	1.596	1.239	0.363	0.442
INT	0.791	0.989	0.109	0.206

Source: Authors' work

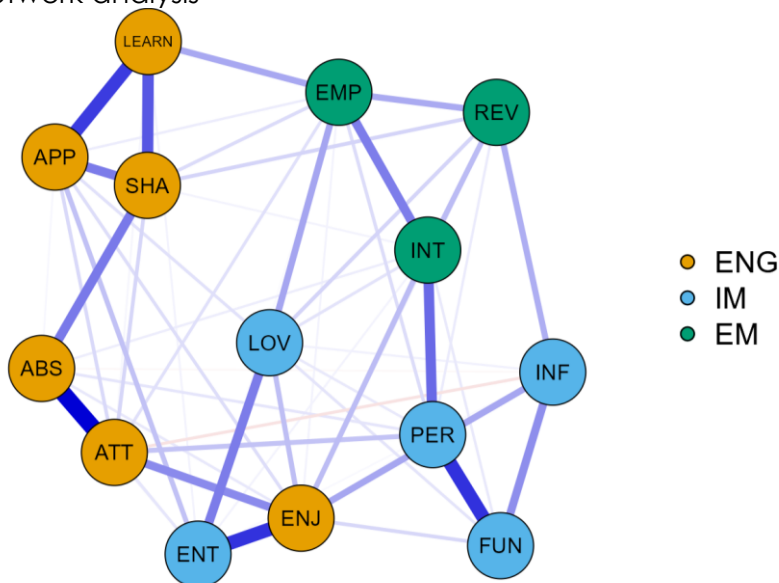
Figure 2 presents the network graph, which illustrates the relationships among engagement (ENG), intrinsic motivation (IM), and extrinsic motivation (EM) variables in the context of sports club social media interactions. The nodes are color-coded: orange for engagement, blue for intrinsic motivation, and green for extrinsic motivation. The thickness of the connecting lines indicates the strength of the correlations.

The graph reveals that engagement variables, particularly active participation (APP), sharing (SHA), and learning (LEARN), are closely interlinked. This suggests that users who actively participate and share content are also likely to engage in learning behaviours on the platform. Similarly, enthusiasm (ENT), enjoyment (ENJ), and absorption (ABS) are strongly connected, indicating that users who are enthusiastic and enjoy the content are also more likely to become absorbed in their social media interactions.

Within the intrinsic motivation group, brand love (LOV) occupies a central position, demonstrating strong connections with both engagement behaviours and other intrinsic motivations, such as personal identity (PER) and fun (FUN). This centrality underscores the pivotal role that emotional attachment and identity-related motivations play in driving user engagement on social media. Extrinsic motivation variables, including rewards (REV), empowerment (EMP), and integration and social interaction (INT), are also connected to both engagement and intrinsic motivation factors. However, these connections are generally weaker, as indicated by the thinner lines, suggesting that while extrinsic motivators are relevant, they exert a less significant influence on engagement compared to intrinsic factors.

Information seeking (INF), a key intrinsic motivation, shows substantial connectivity across the network, linking to both extrinsic and intrinsic motivations. This highlights its critical role in driving user engagement, suggesting that the provision of timely and relevant information is a primary motivator for users.

Figure 2
Network analysis



Note: ENG – Engagement; IM- intrinsic motivation; EM - extrinsic motivation

Source: Authors' work

Structural equation analysis

Structural equation modelling (SEM) was employed to test the hypotheses of the research. In this analysis, Engagement was conceptualised as a second-order latent variable, which is constructed based on the average scores of several first-order constructs. These constructs include Enthusiasm (ENT), Enjoyment (ENJ), Attention (ATT), Absorption (ABS), Sharing (SHA), Learning (LEARN), and Active Participation (APP). Each of these constructs represents a different facet of user engagement with

sports club social media, collectively contributing to the overall measurement of engagement within the SEM framework. The regression equation for testing the hypothesis was formed with the second-order variable ENG, while the independent variables are average scores of variables Information Seeking (INF), Fun (FUN), Personal Identity (PER), Brand Love (LOV), Rewards (REV), Empowerment (EMP), and Integration and Social Interaction (INT). Analysis was conducted using JASP v.19.0.1., and lavaan syntax is presented in Figure 3, while the structure of the models is depicted in Figure 4.

Figure 3

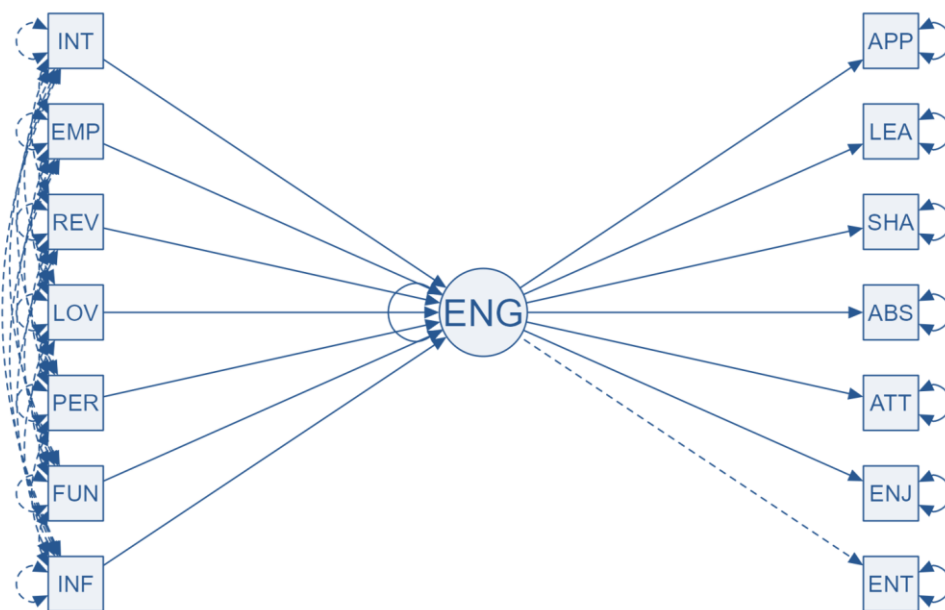
Lavaan syntax

```
#Second-order factor ENG
ENG =~ ENT + ENJ + ATT + ABS + SHA + LEARN + APP
# Regression equation for testing hypothesis
ENG ~ INF + FUN + PER + LOV + REV + EMP + INT
```

Source: Authors' work

Figure 4

Path diagram



Source: Authors' work

The fit indices presented in Table 8 indicate that the structural equation model used in this study exhibits an excellent fit to the data. The Comparative Fit Index (CFI) is reported at 0.995, and the Tucker-Lewis Index (TLI) is at 0.994, both of which are well above the conventional threshold of 0.95, indicating a close fit to the model. The Root Mean Square Error of Approximation (RMSEA) is 0.057, which is below the recommended cut-off of 0.06, suggesting that the model has a good approximation of the population covariance matrix. Similarly, the Standardized Root Mean Square Residual (SRMR) is 0.051, which is also within the acceptable range, indicating that the residuals are minimal. The Goodness of Fit Index (GFI) is extremely high at 0.996, further confirming the model's strong fit to the data.

Table 8
Fit indices

Index	Value
Comparative Fit Index (CFI)	0.995
Tucker-Lewis Index (TLI)	0.994
Root mean square error of approximation (RMSEA)	0.057
Standardised root mean square residual (SRMR)	0.051
Goodness of fit index (GFI)	0.996

Note. T-size CFI is computed for $\alpha = 0.05$. The T-size equivalents of the conventional CFI cut-off values (poor < 0.90 < fair < 0.95 < close) are poor < 0.853 < fair < 0.916 < close for model
Source: Authors' work

Table 9 presents the factor loadings for the second-order latent variable Engagement (ENG), indicating how strongly each of the first-order constructs—Enthusiasm (ENT), Enjoyment (ENJ), Attention (ATT), Absorption (ABS), Sharing (SHA), Learning (LEARN), and Active Participation (APP)—contributes to the overall engagement construct. All the standardised factor loadings are higher than 0.5, indicating a good fit for the second-order latent variable.

Table 9
Factor loadings for the second-order variable engagement (ENG)

Latent	Indicator	Estimate	Std. Error	z-value	p	Standardised
ENG	ENT	1.000	0.000			0.799
	ENJ	1.116	0.037	30.481	< .001	0.893
	ATT	1.047	0.035	29.746	< .001	0.837
	ABS	0.980	0.034	28.938	< .001	0.784
	SHA	1.009	0.034	29.296	< .001	0.806
	LEARN	0.943	0.033	28.444	< .001	0.754
	APP	1.004	0.034	29.234	< .001	0.802

Source: Authors' work

The regression analysis in Table 10 examines the correlation between intrinsic and extrinsic motives and engagement (ENG) with the social media platforms of sports clubs.

Table 10
Regression analysis

Outcome	R-squared	Predictor	Estimate	Std. Error	z-value	p	Stand. Load.	Hypothesis
Intrinsic motivation								
ENG	0.674	INF	0.020	0.032	0.615	0.539	0.024	H1a
		FUN	-0.006	0.027	-0.220	0.826	-0.010	H1b
		PER	0.076	0.025	3.072	0.002**	0.149	H1c ✓ (1%)
		LOV	0.152	0.023	6.736	< .001**	0.261	H1d ✓ (1%)
Extrinsic motivation								
		REV	0.039	0.018	2.144	0.032***	0.072	H2a ✓ (5%)
		EMP	0.181	0.024	7.590	< .001**	0.344	H2b ✓ (1%)
		INT	0.098	0.033	2.955	0.003**	0.158	H2c ✓ (1%)

Note: ** statistically significant at 1%; * 5%

Source: Authors' work

The model accounts for a significant proportion of the variation in involvement, with around 67.4% of the variance attributed to these motives. Information Seeking (INF) is

not a major intrinsic motive among the factors influencing engagement, and Fun (FUN) does not show significant predictive power. Personal Identity (PER) has a strong and statistically significant impact on engagement, suggesting that individuals who manifest their identities through social media engagements are more inclined to display higher levels of involvement. Brand Love (LOV) is a reliable predictor, highlighting the significance of emotional connection to the sports club in promoting active participation.

Extrinsic motives study shows that Rewards (REV) have a small but significant effect on engagement, supporting hypothesis H2a at a significance level of 5%. Empowerment (EMP) has a robust and statistically significant impact on engagement, supporting hypothesis H2b at a significance level of 1%. Integration and Social Interaction (INT) strongly predict engagement, with a precise estimate of 0.098 and a statistically significant p-value of 0.003, supporting hypothesis H2c at a significance level of 1%. These findings underscore the significance of social connection and interaction in stimulating user engagement with sports club social media platforms.

Conclusion

This study explored the influence of intrinsic and extrinsic motivations on consumer engagement with sports club social media, leveraging the theoretical framework of the Uses and Gratifications Theory. The findings revealed that both intrinsic motivations, such as personal identity, entertainment, and brand love, and extrinsic motivations, including rewards, empowerment, and social interaction, significantly impact consumer engagement. Intrinsic motivations, such as meaningful commenting and active participation, were shown to be particularly strong predictors of high-quality engagement behaviours. In contrast, extrinsic motivations were more closely associated with content consumption and sharing behaviours.

This research contributes to the understanding of consumer engagement on social media by integrating motivation theory with uses and gratifications theory. It highlights the essential role of intrinsic motivations, particularly emotional attachment, and identity expression, in fostering sustained and meaningful engagement. The findings support the notion that while extrinsic rewards can drive initial interactions, they are less effective in promoting deeper, long-term engagement unless they resonate with users' intrinsic motivations.

The results suggest the importance of creating social media strategies that address both intrinsic and extrinsic motivations for sports clubs and marketers. Emphasising content that builds emotional connections aligns with fans' identities and provides entertainment can enhance engagement. Moreover, integrating extrinsic motivators such as rewards and social interaction opportunities can complement these efforts, particularly in encouraging sharing and participation.

The study's limitations include its reliance on a specific geographic sample and self-reported data, which may introduce bias and limit generalizability. Future research could explore these relationships in different cultural contexts or across various sports to validate and extend the findings. Additionally, longitudinal studies could provide insights into how motivations and engagement evolve and how emerging social media platforms influence these dynamics. Further research could also examine the interplay between intrinsic and extrinsic motivations in driving brand loyalty and advocacy in the digital age.

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Operational Employability Model: A Case Study of Graduate Employability in Croatia

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Abstract

Background: The employability of graduates has become a central topic in higher education policy and research. However, the construct still needs to be clarified.

Objectives: The objective of this paper is to demonstrate the applicability of an operational employability model in analysing the transition from study to work on a sample of graduates in Croatia as part of a larger Eurograduate pilot survey. The model has been rooted in the theories of human capital, cultural and social capital and constructivist educational theory.

Methods/Approach: Factor analysis was applied to reduce the number of measured variables into factor scores that were used as predictors in multiple regression analysis. Cox regression, logistic regression and linear regression were applied to test the employability model.

Results: The results showed that cultural capital, human capital, and bridging social capital, as well as high-impact practises during studies, such as volunteering and internships, have a positive impact on the likelihood of finding employment in less time after graduation in an occupation that vertically matches the qualification, and in a job with a higher monthly income.

Conclusions: The results have shown that cultural capital, human capital, and bridging social capital influence the probability of finding employment in a job that matches the level of qualification in a shorter time after graduation and in a job with a higher monthly income. These findings have practical implications for educators, policymakers, and employers, providing insights into the factors that can enhance graduate employability.

Keywords: employability operational model; graduate employability; human capital; social capital; cultural capital; constructivist theory

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Introduction

Recent studies have highlighted significant trends in education and employment outcomes across Europe, particularly concerning the impact of education length on youth employment. Krpan et al. (2023) utilised a hierarchical clustering approach to examine how variations in the duration of education correlate with employment rates among European youth, revealing distinct patterns that suggest longer educational periods might lead to better employment prospects. Additionally, the role of cultural and international dimensions in shaping innovation and entrepreneurship within higher education institutions has been explored by Grèzes (2021), who proposed a typology of learning universities that integrate these aspects to foster entrepreneurial mindsets. Moreover, the shift to e-learning during the COVID-19 pandemic, as analysed by Pejić Bach et al. (2023), underscored how different countries' development levels and pandemic responses significantly influenced the effectiveness of online education, further impacting educational and employment outcomes.

In recent years, there has been considerable concern about the effectiveness of institutional, national, and supranational policies and practices in equipping higher education students for the labour market. This has led to an increased interest in employability, which is usually understood as "the capability to obtain and maintain a job and ensure the supply of competence in the labour market" (Siivonen et al., 2023, p.1).

Various employability models and frameworks have emerged with "narrow", "broad", or "holistic" theoretical foundations or with a specific focus (Eimer & Bohndick, 2023, p. 3). They reflect different perspectives on employability that are taken by a plurality of stakeholders, each with a "different approach and scope serving to highlight different issues and domains of action in which they work." (Williams et al., 2016, p. 3).

One of the first frameworks for analysing the concept of employability was developed by Hillage and Pollard (1998, p.2), who argued that employability depends on "the knowledge, skills and attitudes they possess, the way they use those assets and present them to employers and the context [...] within which they seek work. Three of the four components in their framework focussed on graduates' skills and knowledge and contain only one external factor that influences employability.

McQuaid and Lindsay (2005) broadened the analytical framework of employability by placing greater emphasis on the external circumstances that influence employability, such as education and training, work experience, personal qualities and labour market conditions. They defined employability as a set of individual and organisational attributes that enable individuals to secure and maintain employment and to move within and between jobs.

Another example of the balancing of labour supply and demand through sets of micro and macro factors on both sides is the Kleinman and West model (1998). Micro factors on the supply side include personal and social skills, occupational skills and qualifications, and key competencies such as literacy and numeracy. In contrast, macro factors include the availability and accessibility of transport and childcare, as well as the presence of various forms of discrimination based on age, race, and so on. On the demand side, micro factors include the number of jobs in the local economy, the type of employers, and formal and informal employment procedures. Macro factors include labour market demand at the economic level, macroeconomic policies, and confidence in the economic sector. Although the model attempts to consider and balance factors on the supply and demand side when looking at employability and to point out the importance of the context of current public policy, the situation in education, the labour market and the economy, it is still built on a one-

dimensional interpretation of employability as a function of the match between supply on the education system side and demand on the labour market.

In an effort to consider internal and external factors of employability, Thijssen et al. (2008) have proposed a model in which they represent the construct of employability through three conceptual components that describe employability like concentric circles from the narrowest to the broadest definition. The first component, in the narrowest sense, refers to a person's ability to work at a particular job. The second component refers to the possession of various overarching skills that enable the individual to be employed in different jobs, and the third includes external, contextual factors such as personal and workplace circumstances that influence the individual's chances of success in the labour market.

More recently, Tomlinson (2017) has outlined a graduate capital model that encompasses a range of human, social, cultural, identity and psycho-social dimensions acquired through graduates' formal and informal experiences. The model demonstrates how the components of the different capitals overlap and relate to graduate employment by exploring how these forms might be developed in and around higher education. Based on the Graduate Capital Model, Tomlinson (Tomlinson et al., 2022) developed a psychometric instrument called the "Graduate Capital Scale" that seeks to operationalise this capital and help students to self-assess their confidence in transitioning to the labour market.

From the overview of the development of employability analytical frameworks and the employability construct, it is clear that the early models largely focus on the characteristics of the individual, while more recent approaches emphasise the interaction between different interrelated factors and different forms of capital, such as human capital, social capital, cultural capital, identity capital and psychological capital (Nghia et al., 2020; Pham & Jackson, 2020), in addition to health capital, scholastic capital, market-value capital, career identity capital, and economic capital (Donald et al., 2024a) as well as to resources that influence graduates' prospects in the labour market (Nghia et al., 2020) and contextual determinants such as the local labour market opportunities and life circumstances (Forrier et al., 2018). The development of employability models that incorporate internal and external factors has enabled a "much broader thematic framework with a clearer focus on the individual and macro-economic dimensions of employability and a shift in focus from hard-to-employ groups to all labour contingents" (Rimac & Ogresta, 2018, p.14).

However, researchers agree that more research is needed to capture the dynamic nature of employability development (Akkermans et al., 2024). The construct of employability is still vague because employability models and analytical frameworks often need a solid theoretical basis, tools and the availability of comparable data to test them systematically and across countries. One step forward in systematic data collection is the Eurograduate survey, which was initially piloted in 2018 with data sets from eight EU Member States (Meng et al., 2020) and then rolled out to seventeen EU Member States in 2022 (results yet to be available). The availability of data collected through the Eurograduate pilot survey enabled a more comprehensive approach to analysing the employability factors of graduates. The operational model presented in this paper has been developed based on the Eurograduate pilot survey (Rimac, 2020), and it focuses on early career outcomes of employed higher education graduates.

Three research propositions establish the employability predictors associated with three forms of capital and the learning environment during higher education.

- RP1: Human, cultural, and social capital and the activating learning environment during higher education positively influence finding employment in an occupation that matches the level of the acquired qualification.

- RP2: Human, cultural, and social capital and the activating learning environment during higher education positively influence monthly incomes.
- RP3: Human, cultural and social capital and the activating learning environment during higher education positively influence finding employment in a shorter time after obtaining the qualification.

The objective of this paper is to elaborate on an operational employability model based on the theories of human capital, cultural and social capital, as well as on the constructivist educational theory and tested on a set of data collected with the pilot Eurograduate survey. The operational employability model presented in this paper is based on the model used to analyse the employability of graduates from higher education institutions in Croatia (Tecilazić, 2023).

The first part of this paper, after the introduction, describes the theoretical framework, and the second part details the design of the operational employability model based on the given theoretical framework and adapts it to the Eurograduate instrument. The third part presents the methodology used to test the operational employability model on a sample from the Eurograduate pilot survey, and the fourth part contains the results of the analysis and the discussion. The conclusion summarises the relevance of the operational employability model and identifies opportunities for its further application as well as its limitations.

Theoretical Framework

The broad theoretical framework for understanding employability used in this study includes the economic theory of human capital developed in the 1960s by the economists Gary Becker and Theodore Schultz (Becker, 1962; Schultz, 1961), the theories of cultural and social capital advanced by the French sociologist Pierre Bourdieu (Bourdieu, 2018, 1986; Bourdieu & Passeron, 1990), and constructivist theories of education (Davis et al., 1993; Phillips, 1995). Drawing on the theories from multiple disciplines, this theoretical framework offers an interdisciplinary basis for understanding the complex employability construct.

Human capital is generally and broadly defined as the skills and competencies of a person. De la Fuente and Ciccone describe it as “knowledge and skills embodied in people and accumulated through schooling, training and experience that are useful in the production of goods, services and further knowledge” (Fuente & Ciccone, 2003, p.10). Human capital in the mode of acquired knowledge is gained through formal high-level education and training and empowers students in the labour market (Tomlinson, 2017). Human capital theory emphasises the importance of education and training for the acquisition of skills and knowledge and, thus, for the improvement of an individual’s productive capacity (Becker, 1962). The research findings support the basic principles of human capital theory, according to which investment in education and training helps to improve individual and social outcomes, including the employability of individuals (Babić, 2019).

According to the principles of human capital theory, individuals are responsible for the decisions on investment in their education as well as for their educational and career outcomes. However, critics of human capital theory argue that its neoliberal ideology and the neoclassical economic principles that underpin human capital theory narrow education to its economic purpose and focus on technical skills and knowledge necessary for finding employment (Edeji, 2024). In such a way, human capital theory as a profit-based neoliberal ideology “neglects the influence of social structure on educational inequality, which greatly contributes to educational inequity” (MacKenzie & Chiang, 2023, p. 8).

Moreover, to focus only on a person's skills and knowledge in explaining career outcomes would mean ignoring the broader social context that plays an important role in creating educational and training opportunities for individuals (Badescu et al., 2011; Baranović et al., 2015; Black & Smith, 2006; Coleman, 1988; Ortiz-Gervasi, 2023; Zhang, 2005). The broader social context that determines a person's opportunities (Loury, 1977, 1981) includes an individual's cultural and social capital which determines their educational choices (Becker & Hecken, 2009; Boudon, 1974; Erikson et al., 2005; Puzić & Košutić, 2015; Van De Werfhorst et al., 2003) thereby influencing different evaluation of the costs, benefits and risks associated with educational choices (Boudon, 1974), as well as academic achievement (Bourdieu, 2018; Bourdieu & Passeron, 1990) and facilitating access to social resources and employment strategies that are critical to securing quality employment (Breen & Goldthorpe, 1997; Collins, 1979; Halsey et al., 1980).

The theory of cultural capital states that a person's cultural knowledge, family background and behaviour can have a significant impact on their life chances and influence their social mobility and economic success. Cultural capital is a form of knowledge acquired through socialisation and education that can be institutionalised in the form of parents' educational qualifications and used to gain access to certain social and economic opportunities (Bourdieu, 1986), who argued that cultural capital is often unequally distributed, with members of higher social classes having greater access to it than members of lower social classes. This inequality often manifests itself in early educational choices, later academic performance and later career paths, whereby educational institutions contribute to the reproduction of social inequalities.

However, the educational experience and its formative potential can significantly alter educational and professional outcomes, as different educational practices and learning experiences have an impact on the development of human potential. According to constructivist educational theory, people construct their knowledge by building on their previous knowledge and experiences, developing their overall understanding of the world and matching their new ideas and experiences against existing knowledge (Carlile & Jordan, 2005).

The constructivist learning paradigm emphasises that teachers should actively engage students in learning and create a learning environment (Barr & Tagg, 1995) and is the basic theory behind the student-centred learning approach (Matthews, 2020). Empirical research supports the constructivist approach and proves that students' performance is improved when supported by activating learning environment (Ahmad et al., 2015) where teachers' intentions are focused on developing, changing or transforming students' conceptions instead of instructing them or conveying the content (Prosser et al., 2005).

Such transformative learning brings about a change in the "assumptions through which we understand our experiences, and that selectively shape and delimit our expectations, perceptions, cognition, and feelings" (Mezirow & Taylor, 2009, p.20). In line with constructivist and transformative theories, knowledge and skills are more likely to be developed through student engagement and activating learning practises such as teamwork (Li & Guo, 2015), project-based learning and flipped classrooms (Schell & Mazur, 2015), research-based learning (Børte et al., 2023), problem-based learning, critical thinking, deep learning, case studies and research-based learning approaches.

Research suggests that graduates are more satisfied with study programmes designed in a more problem-based learning and teaching manner and would choose the same study programme at the same institution rather than graduates who studied at programmes with a more traditional lecture-based approach applied to a greater

extent (Tecilazić, 2022). Therefore, some researchers argue that shifting from traditional lecture-based teaching to more student-centred, interdisciplinary learning supported by information and communication technologies and international collaboration is needed (Miseyanni et al., 2018).

In addition to these activating pedagogical approaches, research shows that specific high-impact practises integrated into the curriculum or extracurricular activities such as study abroad (Adle, 2021), work-based learning and internships (Jackson et al., 2024; Rowe et al., 2023) paid or unpaid student jobs, volunteering, student research projects and community engagement activities have a proven impact on the employability of graduates (Wolniak & Engberg, 2019). Therefore, the role of higher education in supporting students to develop their employability skills, which is necessary to facilitate their transition to the labour market, is pivotal (Van der Baan et al., 2024).

Finally, the choice of employment strategies of graduates is influenced by the social capital of the individual. According to Bourdieu, social capital is a resource made up of family and personal social connections and relationships. It is defined as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalised relationships of mutual acquaintance and recognition" (Bourdieu, 1986, p.26). Social networks are built on trust, which facilitates cooperation and the exchange of valuable information and resources (Putnam, 1995). They can, therefore, play a role in creating opportunities for educational and economic advancement (Coleman, 1988). Social capital, which manifests itself in the form of social networks, connections and relationships, can be used to gain access to valuable resources such as information and social support (Lin, 1999) and can also help to find better-paying jobs, thereby improving individual and societal outcomes (Granovetter, 1995).

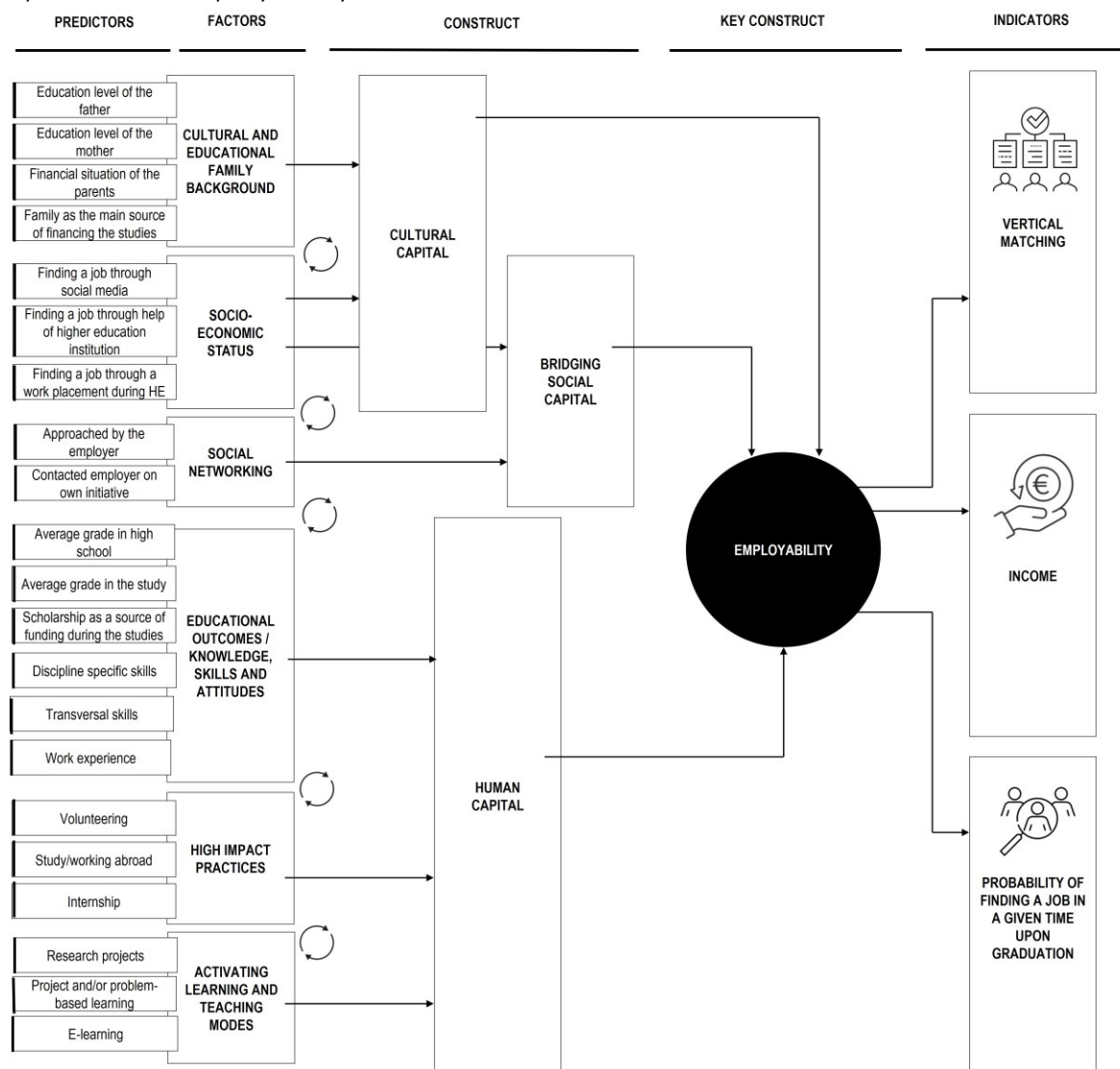
The theories of human, cultural and social capital supported by the constructivist theory formed the theoretical framework for the development of the operational employability model, which encompasses various factors that are assumed to influence the employability of higher education graduates. The construction of this operational employability model was built on previous research and a review of existing analytical frameworks that reveal its complexity and multidimensionality and that provide indicators for measuring employability. The model was finally adapted to the Eurograduate survey and then tested on a sample of graduates from Croatian higher education institutions to measure their early career outcomes.

Operational Employability Model

Various models and frameworks have been developed to analyse employability, and discussions have emerged about the factors influencing the transition of graduates into the labour market (Nghia et al., 2022). These employability models and studies usually aim to underpin the institutional developments and practise of higher education institutions, curricular or extra-curricular activities to develop student's employability skills (Jackson et al., 2024), or they tend to support national or supranational employment and education policies looking at how higher education institutions effectively prepare students for the labour market (Bennett, 2019). Furthermore, these models often emphasise the factors that influence employability but place less emphasis on how employability can be measured due to the vagueness of the term. Finally, there are concerns that researchers work in their silos and that there is a lack of terminological consistency, so different terms are used for the same concepts (Donald et al., 2024b).

Based on the given theoretical framework and building on the existing models and analytical frameworks on employability, the operational employability model presented in this paper (Figure 1) includes cultural, social and human capital as predictors of employability, which is measured by three indicators of employability of employed individuals: vertical match of qualification to occupation, probability of finding a job within a short time after graduation, and income level. This operational model of employability is grounded in a robust theoretical foundation and aims to enhance understanding of the predictors of employability, as measured by a defined set of indicators. It originated from a pilot survey conducted among graduates in eight European countries in 2018, which was repeated in seventeen European countries in 2022. The use of a standardised questionnaire and comparable data sets ensures consistency across countries and over time. This model specifically targets initial employability and early career outcomes, analysing the transition from higher education to the labour market and distinguishing it from other employability models.

Figure 1
Operational Employability Model



Source: Author's work based on Tecilazić (2023)

Methodology

The operational employability model was empirically tested, and the analysis was conducted on a sample of Bachelor-level and Master-level graduates from university and non-university types of higher education institutions in Croatia who graduated in the academic year 2016/2017 and participated in the Eurograduate pilot survey from October 2018 to February 2019. Data were centrally collected and anonymised by the Deutsche Zentrum für Hochschul und Wissenschaftsforschung, which made the data available in accordance with the GDPR.

The dataset was weighted based on population data and contained the sample of the total number of 4115 graduates grouped according to sex (59,3% female; 40,7% male), institution type (69,4% university; 30,6% non-university), qualification level (53,1% Bachelor; 46,9% Master); education fields (5,8% Education; 9,1% Arts and Humanities; 7,0% Social Sciences, Journalism and Information; 29,1% Business, Administration and Law; 5,0% Natural Sciences, Mathematics and Statistics; 5,7% Information and Communication Technologies; 16,6% Engineering, Manufacturing and Construction; 4,4% Agriculture, Forestry, Fisheries and Veterinary; 10,2% Health and Welfare; 7,1% Services).

In order to test the research propositions and establish predictors of employability, the operational employability model was applied. Factor analysis was applied to reduce the number of measured variables indicative of the same constructs to create factor scores, which were used in multiple regression analysis as predictors. Logistic regression was applied to test predictors of vertical matching of qualification with occupation. The Cox regression was used to identify factors influencing the achievement of the first employment in a shorter time after graduation. Linear regression analysis was employed to establish factors that determine monthly income. The most significant and relevant results are presented and discussed in the following part of this paper.

Results

Factor analysis

To develop an operational model of employability, three-factor analyses were first conducted to reduce the number of measured variables indicating the same constructs and to form factor scores, which were later used as predictors in a multiple regression analysis. The first-factor analysis included variables indicative of individual attributes and family socio-cultural background (Table 1).

It resulted in three factors, two of which were included in the operational model of employability: sociocultural background and educational outcomes (knowledge, skills, and attitudes). The second-factor analysis referred to the learning and teaching modes predominantly used in the study programme and resulted in two factors, one indicating activating learning and teaching practises and the other passive learning and teaching modes (Table 2). The third-factor analysis included high-impact practices experienced by the graduates during their study programme (Table 3).

Table 1

Individual Attributes and Family Socio-Cultural Background (Factor Scores)

Measured variables	Socio-cultural background	Educational outcomes	Additional efforts
Highest education level of the father"	0.772	-0.012	0.032
Highest education level of the mother	0.795	0.048	-0.019
Family as the main source of financing the studies	0.367	0.316	-0.254
Financial situation of the parents	0.579	-0.114	0.012
Scholarship as a source of financing the studies	-0.183	0.700	-0.072
Average final examination grade in secondary education	0.065	0.664	0.006
Average final grade in higher education	0.023	0.609	0.328
Extra work above what was required to pass exams	-0.019	-0.019	0.873
Striving for the highest possible marks	0.010	0.118	0.872

Source: Author's work based on Tecilazić (2023)

Table 2

Learning and Teaching Modes (Factor Scores)

Measured variables	Passive learning and teaching modes	Activating learning and teaching modes
Lectures	0.836	-0.323
Group assignments	0.598	0.540
Written assignments	0.793	-0.013
Oral presentations by students	0.802	0.140
Self-study	0.706	-0.433
Participation in research projects	-0.079	0.847
Internship as part of or outside the curriculum	-0.112	0.589
Project and/or problem-based learning	0.286	0.722
E-learning	-0.277	0.653

Source: Author's work based on Tecilazić (2023)

Table 3

High Impact Practises (Factor Scores)

Measured variables	Study/working abroad	Volunteering	Work experience	Internship
Study abroad	0.774	0.139	0.032	-0.191
Mobility period during studies	0.980	0.056	0.034	0.006
Internship as part of or outside the curriculum (abroad)	0.734	-0.056	0.017	0.233
Voluntary activity related to higher education institution	0.068	0.741	0.029	0.109
Voluntary activity not related to higher education institution.	0.017	0.737	0.088	-0.051
Work experience in the country of HEI not related to study programme	-0.050	0.279	0.663	-0.004
Work experience abroad not related to study programme.	0.168	0.063	0.584	-0.059
Work experience before studying	-0.108	-0.372	0.599	0.087
Internship as part of or outside the curriculum (home)	0.030	0.054	-0.015	0.954

Source: Author's work based on Tecilazić (2023)

The measured variables and corresponding factors are included in the operational employability model, which was developed and first tested on a set of data comprising individuals graduating in Croatia in 2016/2017 (Tecilazić, 2023), presented in this study with some modifications.

Cultural capital is described by the constructs of cultural and educational family background and socioeconomic status, operationalised by two groups of measured variables: "the education level of the father", "the education level of the mother", as well as by "the financial situation of the parents during the studies" and "the family as the main source of financing the studies". Social capital, which is derived from the socioeconomic status of the family, is primarily measured using social networks and resources used in strategies applied to find a first job. In this context, we distinguished between two types of social capital, namely "bonding social capital", which refers to a type of social capital that is created within a community, and "bridging social capital", which refers to the creation of connections between different social groups (Putnam, 2000). Bonding social capital in this paper refers to the search for a job through friends, family, and acquaintances. It is therefore linked to family social capital, while bridging social capital includes the search for a first job "through social media", "through the help of higher education institution", or through a "work placement during higher education". In addition, bridging social capital is also characterised by the individual "being "approached by the employer" and "contacting the employer by individual's initiative" as two successful employment strategies. In the revised operational employability model, only bridging social capital is explicitly included as a predictor of employability.

In the revised operational employability model, human capital is described by three groups of variables that are intertwined and related to other constructs. First, educational outcomes (knowledge, skills and attitudes) include the "average final examination grade in secondary education", the "average final grade in higher education", and the "scholarship as a source of financing the studies", as well as "discipline-specific skills" and "transversal skills", both needed for graduates' employment outcomes (Nghia et al., 2020). These elements are related to the personal attributes of the individual's human capital developed through education and training. Specific learning experiences in higher education were measured by the predominant use of certain learning and teaching modes during studies such as "participation in research projects", "project and/or problem-based learning", "e-learning" and by specific high-impact practises such as "internship or study-related work placement", "study/working abroad" and "volunteering". These practises, when supported by higher education institutions, can therefore be analysed as factors in the development of human capital and thus as possible predictors of employability.

The revised model emphasises the interdependence between different groups of predictors. For example, socioeconomic status as a construct is intertwined with cultural and educational family background and social networks, which is why their overlap is visible in the operational model of employability, as is the overlap of social networks with an individual's characteristics.

On the output side of the operational employability model, three indicators were defined to measure the employability of employed individuals in the early career phase: employment in an occupation corresponding to the level of qualification acquired, the time elapsed from qualifying first employment, and the level of income.

Firstly, the vertical match between the qualification and occupation shows that the labour market values the skills and knowledge acquired during higher education. This criterion of employability corresponds to the basic concepts of human capital theory, which establishes a link between investment in the acquisition of knowledge and skills

needed to perform more complex occupations where the expected tangible and intangible returns are greater. Employment in a profession that corresponds to the level of the qualification acquired is considered to be an important indicator of the employability of people in the early career phase. On the other hand, horizontally matched employment, which describes employment in the same or a field to the field of study, is more controversial, as successful employment is also possible outside the field of study, which becomes even more evident with the increase in interdisciplinarity, multidisciplinary and interdisciplinarity, as well as with the increase in the importance of transversal skills. For this reason, this indicator was ultimately removed from the revised model.

Secondly, in empirical research analysing employment prospects after graduation, the probability of finding a job in a shorter period is usually used as a measure of employability. However, this indicator has its limitations, as graduates may delay entering the labour market for various reasons, which does not necessarily make them less employable. Therefore, these limitations must be taken into account when interpreting the results.

Thirdly, the level of earnings as a criterion for measuring employment success derives directly from human capital theory. It is also an indicator of the value of individual skills and competencies used at work and, thus, an indicator of employability.

The operational employability model was developed to analyse the determinants of employability of graduates at an early stage of their careers using the Eurograduate survey as a measurement instrument. The following part shows the results of an analysis conducted on a limited set of data to test the operational employability model.

Predictors of vertical (mis)match between qualification and occupation

The analyses have shown that, under certain circumstances, cultural capital, human capital, and bridging social capital influence the probability of finding employment in a job that matches the level of qualification in a shorter time after graduation, with a higher monthly income.

The logistic regression analysis determined the factors for employment in an occupation corresponding to the level of qualification achieved (Table 4). The results showed that the probability of finding suitable employment in an occupation corresponding to the qualification level is higher for graduates with a university bachelor's degree or a university master's degree if they have greater family cultural capital.

Human capital plays an important role for graduates with a university master's degree, and social capital is more important for graduates with a non-university bachelor's degree. More specifically, the results of the analysis show that controlling for other variables, university graduates with a bachelor's degree and higher cultural capital are 70.3 % more likely to find employment matching their level of qualification ($\text{Exp}(B)=1.703$; $\text{S.E.}=0.26$) than graduates with lower cultural capital from the same group. This is in line with the findings of the Eurograduate report for Croatia, according to which the majority of university graduates with a bachelor's degree continue their studies because their qualifications are not recognised in the labour market (Rimac, 2020).

However, those with higher cultural capital can more easily compensate for the lack of skills and knowledge acquired through their education. Similarly, university graduates with a Master's degree and higher cultural capital are 36.6 % more likely to find employment corresponding to their level of qualification ($\text{Exp}(B)=1.366$; $\text{S.E.}=0.084$).

than those with lower cultural capital. These results confirm the main propositions of cultural capital theory, which states that academic and non-academic outcomes depend on the knowledge passed down through family members. The fact that these results are specifically relevant to two groups of university graduates also means that even when access to higher education is opened up to students from lower socio-economic backgrounds, social differences remain. These graduates have more difficulty in finding a job where they can utilise the skills and knowledge they have acquired through higher education.

Table 4

Predictors of vertical (mis)match between qualification and occupation

	University Bachelor		University Master		Non-university Bachelor	
	S.E.	Exp(B)	S.E.	Exp(B)	S.E.	Exp(B)
Education	1.493	5.349	0.457	3.404*	1.098	11.844*
Arts and Humanities	0.967	0.742	0.439	2.184	-	-
Social Sciences. Journalism. Information	0.788	0.363	0.433	1.682	0.923	9.346*
Business. Administration. Law	0.672	0.136*	0.368	1.947	0.434	3.232*
Natural Sciences. Mathematics. Statistics	1.037	0.152	0.509	2.939*	-	-
Information and Communication Technologies	1.347	3.549	0.57	4.085*	0.551	5.943*
Engineering. Manufacturing and Construction	0.884	0.322	0.391	1.318	0.491	4.283*
Agriculture. Forestry. Fisheries. Veterinary	-	-	0.571	0.834	0.731	1.01
Health and Welfare	1.23	1.027	0.433	4.026*	0.513	9.177*
Cultural capital	0.26	1.703*	0.084*	1.366	0.135	1.17
Human capital	0.22	1.307	0.092*	1.426	0.156	1.261
Passive learning and teaching modes	0.22	0.646*	0.082	0.939	0.118	0.78*
Activating learning and teaching modes	0.215	0.973	0.076	1.039	0.133	0.711*
Study abroad	0.219	1.048	0.076	1.001	0.193	0.635*
Volunteering	0.223	1.251	0.08	0.982	0.141	1.127
Work experience	0.207	0.945	0.081	1.221*	0.119	0.971
Internship	0.216	1.277	0.083	0.884	0.151	0.87
Employment through electronic media	0.48	0.769	0.193	0.759	0.309	0.727
Employment through Employment Agency	0.831	1.645	0.194	0.836	0.338	1.063
Employment - contacted employer by own initiative	-	-	0.338	1.064	0.315	1.705*
Employment through social networks	0.501	0.914	0.191	1.39	-	-
Employment - approached by employer	0.712	2.005	0.271	2.51*	0.336	1.309
Employment through internship	-	-	0.367	1.446	-	-
Employment through family. friends. acquaintances	0.457	0.791	0.196	0.455*	0.283	1.155
Employment through help of HEI	-	-	0.362	1.336	-	-
Employment through work placement during HE	-	-	0.448	0.898	-	-
Constant	0.797	3.987	0.415	0.868	0.531	0.631

Note: * $p < 0,05$

Source: Author's work

Human capital manifested through better education and academic outcomes contributes to finding employment matching the level of qualification, in the case of graduates with a university Master's degree. Those graduates have 42.6% (Exp(B)=1.426; S.E.=0.092) higher odds of finding a suitable qualification level-matching employment if they have a one-factor score of higher human capital.

Non-university graduates with Bachelor's degrees who have used their social capital and applied strategies to bridge social gaps when seeking their first job have a higher probability of finding employment that matches the level of their qualification. Those Bachelor-level graduates from professional higher education institutions who found their employment by contacting the employer by their initiative

have 70.5% higher odds ($\text{Exp}(B)=1.705$; $\text{S.E.}=0.315$) of finding employment at the same level as their qualification than those graduates from the same group who used other job seeking strategies.

The analysis's results regarding the modes of learning and teaching predominantly used during the degree programme showed that both passive and activating modes of learning and teaching have a negative influence on the search for a job that corresponds vertically to the qualification. These controversial results point to shortcomings in the Eurograduate pilot questionnaire, in which respondents were asked to rate the frequency of use of each mode of learning and teaching separately so that the different modes are not measured in relation to each other.

Predictors of finding employment with higher income

The results of the analysis also showed that graduates with a bachelor's degree from a university who have found employment through contacts within their social community or who have spent time studying abroad are more likely to be employed in jobs below their qualification level. The former supports social capital theory, which states that bonding social capital can be a barrier to better career outcomes, particularly for those from less privileged social backgrounds. The latter can be explained by the fact that those who have spent time studying abroad, compared to those who have stayed at their home university, need more social capital to build their social networks and use them later to find suitable employment (Table 5).

These results largely support the first research proposition (RP1), which is that human, cultural, and social capital, and the activating learning environment during higher education have a positive influence on finding employment in an occupation that corresponds to the level of qualification acquired.

The second research proposition (RP2), which concerns the predictors of finding a job with a higher income, was largely confirmed.

When analysing the predictors of a higher monthly income, it was initially established that there are no major differences in income between the groups of graduates analysed, which is why it was difficult to identify factors that influence higher incomes. However, it can be seen that holders of degrees in the fields of "information and communication technologies" and "engineering, manufacturing and construction" stand out positively here, as they are more likely to be employed in better-paid jobs than others.

When looking at the different capitals as possible predictors of employability, the analysis showed that among graduates with a professional master's degree, those with higher cultural capital work in occupations with higher earnings, such that they are likely to have an average monthly income that is EUR 174 higher ($B=174.051$; $\text{S.E.}=51.024$) when their cultural capital increases by one-factor score.

Social capital, which manifests itself in the social networks that an individual activates in search of employment in order to bridge social gaps (bridging social capital), increases the probability of finding employment with a higher income. University graduates with a Master's degree who found their first job after graduation with the help of their social networks had an average monthly income that was EUR 489 higher ($B=488.582$; $\text{S.E.}=157.008$) than those who used other job search strategies. On the other hand, graduates who did not activate their other social networks but found employment through the employment agency or their families, friends and acquaintances were more likely to have found employment with a lower income.

Table 5
Predictors of finding employment with higher income

	University Bachelor		University Master		Non-university Bachelor		Non-university Master	
	B	S.E.	B	S.E.	B	S.E.	B	S.E.
Education	-634.238	378.247	-318.067	215.681	-93.429	315.982		
Arts and Humanities	-471.735	377.502	-350.737	217.003	-458.387	597.933		
Social Sciences, Journalism, Information	-786.878*	310.501	-196.521	221.292	-9.294	315.04		
Business, Administration, Law	-704.494*	248.62	-100.993	190.103	205	162.312	-46.734	211.528
Natural Sciences, Mathematics, Statistics	-730.624	448.193	-174.432	235.777				
ICT	-222.955	356.351	701.42*	241.484	277.623	206.423	204.735	262.289
Engineering, Manufacturing and Construction	-589.546	350.454	181.022	200.601	676.195*	175.462	168.754	265.973
Agriculture, Forestry, Fisheries, Veterinary	-444.097	535.061	-303.795	279.884	133.896	270.393	-643.504	367.114
Health and Welfare	-516.369	470.195	172.708	206.354	208.956	178.773	-246.079	304.037
Cultural capital	-99.533	92.947	-8.237	36.452	-4.068	48.956	174.051*	51.024
Human capital	-82.511	82.363	46.029	40.247	-106.562	55.665	-112.039	64.444
Passive L&T modes	65.378	83.718	-24.708	36.874	-66.798	44.22	8.535	43.528
Activating L&T modes	-135.703	86.195	-32.597	35.639	-4.353	47.978	75.819	62.676
Study abroad	-314.886*	85.259	-57.355	32.599	-165.999*	68.508	-281.736*	74.444
Volunteering	14.404	82.128	53.456	35.922	141.891*	50.105	194.576*	57.009
Work experience	-17.21	81.131	-42.498	37.311	-103.185*	43.25	-96.666	52.044
Internship	-54.321	78.673	-66.171	38.098	136.034*	56.617	35.703	57.3
Employment through electronic media	363.158	188.174	96.128	89.351	24.212	116.458	-55.299	119.587
Employment through Employment Agency	-19.843	289.368	-307.094*	89.477	-300.282*	122.675	-195.596	129.224
Employment - contacted employer by own initiative			488.582*	157.008				
Employment through social networks	21.424	195.979	-156.351	84.469	-187.63	114.539	-305.424*	129.688
Employment - approached by employer	296.428	275.289	112.995	104.578	170.935	129.306	43.653	160.686
Employment through internship			-5.729	138.644				
Employment through family, friends, acquaintances	45.985	181.638	-56.982	92.593	3.421	105.193	-186.847	121.963
Employment through help of HEI			-213.325	143.295				
Employment through work placement during HE			154.125	197.23				

Note: * $p < 0,05$

Source: Author's work

In addition, voluntary work and internships during the studies have a positive influence on access to a better-paid first job. Graduates with a bachelor's degree from non-universities who have gained volunteering experience during their studies will earn, on average, EUR 142 more per month ($B=141.891$; $S.E.=50.105$) than

graduates without such experience. Similarly, graduates in the same group who have completed an internship during their studies will have salaries on average EUR 136 higher ($B=136.034$; $S.E.=56.617$) than those who have not completed an internship. These practises can, in turn, be attributed to the increased social capital that a person can build up during their studies by making connections with potential employers through various learning activities. Graduates who have completed a study period abroad are also more likely to find their first job with a lower income than their counterparts who stayed at their home higher education institution. This, in turn, can be attributed to a lack of social capital among those who did not build up their social networks sufficiently during their studies.

Conclusion

This paper provides new insights into the transition from higher education to the labour market. It makes a scientific contribution to the theoretical discussion and development of the construct of employability. Analysing the results of the original empirical research provides new insights into the predictors of employability.

The aim was to test an operational model of employability developed based on human, cultural, and social capital theories and constructivist educational theory, which were adapted to the Eurograduate survey. Three research propositions were formulated to examine the impact of cultural, social and human capital, including the role of the learning and teaching environment, on the employability of graduates at an early stage of their career. Employability is measured here by the probability of finding a first job after graduation in an occupation corresponding to the level of qualification, in a position with a higher monthly income and in a shorter time after graduation.

The model was tested in one country (Croatia) and proved to be applicable for analyses in other countries that participated in the survey in order to compare the results and measure the employability of people gaining qualifications and looking for work in different countries. The results largely support the second research proposition (RP2), which is that human, cultural, and social capital and the activating learning environment during higher education have a positive influence on higher monthly incomes. The third research proposition (RP3) was examined to test the impact of the employability predictors identified by the model on the probability of finding employment in a shorter time after graduation. The only significant result supporting the research propositions was found for the influence of social capital built up through internships during the studies. Graduates with a Master's degree who have completed an internship during their studies are more likely to find a job in a shorter time after graduation than those who have not completed an internship.

To better understand these results, it must be taken into account that more than 50 % of graduates with a bachelor's degree continue their studies at the Master's level and were therefore not included in the analysis. However, these results call into question the indicator of finding a job shortly after graduation, as graduates may decide to postpone their employment for various reasons and possibly look for better opportunities instead of accepting the first job. This is obviously only possible for those who come from privileged families who can support them in their job search and career choice. Therefore, a more in-depth analysis would be necessary to understand better the reasons for postponing employment.

Regarding the assumed positive effects of activating learning and teaching modes predominantly used by higher education institutions and specific high-impact practices that contribute to human capital formation and thus employability, the analyses provided limited support for the three research propositions, confirming only

volunteering and internships as practices with a significant impact on employability. However, further research is needed to investigate the different practices of higher education institutions that can lead to better employment outcomes.

However, the model has some limitations. Despite the intention to capture the complexity of the employability construct in this study, the definition of employability has been adapted to the study of early career outcomes and the available data from the Eurograduate survey. The operational model of employability, therefore, does not include all elements that are theoretically considered important to the wider discussion of employability. External factors such as the local economy and economic development, which determine the demand for labour, as well as the skills profile of current job seekers in the labour market, which make graduate employment a more or less competitive process, and the family and personal circumstances of job seekers such as place of residence, transport infrastructure, availability of childcare, etc., undoubtedly have an impact on employability outcomes but have not been included in the model as they are not captured by the Eurograduate research instruments used and represent the limitations of this research.

The operational employability model presented in this paper can support further research about the predictors of graduate employability during the transition from study to work and the comparative cross-country analysis of graduate employability. The application of this model will ultimately help to improve our understanding of the multifaceted determinants of employability.

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Opportunities or Challenges? The Interplay between Artificial Intelligence and Corporate Social Responsibility Communication

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Abstract

Background: The rapid development of Artificial Intelligence (AI) offers both opportunities and challenges for its application in Corporate Social Responsibility (CSR) communication. While AI can enhance CSR initiatives, its impact on consumer relations and brand perception remains inconsistent. **Objectives:** This study aims to explore the academic landscape of AI's role in CSR communication, focusing on publication trends, key authors, research topics, and future directions. **Methods/Approach:** A bibliometric analysis was conducted on 1,094 articles related to AI and CSR communication, retrieved from the Web of Science database from 2000 to February 2024. Using CiteSpace software, the study mapped research trends by analysing disciplines, countries, institutions, authors, references, and keywords. **Results:** The United States and China lead in publication output, with key research themes including social media impact, management strategies, and consumer trust. Emerging trends point to the importance of privacy, service quality, and perceived value in AI-driven CSR initiatives. **Conclusions:** The integration of AI in CSR communication is an evolving field, with significant contributions from social media research and consumer behaviour studies. Future research should address ethical concerns and long-term effects on consumer trust and engagement.

Keywords: CSR communication; AI; Consumer; CiteSpace; bibliometric

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Introduction

Corporate Social Responsibility (CSR), as a crucial practice concerning the social impact and sustainable development of enterprises, has become one of the focal points in contemporary business. With the rapid development and extensive application of Artificial Intelligence (AI) technology, the application of AI in CSR communication presents new opportunities and challenges for businesses. Through AI technology, enterprises can effectively convey their social responsibility information, enhance their brand image, and better meet the growing expectations of consumers. However, despite some initial achievements in the application of AI in CSR communication, there remain many issues and challenges in this research field that require further exploration.

Firstly, research on AI in CSR communication is still in its infancy, especially considering that AI is a widely applicable field, and its application in CSR communication can be both methodological (Wu et al., 2024; Ruhana et al., 2024) and in terms of products and services (KAZEMI et al., 2023; Galiano-Coronil et al., 2024). As of May 2024, a search on the Scopus platform yielded only 88 research articles that simultaneously address both CSR and AI. However, only one relevant article utilising bibliometric analysis has been found so far (Thomas et al., 2024), which also does not delve into the analysis of the impact on and relationship with consumers. Therefore, this study aims to fill this gap by using bibliometric methods. Additionally, most studies remain at the theoretical exploration and case analysis level. Understanding the most pressing concerns of researchers and businesses in this field is crucial for better problem-solving and predicting future research trends. Secondly, there is inconsistency in research findings regarding consumers' attitudes, perceptions, and behavioural responses to AI technology. Some researchers believe that the application of AI makes consumers more receptive to product usage and understand corporate content (Yuan, 2018). However, others argue that consumers subjectively reject AI services, especially when they perceive that AI provides the service, as they feel a lack of warmth and sincerity, leading to opposition to its use. Moreover, a weak point in current research is the lack of long-term effects studies, with research often limited to short-term outcome evaluations and lacking tracking studies on consumers' long-term cognitive and behavioural changes. Finally, a theoretical framework for understanding the impact mechanisms and pathways of AI in CSR communication has yet to be established, lacking systematic organisation and explanation (Cheng et al., 2022).

To address these issues, this study will conduct an in-depth analysis using bibliometrics. As a quantitative research method, bibliometrics possesses characteristics of systematicity, objectivity, and scientific rigour, enabling researchers to review existing literature comprehensively and discover patterns and trends therein (Lim et al., 2022; Zhao et al., 2023). CiteSpace, developed by Professor Chaomei Chen, is a Java-based co-citation network visualisation application used to detect and reveal the research frontiers and turning points in knowledge domains (Chen, 2006), primarily applied in bibliometric research (Chen et al., 2014). This study not only employs this software to analyse the publication, country, author, and keyword distribution of research related to the impact of AI on CSR communication with consumers but also makes predictions on trends and summarises the current hotspots and issues faced by the industry and academia in this field based on these analyses.

Therefore, this study contributes significantly to the theoretical domain by addressing existing research gaps and potentially advancing further theoretical development. Moreover, it offers valuable practical insights that can aid in the formulation of targeted and effective AI application strategies and practical

recommendations for enterprise managers. These insights have the potential to foster corporate social responsibility practices and promote sustainable development.

The structure of this study is as follows: The first part introduces the current research status, purpose, and significance of studying the impact of AI on CSR communication with consumers. The second part consists of a literature review on the Application of AI technology in CSR, as well as a review of the literature on Consumer attitudes toward AI for CSR communication. The third part introduces the research methods and presents the specific research process. The fourth part involves data analysis, including results on authors, publications, countries, keywords, and trends. The fifth part proposes conclusions and discussions, covering major findings, contributions, limitations, and future research pathways.

Literature review

Application of AI technology in CSR

Artificial Intelligence (AI) technology has become a cornerstone in the evolution of business practices, with its applications permeating various domains, including Corporate Social Responsibility (Dogru & Keskin, 2020). The prevalence of AI in businesses and organisations is highlighted by its ability to mimic human intelligence, enabling machines and models to predict outcomes and provide insights that inform strategic decision-making². In the realm of CSR, the integration of AI is particularly significant as it aligns business operations with Environmental, Social, and Governance (ESG) factors, addressing the urgent global issues of environmental and social equality (Gore et al., 2023; Atanasov et al., 2023).

AI tools such as Natural Language Processing (NLP), data analytics, and machine learning are instrumental in helping businesses understand the impacts of their CSR efforts. By leveraging these technologies, organisations can develop and implement sustainable practices that contribute to their growth while also fulfilling their social and environmental responsibilities¹. The transformative power of AI extends beyond CSR, affecting various sectors and industries, from finance to marketing, and reshaping the landscape of business management and operations (Lakhan, 2022).

In summary, the application of AI in the CSR domain is a testament to the technology's potential to foster sustainable growth and enhance the efficacy of CSR initiatives. As businesses continue to integrate AI into their economic models, they are better equipped to coordinate actions with ESG factors, ensuring a responsible and sustainable approach to growth (Gore et al., 2023; Lakhan, 2022).

Consumer attitudes toward AI for CSR communication

Consumer attitudes towards companies using AI technology for Corporate Social Responsibility (CSR) communication are multifaceted and influenced by various factors such as trust, perceived usefulness, and ethical considerations. Trust plays a pivotal role in the acceptance of AI technologies, as demonstrated by a study that found trust to significantly affect the intention to use AI voice assistants, with perceived usefulness and attitude towards the technology acting as mediators (Choung et al., 2023). This indicates that for companies to use AI in CSR communication effectively, they must ensure that their AI systems are perceived as useful and trustworthy.

The concept of initial trust, along with perceived risk, has been shown to be critical in the public's acceptance of automated vehicles (Zhang et al., 2019). This suggests that in the context of CSR communication, initial trust in the AI system could be a key determinant of its acceptance. Companies should aim to build this trust by

demonstrating the usefulness of the AI system and minimising perceived risks associated with its use.

Ethical implications are also a significant concern for consumers when it comes to AI in marketing, which would extend to CSR communication (Gonçalves et al., 2023; Du & Xie, 2021). Perceived risk has a notable impact on attitudes towards AI, ethical concerns, and perceived trust. Therefore, companies must address ethical issues transparently to foster consumer acceptance of AI-driven CSR initiatives.

Furthermore, the nature of consumer-AI interactions is influenced by factors such as trust, empathy, attachment, and anthropomorphism (Pop et al., 2023; Wu et al., 2024). Companies should consider these factors when designing AI systems for CSR communication to ensure that the interactions are perceived positively by consumers.

Lastly, public opinion towards AI varies by demographic and region, with differences in trust levels observed across gender, socioeconomic status, and geographic location (Zhang, 2021). Companies should be mindful of these differences when using AI for CSR communication to tailor their approach to different segments of the population.

In conclusion, for companies to successfully use AI technology for CSR communication, they must build trust and address ethical concerns while considering the demographic and regional differences in attitudes towards AI. Ensuring the AI system is perceived as useful and minimising perceived risks are also crucial for consumer acceptance and trust in this communication approach.

Methodology

Research approach

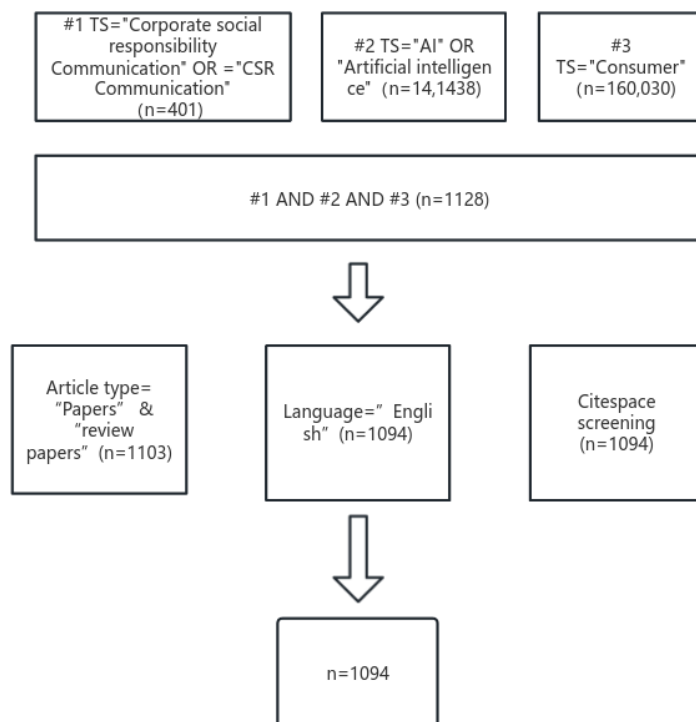
In this study, we will utilise CiteSpace 6.2.R3 software for literature analysis. CiteSpace is a widely employed tool for academic literature analysis (XIE et al., 2018; Chen, 2000; An & Xing, 2023). CiteSpace has been acknowledged for its macro analysis capabilities, with a focus on literature and periodicals, and its potential for future integration with various visual analysis tools to achieve more accurate results (XIE et al., 2018). Thus, it furnishes a reliable analytical foundation for in-depth exploration of the impact of Artificial Intelligence (AI) on consumer satisfaction within Corporate Social Responsibility (CSR) communication. Several factors were considered when selecting CiteSpace software as our literature analysis tool. Firstly, CiteSpace offers robust visualisation capabilities, facilitating the intuitive presentation of citation relationships, collaborative networks, and thematic evolution among publications. This visualisation capability enables us to comprehend the interconnections among literature more intuitively and swiftly capture research domain hotspots and trends. Secondly, CiteSpace supports network analysis, aiding in the discovery of associative patterns among publications, such as citation relationships and collaborative networks. Through network analysis, we can delve deeper into the connections among literature, identifying latent research topics and pivotal nodes to guide our research direction and focus (An & Xing, 2023). Thirdly, CiteSpace enables time-series analysis of literature data, assisting us in tracking the developmental trajectory and evolutionary trends of research domains, which is crucial for understanding the fluctuation patterns and trends of AI's impact on consumer satisfaction within CSR communication, thereby facilitating a more accurate grasp of the timeliness and forefront of our research. Lastly, CiteSpace supports the export of analysis results in various formats, such as images and tables, facilitating the intuitive presentation of analysis results in research reports or papers. Additionally, the process of using CiteSpace is recordable, ensuring the reproducibility of the research process and

enhancing the scientific rigour and credibility of our study (Chen, 2006). In summary, we have chosen CiteSpace software as our literature analysis tool because of its powerful visualisation and analysis functionalities, which can assist us comprehensively and thoroughly explore the impact of AI on consumer satisfaction within CSR communication, thereby providing reliable data support and analytical foundation for our research.

Data source and screening

This study utilises the Web of Science Core Collection as the data collection platform. Editions selected include the Science Citation Index Expanded (SCI-EXPANDED) from 2000 to February 2024, the Social Sciences Citation Index (SSCI) from 2006 to the present, and the Arts & Humanities Citation Index (AHCI) from 2008 to the present. The data collection process is depicted in Figure 1, with priority given to the titles, abstracts, and keywords of the literature to ensure thoroughness and credibility. The search period spans from January 1, 2000, to February 20, 2024, using the following search criteria: #1 TS="Corporate social responsibility Communication" OR ="CSR Communication" AND #2 TS="AI" OR "Artificial intelligence" AND #3 TS="Consumer", resulting in a total of 1128 articles. Non-journal articles were excluded from the analysis. Other languages are deemed not applicable to this study except English. After screening, 1094 articles meeting the criteria are compiled.

Figure 1
Data Collection and Screening Process



Source: Author's work

These publications cover 158 disciplinary fields, with business, management, environmental studies, and electrical engineering accounting for 65% of the total. Table 1 presents a detailed classification of literature by research disciplines.

Table 1

Top 10 research disciplines in this field

Ranking	Web of Science Categories	Record Count	% of 1,094
1	Business	382	34.93
2	Management	148	13.54
3	Environmental Studies	89	8.17
4	Engineering Electrical Electronic	77	7.00
5	Environmental Sciences	71	6.50
6	Computer Science Information Systems	69	6.30
7	Green Sustainable Science Technology	66	6.00
8	Communication	55	5.00
9	Telecommunications	49	4.50
10	Computer Science Artificial Intelligence	43	3.93

Source: Author's work

Parameter setting and analysis

This study employs CiteSpace 6.2.R3 software to detect the frequency or occurrence rate of the keywords "AI" and "corporate social responsibility communication" in the domain of "consumers". The purpose of using this software is to understand the research hotspots and development trends in this field. The time slice is set from January 2000 to February 2024.

When setting the parameters, several factors were considered to enhance the effectiveness of the analysis: Firstly, the node types were specified as authors, institutions, countries, keywords, and references. This setting allows for comprehensive consideration of various entities involved in the research domain, including individual contributors, institutional affiliations, geographical distributions, as well as specific terminologies and reference usage. Secondly, the value of "TopN" is set to 50. By selecting the top 50 nodes based on certain criteria (e.g., citation counts), the analysis focuses on the most influential and prominent elements within the network, facilitating a better understanding of key figures and topics in the field. Thirdly, in the g-index calculation, the value of parameter K is set to 10. This adjustment aids in capturing the overall impact and significance of publications by considering both the number of citations received by individual articles and the distribution of these citations among the entire set of articles. Lastly, the network is pruned by selecting "pathfinder" and "pruning merged networks". This trimming process helps refine the network structure, removing redundant or less relevant connections and focusing on core relationships and patterns.

These parameter settings in CiteSpace were selected based on previous research and the recommendations of Professor Chaomei Chen, the developer of the software (Chen, 2016), aiming to ensure a comprehensive and in-depth analysis of the research landscape regarding AI and corporate social responsibility communication in the consumer domain. By adopting these parameters, we aim to reveal the development trends and key research topics in this field over the specified period, providing meaningful insights.

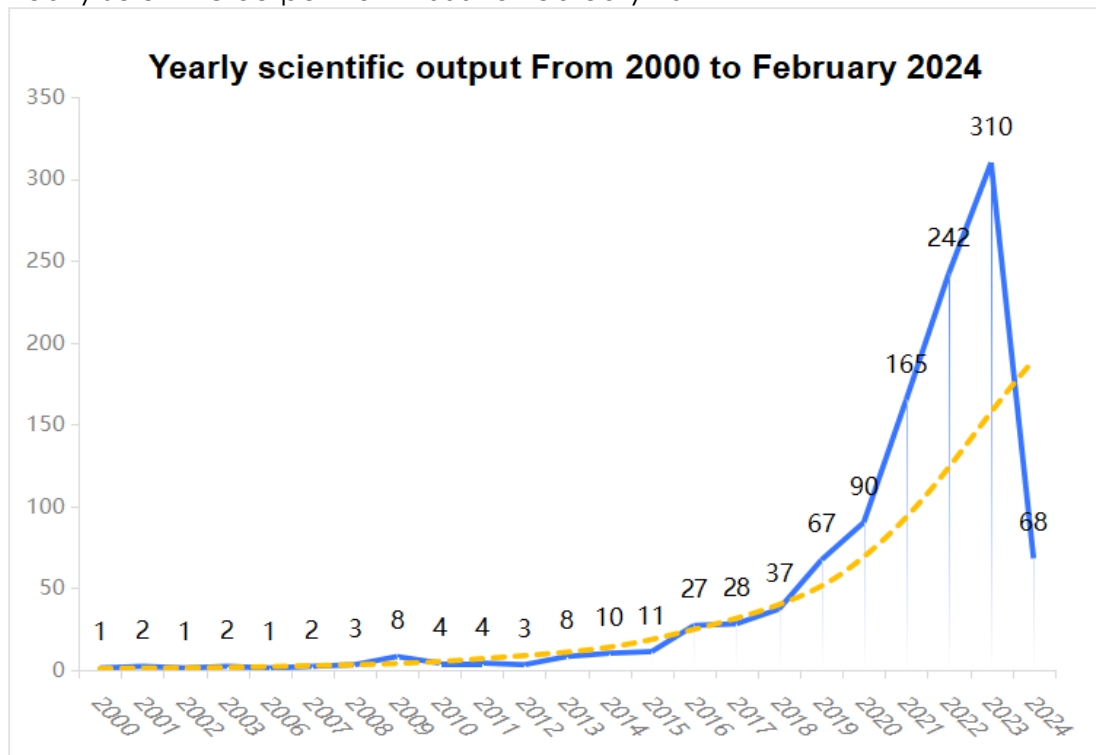
Bibliometric analysis

Publication trend

According to the data depicted in Figure 2, there is a stable growth trend in the number of publications concerning artificial intelligence (AI) within the domain of

consumer corporate social responsibility communication. As evidenced by the fitted curve, this field gradually garnered attention from the academic community in the early 21st century. Prior to 2012, scholars showed relatively low interest in this area, with an average of only 2.8 articles published annually. However, from 2013 to 2018, there was a substantial increase in the number of relevant articles, the average number of publications per year is about six. In contrast, during the period from 2019 to 2023, the quantity of related publications experienced a significant surge, reaching its peak in 2023.

Figure 2
Yearly scientific output from 2000 to February 2024



Source: Author's work

The data collected for this analysis concluded on February 17, 2024, and thus does not encompass complete statistical information for the year 2024. Nevertheless, based on the observed trend, we can anticipate a continued increase in the number of publications in this field, aligning with the stable growth trend depicted by the fitted curve formula. To predict the number of publications in 2024 based on the provided data, we can use a trend analysis method. One common approach is linear regression, where we fit a straight line to the data points and use it to estimate future values (Bianchi et al., 1999). Average Growth Rate = $[(\text{Final Year Publications} / \text{Initial Year Publications})^{(1 / \text{Number of Years})}] - 1 = [(310 / 1)^{(1 / 23)}] - 1 = 0.2178$ or 21.78%. Predicted Publications in 2024 = 2023 Publications * $(1 + \text{Average Growth Rate}) = 310 * (1 + 0.2178) \approx 377.8$. Therefore, based on the trend analysis using linear regression and the average annual growth rate, the predicted number of publications in 2024 is approximately 378. These figures reflect the increasingly close and significant relationship between artificial intelligence and consumer corporate social responsibility communication, generating widespread attention and discussion within the academic community.

Country/region analysis

According to the country collaboration network generated by CiteSpace software, the United States, China, and the United Kingdom are the top three countries in terms of the number of published papers in this field (Table 2). Among them, the United States ranks first with 312 papers, accounting for approximately 28.5% of the total literature, demonstrating its strong capabilities and influence in this field. China closely follows, with a total of 228 published papers, accounting for 20.8% of the total, indicating that Chinese scholars also possess a high level of research competence and productivity in this field. Additionally, countries such as Australia, India, and South Korea have gradually increased their research investment in this field and have achieved certain results.

In terms of research timeline in each country, the United States not only leads in the number of published papers but also initiates the research as soon as possible (beginning in 2000). Following this, Chinese scholars conducted preliminary research and began publishing related papers. Countries such as the United Kingdom, Spain, Germany, and France conducted relevant research almost before 2010, hence maintaining a stable and continuous increase in publication volume. In contrast, Australia, India, Italy, and South Korea started their research relatively later, with the first batch of research concentrated around 2015. These data reflect differences in the understanding and investment levels of each country regarding the importance of this field.

Table 2

The top 10 countries with the highest number of publications

Ranking	Country	Count	Year	Most cited authors
1	USA	312	2000	Bhattacharya, C B
2	CHINA	228	2002	Kim, S
3	ENGLAND	106	2008	Lu, Vinh Nhat
4	AUSTRALIA	83	2014	Wirtz, J
5	INDIA	66	2013	Pillai, R
6	SOUTH KOREA	66	2015	Sohn, K
7	SPAIN	62	2009	Currás-Pérez, R
8	ITALY	58	2013	Pesapane, F
9	GERMANY	58	2009	Du, S
10	FRANCE	52	2008	Parguel, B

Source: Author's work

CiteSpace employs several centrality metrics to assess the importance of documents or authors, with one of the most common being "Betweenness Centrality." The betweenness centrality is defined for each node in a network. It measures how likely an arbitrary shortest path in the network will go through the node. The calculation of Betweenness Centrality is to divide the sum for each node by the total number of possible node pairs (excluding the node itself) to obtain its Betweenness Centrality value. If a node has a high mediation centrality in the network, it means that it plays a key mediating role in information dissemination and cooperation (Chen, 2000).

In addition to numerical advantages, Lithuania (0.73), Romania (0.57), Pakistan (0.45), France (0.44), and Germany (0.38) have the highest centrality among countries (Table 3), this shows that the above-mentioned countries have had a certain influence and made outstanding contributions in this field. It is worth noting that conducting scientific and technological cooperation in different regions and backgrounds will better promote global technological innovation and progress.

Table 3

Analysis of national contribution centrality

Ranking	Country	Centrality	Most cited authors
1	LITHUANIA	.73	Czinkota, M
2	ROMANIA	.57	Pelau, C
3	PAKISTAN	.45	Nawaz, Nishad
4	FRANCE	.44	Parguel, B
5	GERMANY	.38	Du, S
6	CHINA	.30	Kim, S
7	GREECE	.27	Alsalemi, A
8	CYPRUS	.27	Czinkota, M
9	SAUDI ARABIA	.26	Kumari, A
10	SWEDEN	.26	Toorajipour, R

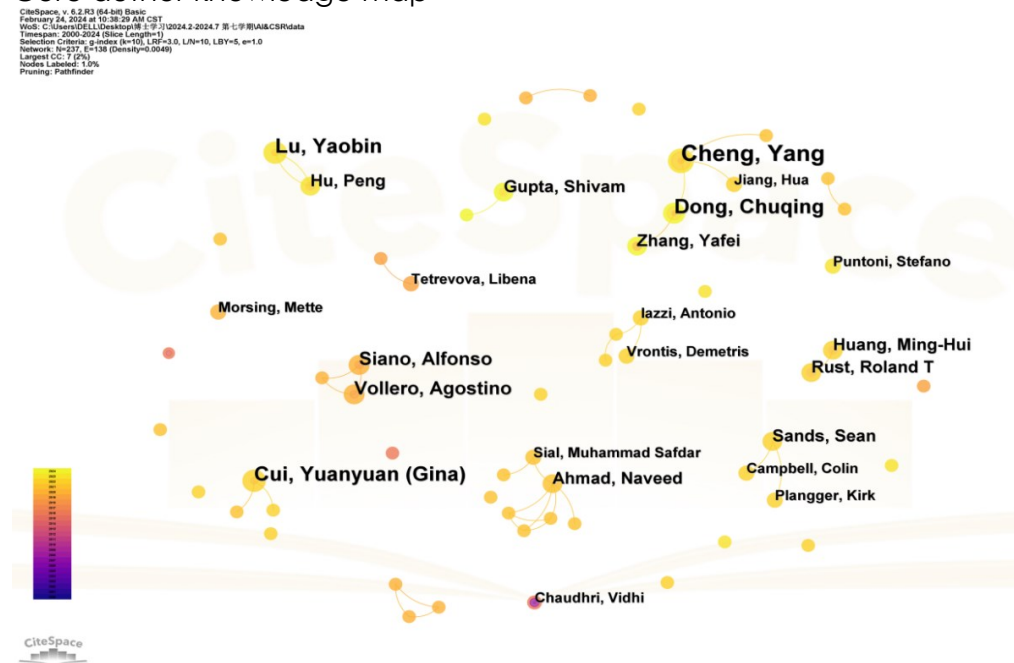
Source: Author's work

Core author analysis

CiteSpace software created the author collaboration network diagram, shown in Figure 3, which contains 237 nodes and 138 lines. Each circular node represents an author, and the size of the shape indicates the author's contribution. The larger the shape, the more the author's contribution, and the smaller the shape, the less the author's contribution. The lines connecting the nodes show the collaboration relationship between authors.

Figure 3

Core author knowledge map



Source: Author's work

Table 4 presents an overview of the top ten authors based on post volume. Cheng Yang, whose inaugural study was published in 2021, stands as the most prolific author in the field with a total of eight posts. Lu Yaobin follows him with six articles, and Dong Chuqing, Cui Yuanyuan (Gina), Siano Alfonso, and Vollero Agostino occupy the third

to sixth positions, respectively. Furthermore, Zhang Yafei, Sands Sean, Rust Roland, and Huang Ming-Hui have made significant contributions to this domain. Overall, the centrality within this network remains low; cooperation primarily revolves around high-output authors. This has fostered strong collaborative relationships and created a positive atmosphere for academic engagement.

Table 4
Result analysis of the core author

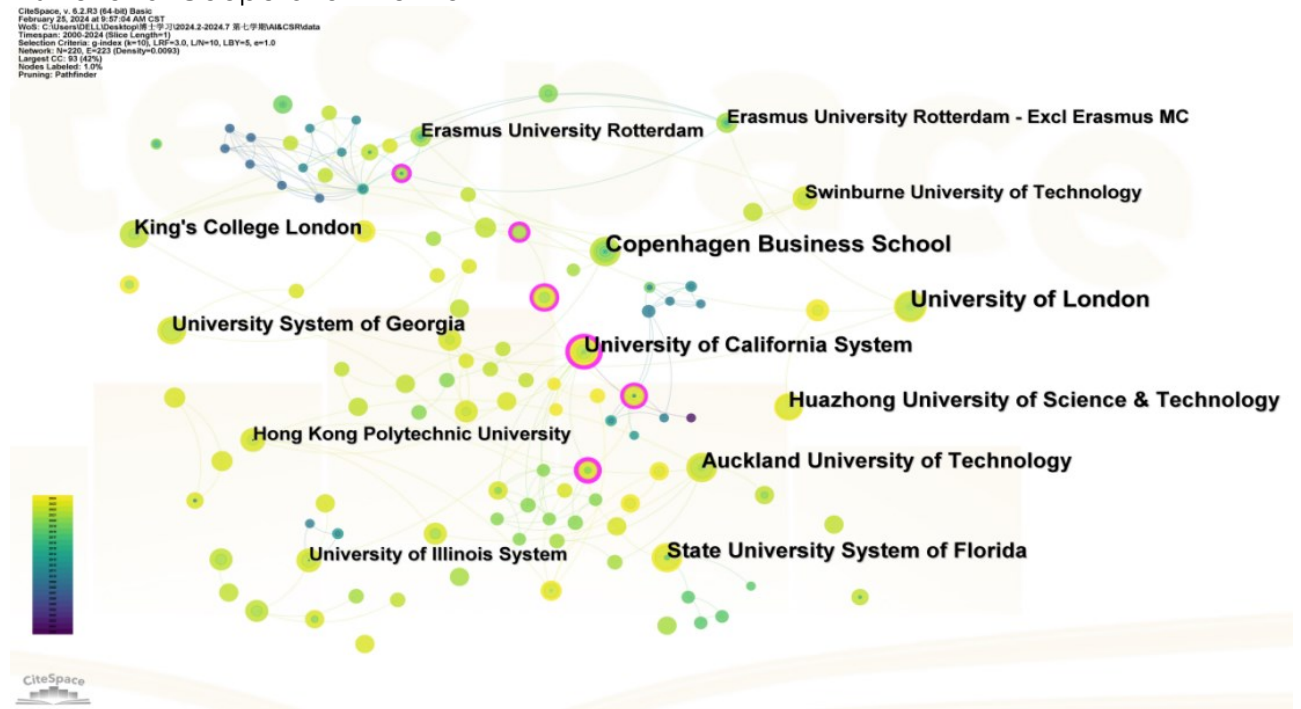
Ranking	Author	Frequency	Year
1	Cheng Yang	8	2021
2	Lu Yaobin	6	2022
3	Dong Chuqing	6	2021
4	Cui Yuanyuan (Gina)	6	2021
5	Vollero Agostino	5	2019
6	Siano Alfonso	5	2019
7	Zhang Yafei	4	2021
8	Sands Sean	4	2022
9	Rust Roland	4	2021
10	Huang Ming-Hui	4	2021

Source: Author's work

Core research institutions analysis

According to the data displayed in the knowledge graph (Figure 4), institutions such as the University of London, Copenhagen Business School, and Auckland University of Technology have outstanding performance in terms of literature output in the field of CSR communication and AI research (Table 5).

Figure 4
Institutional Cooperation Network



Source: Author's work

Table 5

Result analysis of core research institution

Number	Count	Year	Institution
1	14	2021	University of London
2	14	2013	Copenhagen Business School
3	12	2021	Auckland University of Technology
4	12	2021	Huazhong University of Science & Technology
5	11	2001	University of California System
6	11	2018	State University System of Florida
7	10	2021	King's College London
8	10	2022	University System of Georgia
9	8	2010	University of Illinois System
10	8	2009	Erasmus University Rotterdam

Source: Author's work

The contributions of these institutions have played an important role in promoting the development of this field. At the same time, there is also a very close cooperation relationship, with a total of 220 institutions participating and 223 cooperative relationships existing. Of note is the international attention to artificial intelligence in consumer social responsibility communication. Major institutions such as the University of California system and Cornell University have formed a stable and extensive cooperation network, playing an active role in promoting international academic exchanges (Table 6).

Table 6

Centrality analysis of core research

Ranking	Institution	Centrality
1	University of California System	.20
2	Cornell University	.20
3	Harvard University	.19
4	University of Pennsylvania	.16
5	National University of Singapore	.15
6	IESEG School of Management	.15
7	Kennesaw State University	.08
8	University of London	.07
9	Centre National de la Recherche Scientifique (CNRS)	.07
10	King's College London	.06

Source: Author's work

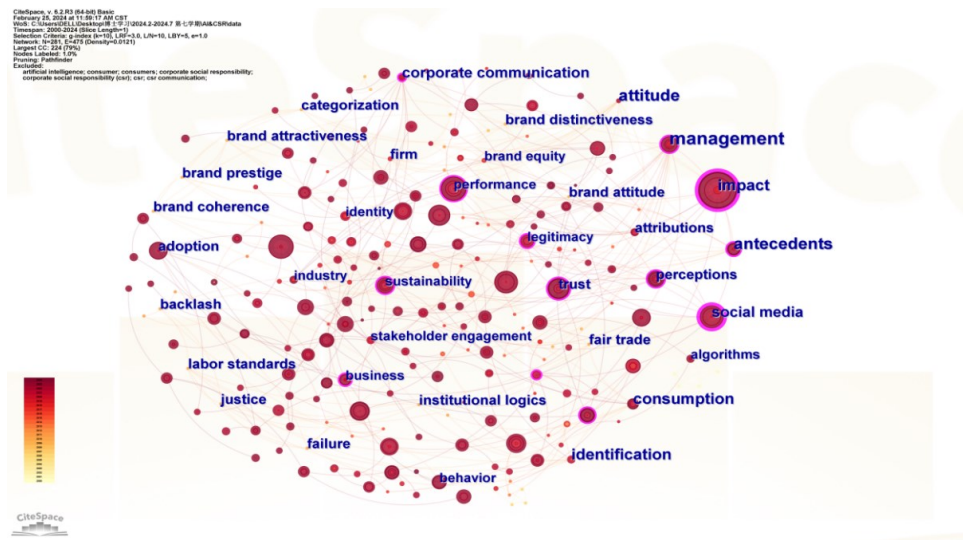
Overall, knowledge graph analysis clearly shows the contributions made by various core research institutions in consumer corporate social responsibility communication and artificial intelligence research and their close cooperation relationships with each other.

Research hotspots and evolution trends

Keywords/research hotspot analysis

According to the keyword analysis knowledge graph shown in Figure 5, we can observe the hotspots and focuses of CSR communication and artificial intelligence (AI) research in the consumer field.

Figure 5
Keyword knowledge map



Source: Author's work

Through the analysis of keyword frequency, we found that "impact," "performance," "information," "social media," "technology," "strategy," "engagement," "model," "management" and "communication" have the highest frequency of appearance (Table 7). Particularly noteworthy is that "social media," "impact", and "management" have higher centrality throughout the entire knowledge graph, indicating widespread attention in CSR communication, AI, and consumer research.

Furthermore, Figure 5 elucidates that there exists a total of 281 keywords ($N=281$), accompanied by 475 interconnections ($E=475$), and portrays a network density of 0.0121 within the realms of CSR communication, artificial intelligence, and consumer behaviour. This intricate web encompasses various disciplines, including finance, economics, management, environmental studies, communication, and beyond. Such findings underscore an interdisciplinary and diversified developmental trajectory, which further accentuates the notion that CSR communication channels that integrate AI are progressively steering towards holistic and high-calibre sustainable development.

Table 7
Keyword knowledge map

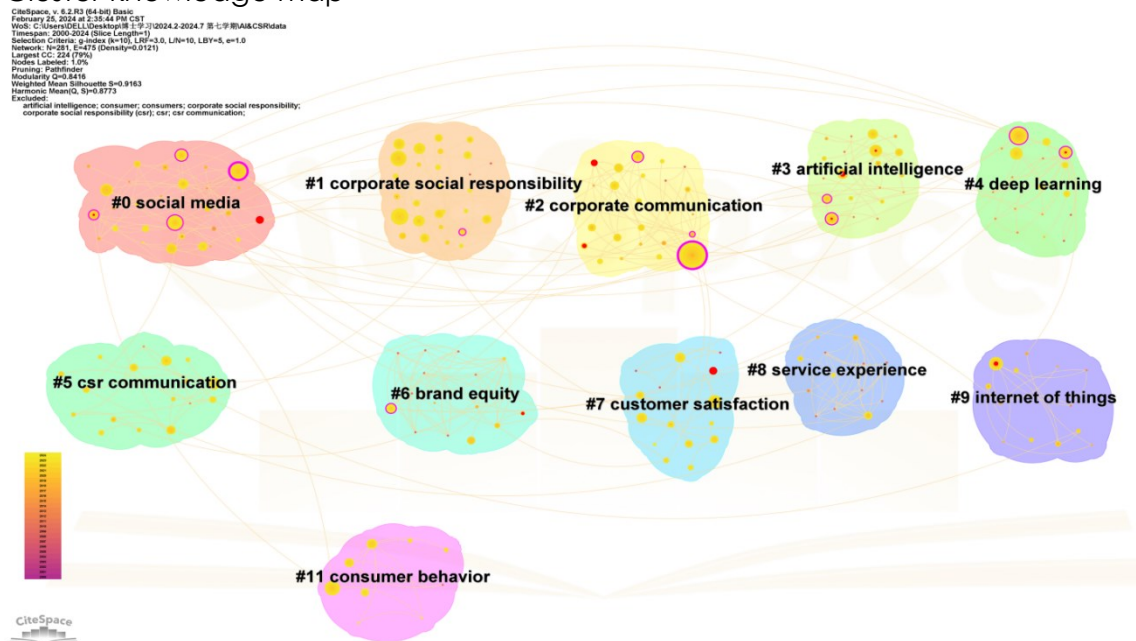
Keywords	Count	Centrality	Year
impact	166	0.24	2008
performance	90	0.12	2014
information	80	0.04	2017
social media	75	0.32	2016
technology	75	0.06	2020
strategy	69	0.09	2009
engagement	67	0.10	2018
model	65	0.05	2017
management	65	0.19	2009
communication	57	0.04	2013

Source: Author's work

Research frontier analysis

This study utilised the knowledge clustering analysis feature of CiteSpace software, combined with the Log Likelihood Ratio (LLR) algorithm, to categorise and summarise the keywords in the field of CSR communication. This process provided a more comprehensive display of the frontier achievements in this field. Following the clustering analysis, we obtained 11 keyword clusters, with a modularisation index Q of 0.8416 exceeding 0.3, indicating the rationality of the network structure concerning AI in corporate social responsibility communication and consumer domains (Figure 6).

Figure 6
Cluster knowledge map



Source: Author's work

Furthermore, the network's Mean homogeneity (Mean Silhouette) of 0.9163 indicates the rational effectiveness of the clustering results, with well-defined keyword sub-clusters and high internal coherence within cluster nodes. These findings contribute to a deeper understanding of the connections and differences between various topics in the field of corporate social responsibility communication, providing important reference points for related research (Table 8).

Cluster 1 mainly studies CSR, including corporate social responsibility, artificial intelligence, CSR communication, CSR, and social media. Cluster 2 mainly studies corporate communication, including corporate communication, utilitarian products, donations, employees, and hedonic products. Cluster 3 mainly studies artificial intelligence, including artificial intelligence, governance, CSR communication, the Czech Republic, and sensemaking. Cluster 4 mainly studies deep learning, which mainly includes deep learning, sentiment analysis, supply chain management, supply chain, and CSR. Cluster 5 mainly studies CSR communication, including CSR communication, artificial intelligence (AI), finance, fintech, and social media. Cluster 6 mainly studies the annual reports, including brand equity, annual reports, attribution theory, corporate culture fit, and visual message. Cluster 7 mainly studies customer satisfaction, including customer satisfaction, information quality, voice assistants,

satisfaction, and linguistic feature analysis. Cluster 8 examines the service experience, mainly including service experience, augmented reality, virtual reality, virtual assistants, and customer experience. Cluster 9 impact studies on the Internet of Things, including the Internet of Things, congruence, employer attractiveness, edge computing, and turnover intention. Cluster 11 studies consumer behaviour, mainly including consumer behaviour, PLS-SEM, empirical research, AI-enabled products, and self-endorsement.

Table 8
Result analysis of cluster knowledge

ID	Size	Silhouette	Top Terms (LLR log –likelihood ratio)
#0 social media	28	0.829	social media; stakeholder engagement; sustainable development; artificial intelligence; legitimacy
#1 corporate social responsibility	28	0.883	corporate social responsibility; artificial intelligence; CSR communication; CSR; social media
#2 corporate communication	25	0.862	corporate communication; utilitarian product; donation; employees; hedonic product
#3 artificial intelligence	20	0.979	artificial intelligence; governance; CSR communication; Czech republic; sensemaking
#4 deep learning	18	0.914	deep learning; sentiment analysis; supply chain management; supply chain; CSR
#5 CSR communication	18	0.832	CSR communication; artificial intelligence (AI); finance; fintech; social media
#6 annual reports	16	0.986	brand equity; annual reports; attribution theory; corporate culture fit; visual message
#7 customer satisfaction	14	0.962	customer satisfaction; information quality; voice assistants; satisfaction; linguistic feature analysis
#8 service experience	13	1	service experience; augmented reality; virtual reality; virtual assistants; customer experience
#9 internet of things	13	0.902	internet of things; congruence; employer attractiveness; edge computing; turnover intention
#11 consumer behaviour	10	1	consumer behaviour; pls-sem; empirical research; AI-enabled products; self-endorsement

Source: Author's work

Based on the analysis of research hotspots, the research areas of corporate social responsibility communication, artificial intelligence, and consumer behaviour from 2000 to 2024 mainly include three directions: 1. CSR communication-related research. 2. AI and its applications and learning research. 3. consumer behaviour research. In CSR communication-related research, scholars focus on corporate communication strategies, influence, and the public's reception and feedback on corporate social responsibility practices. In AI and its applications and learning research, the emphasis is on the utilisation of AI technology in business environments and its impact on consumer behaviour and market trends. Additionally, in the field of consumer behaviour research, scholars explore the psychological factors behind consumer purchase decisions, brand loyalty, and the impact of marketing strategies on

consumer behaviour. These three directions are currently hot topics in this field and are of significant practical importance.

Firstly, research related to CSR communication primarily focuses on clusters 0, 1, 2, 5, and 6. The form of CSR communication is profoundly influenced by industry and institutional pressures and organisational characteristics, challenging the universality of CSR initiatives (O'Connor & Gronewold, 2013). Regarding the application and performance of AI in CSR communication, research is mostly conducted on social media platforms. The dissemination and methods of CSR on social media are concerns for researchers and businesses.

Abitbol and Lee (2017) explored how companies strategically use dedicated pages on Facebook to engage stakeholders and found that alignment with core business themes can effectively attract stakeholders. Meanwhile, an analysis of the communication strategies of Chinese and Japanese companies on Facebook and Twitter revealed that Chinese companies prefer a diversion strategy and demonstrate faster and stronger handling capabilities of online complaints (Yuan, 2018). A survey found that consumers' overall response to AI influencers on Instagram is less trustworthy than traditional influencers (Sands et al., 2022), leading researchers to caution brands against hastily replacing human influencers with AI counterparts. Text-based chatbots are considered innovative but perform poorly on social media platforms; frequent failures lead to consumer resistance (Cheng et al., 2022).

Second, research on artificial intelligence (AI) and its applications and learning primarily focuses on clusters #3, #4, #8, and #9. Intelligent AI devices have become a common presence in the commercial sector, providing a wide range of services from the medical industry to the hospitality sector. From an organisational perspective, AI devices offer several advantages over humans, enabling faster and more accurate execution of certain tasks while also being more cost-effective (Pelau et al., 2021). Consequently, the application and study of AI have become the focal point of researchers and businesses in recent years. Chhetri (2024) proposes that the integration of AI and machine learning technologies in the food industry, particularly in food quality control and safety, not only enhances efficiency and minimises risks but also ensures regulatory compliance, heralding a new era of personalised nutrition, autonomous monitoring, and global collaboration, marking a paradigm shift in the field of food quality control and safety (Chhetri, 2024).

However, the greatest challenge facing the investment and proliferation of AI in enterprises and markets is how to gain better acceptance from stakeholders, with many scholars offering constructive suggestions. Currently, the impact of AI on stakeholders, especially consumers, is not very pronounced, and there are even cases of consumer resistance to AI. Consumer engagement through AI (such as voice assistants) does not directly influence future purchasing intentions (McLean et al., 2021). However, it has been found that when humanoid AI devices can demonstrate empathy and interaction similar to human consumers, they are more likely to be accepted (Pelau et al., 2021). The anthropomorphised attributes of perceived warmth and perceived capability positively affect consumers' perceived trust in chatbots, while communication delay has a negative impact (Cheng et al., 2022).

Furthermore, researchers have found that consumers' acceptance of highly innovative products with very low practical value (such as AI-based smart products) is more influenced by technological interest than utilitarian aspects. Therefore, when facing highly innovative products, consumers are not inclined to "pay the bill" solely for the sake of pursuing "low prices" (Sohn & Kwon, 2020). Yen and Chiang (2020) found that chatbots in AI enable businesses to enhance customer experiences and meet expectations through real-time interactions in e-commerce environments. Thus,

factors influencing consumers' trust in chatbots are crucial. Credibility, capability, anthropomorphism, social presence, and informativeness affect consumers' trust in chatbots, thereby influencing purchase intentions.

Finally, research on consumer behaviour has long been favoured by researchers because consumer behaviour determines a company's profits and reputation. Through the organisation and summarisation of a large body of relevant studies, it has been found that consumer behaviour is influenced by CSR communication and technological applications. Consumer behaviour is the study of how individuals, groups, and organisations choose, acquire, use, and provide ideas, goods, and services to meet their requirements and needs. It refers to the behaviour of customers in the market and its underlying reasons. Customer Behaviour Modelling (CBM) in the field of AI is a frequently mentioned technical concept by researchers. It is constructing a mathematical structure to capture typical behaviours observed in certain customer groups so that similar behaviours can be predicted under comparable conditions.

Meanwhile, scholars have explicitly stated a positive correlation between CSR communication and consumer behaviour. In the banking sector, the use of technology has a positive and direct impact on service quality, customer satisfaction, and consumer purchasing behaviour (Omoge et al., 2022). Corporate social responsibility communication contributes to increasing consumers' likelihood of purchase and admiration for banks (Gupta et al., 2021). Including Generation Y, corporate social responsibility support plays a central role in regulating purchase intentions (Luger et al., 2022).

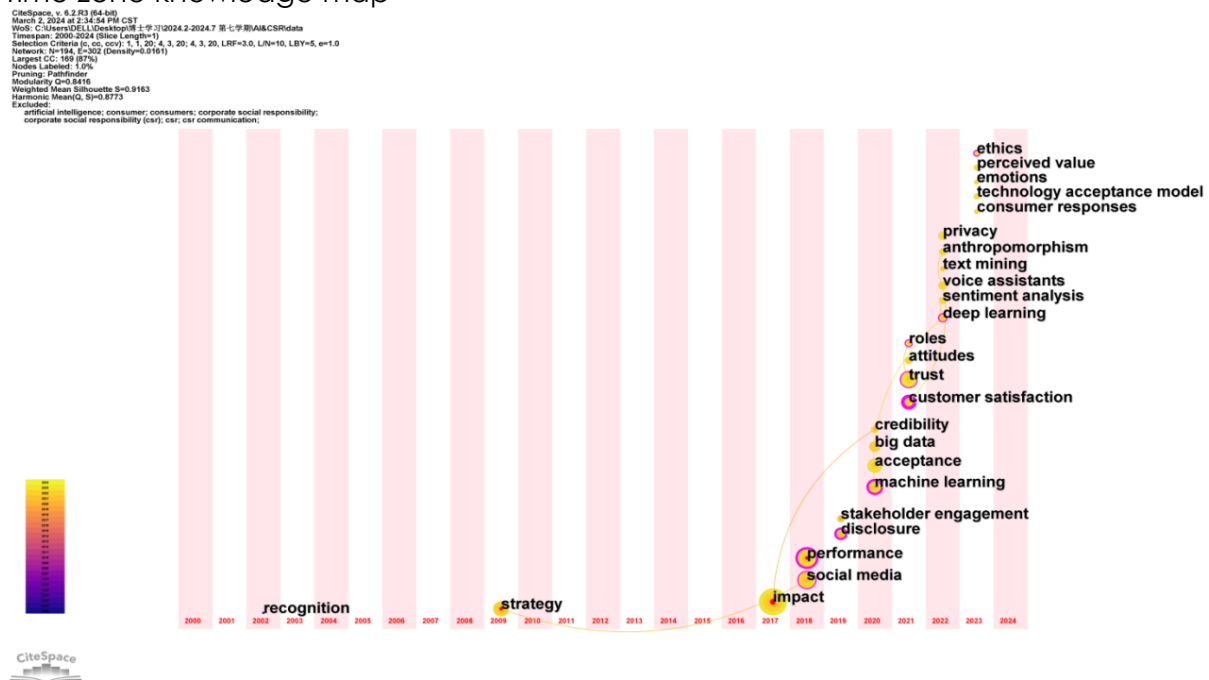
In addition to research on traditional CSR communication and consumer behaviour, scholars have studied the impact of new technologies appearing in social media on consumer behaviour. Laszkiewicz and Kalinska-Kula (2023) conducted research on the influence of computer-generated avatars and virtual influencers (VIs), including those using artificial intelligence (AI) and machine learning, on consumer attitudes and behaviour in social media, revealing the mechanisms of VI attractiveness and their role in shaping consumer attitudes and behaviour.

Research trend analysis

Time zone analysis

As a visual representation of data, a time zone map not only clearly depicts the distribution and changes of keywords in different periods within specific topics or fields but also aids in better understanding the evolving hot topics in the field of CSR communication. Through in-depth analysis of time zone maps, rich information can be extracted, such as the frequency of use of specific keywords or phrases during certain periods, the relationships between related topics, and trend changes. Regarding the impact of AI on consumer satisfaction in CSR communication, the time zone view can clearly display the usage of popular phrases and keywords from 2000 to 2024, spanning approximately 24 years (Figure 7). These data reflect the challenges, opportunities, and evolving trends related to the application of AI technology in CSR communication. By delving into and analysing these data, we can more accurately grasp the challenges faced by AI technology in different stages of CSR communication and provide a reference for future development of rational and effective communication strategies. Therefore, the time zone map has become an important tool for understanding the dynamics of the research field.

Figure 7
Time zone knowledge map



Source: Author's work

Although data collection results show that research on the application of AI in CSR communication and its impact on consumers emerged as early as 2000, analysis reveals that it was not primarily within the disciplines of marketing, economics, and management but rather concentrated in medical and biological-related disciplines. Furthermore, research in this field has not been extensive, with scholars only beginning to study and organise it in 2017 systematically. Over these 7 years, the research can be categorised into three distinct phases: 2017-2019, 2020-2022, and 2023. However, these phases cannot be accurately classified according to the conventional stages of "initiation," "development," and "maturity" because AI in CSR communication and consumer domains is a relatively novel concept. Instead, over these 7 years, the field more closely resembles an initiation phase. As researchers delve deeper, as businesses apply AI in practice and as consumers and markets react, various challenges and issues arise alongside the convenience of AI in CSR communication with consumers. Therefore, the author primarily divides these three periods based on the differing focal points of research questions during each period.

Between 2017 and 2019, research in this field primarily focused on the impact of corporate social responsibility communication on consumers, who often utilised social media platforms for application. However, researchers began to shift away from traditional questionnaire analysis methods towards using media data or more specific analytical approaches, laying a solid foundation for subsequent AI learning and improvement. Etter et al. (2018) suggested using social media data and sentiment analysis to study citizens' emotionally based responses to organisational behaviour. Some scholars provided practical recommendations for companies engaging in CSR communication through social media. They suggested that companies could use hashtags to make thematic information clear and leverage discussions within existing social movements to resonate with consumers, thereby conveying the theme of corporate social responsibility (Saxton et al., 2019). Additionally, frequent tweeting

about corporate social responsibility on social media platforms was found to garner higher user approval (Araujo & Kollat, 2018).

From 2020 to 2022, research in this field primarily focused on two aspects: exploring AI technology and discussing consumer trust in AI. Regarding the exploration of AI technology, this included machine learning, voice assistants, text recognition, and more. Huang and Rust (2020) found a three-stage framework for strategic marketing planning, integrating various AI advantages: mechanical AI for automating repetitive marketing functions and activities, thinking AI for processing data to make decisions, and emotional AI for analysing interactions and human perceptions. Buhalis and Moldavska (2022) found through research on interactions supported by Voice Assistants (VAs) between hotels and guests in the hotel industry that although VA technology is still in its infancy, virtual assistants are increasingly becoming digital assistants, helping hotels improve customer service, expand operational capabilities, and reduce costs.

As for the issue of consumer trust in the application of AI technology in CSR communication, it appears to be one of the concerns and focuses for researchers and businesses. Artificial Intelligence (AI) voice assistants (VAs) continue to be popular among consumers, and while technological means do influence consumers' brand engagement, concerns about trust issues that may arise after AI usage can negatively impact brand engagement behaviour (McLean et al., 2021). Uysal's interviews and on-site research with Artificial Intelligence Assistants (AIAs) users indicated that the anthropomorphism of AIAs may threaten users' identity, thereby depriving them of their power, triggering data privacy issues, and ultimately harming their well-being. These harmful effects are particularly evident in intimate, long-term relationships (Uysal et al., 2022).

In the past year of 2023, researchers have focused more on addressing trust issues and improving how AI serves CSR communication with consumers. Particularly, addressing ethical issues mainly centred around trust problems has drawn attention from practitioners and scholars. Liu et al. (2021) highlighted the need for scrutiny of ethical issues associated with the use of artificial intelligence. This scrutiny can help organisations gain trust, minimise privacy infringements, and ultimately promote responsible success in operating AI on social media platforms. Meanwhile, an increasing number of scholars are utilising technology acceptance models (TAM) to explain the relationship between consumer perception and AI usage. Iancu and Iancu (2023) found in their study involving elderly consumers in the healthcare industry using AI-related systems that perceived ease of use was explained by effort, ability, and perceived external control when interacting with chatbots, while perceived usefulness was supported by perceived ease of use and subjective norms.

Additionally, if individuals perceive the interaction as useful and receive approval from others, they may further utilise chatbots (behavioural intention). This insight suggests that in the design of future AI products and systems, ease of use should be the primary consideration, following responsible AI principles, and effective promotion of AI products and systems should also be conducted to influence consumer perceptions positively. Previous research indicates that consumers perceive non-human (compared to human) agents differently in many aspects (e.g., lacking emotional capability), leading to various behavioural changes when interacting with them. Kim et al. (2022) found that users tend to engage in unethical consumer behaviour more when interacting with non-human (as opposed to human) agents (e.g., artificial intelligence and robots) because the anticipated guilt is reduced. Furthermore, he proposed the moderating effect of anthropomorphism, suggesting that imparting non-human agents with human-like characteristics can reduce

unethical behaviour. Therefore, anthropomorphism in AI regulation can not only increase user trust and experience but also effectively reduce user unethical behaviour.

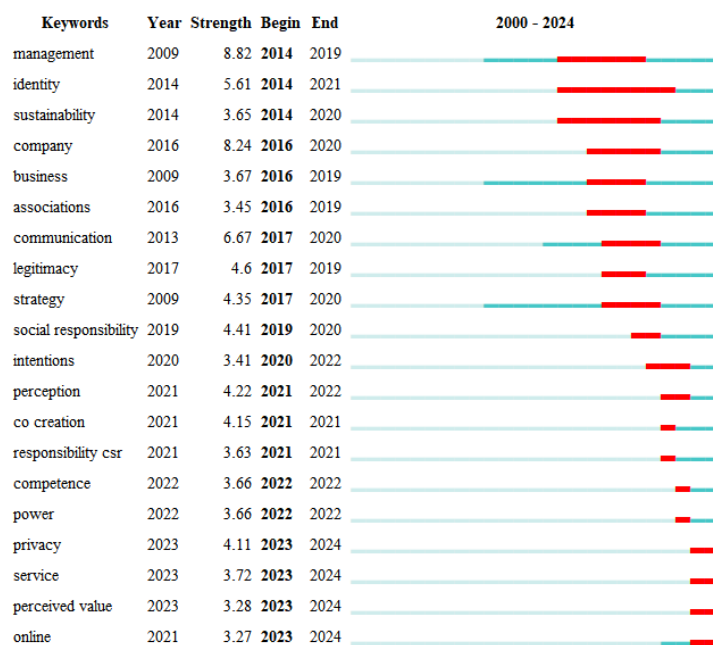
Keywords' burst analysis

Keyword burst analysis is an important method based on big data, which helps the scientific community to understand hot issues in a timely manner by analysing the frequency changes of specific keywords in a particular field. This method not only reveals valuable information about research frontiers and trend predictions but also provides valuable data references for decision-makers. The intensity and duration of keyword bursts over the past 24 years, as shown in Figure 8, reflect the achievements of this method in practical applications. Through in-depth analysis of these data, we can better understand issues that suddenly attract attention in certain fields and provide guiding significance for future related research. Furthermore, with the continuous advancement of technologies such as artificial intelligence and machine learning, keyword burst analysis will also usher in new development opportunities.

Figure 8

Keywords' burst analysis

Top 20 Keywords with the Strongest Citation Bursts



Source: Author's work

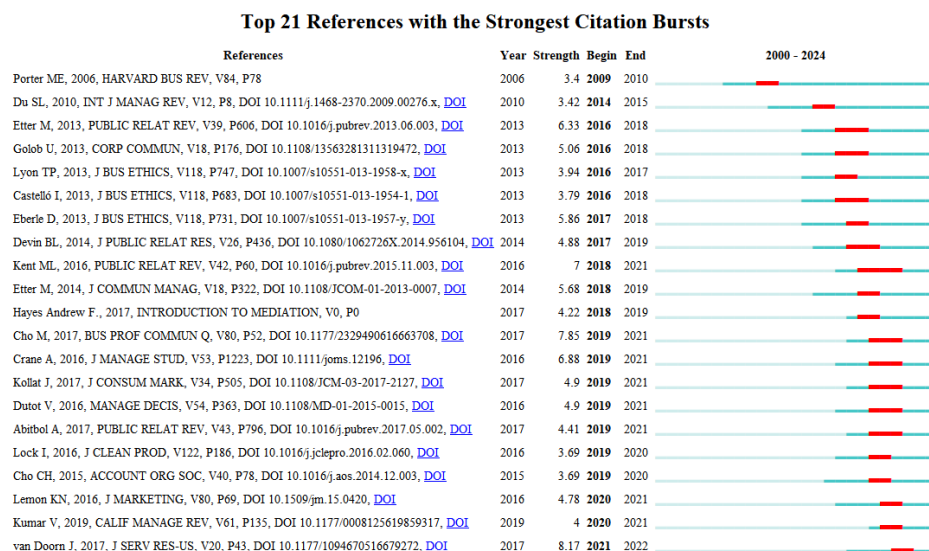
In CiteSpace operations, the period should be set to at least one year, and parameters such as gamma 1.0, $f(x) = \alpha * e^{-\alpha x}$ (where $\alpha 1 / \alpha 0 = 2.0$, $\alpha 1 / \alpha 1 - 1 = 2.0$) should be used for analysis. The red part indicates the period during the outbreak of the epidemic, during which the keyword "management" became a topic of continuous discussion and attention.

In addition, over the past 24 years, "business" and "social responsibility" have also been two keywords with long durations and high levels of attention. These data not only reflect the enduring high involvement of people in issues such as business economy and social responsibility but also help us better understand the changes and evolution of different thematic topics within various fields over time.

Analysis of cited reference burst

According to the data from Figure 9, citations related to artificial intelligence in the field of consumer social responsibility communication show a steady increase year by year, which indicates that research on artificial intelligence in consumer social responsibility has garnered widespread attention from both academia and industry. The primary period is set to at least 2 years in the Citespace. This decision was made because journals published within a one-year period are numerous and widely distributed, allowing for a better reflection of the development of artificial intelligence and consumer social responsibility communication. From the graph, it can be observed that articles such as Cho et al. (2017), Crane et al. (2016), and Etter et al. (2018) have experienced significant citation bursts, indicating that many scholars cited these journals during that period, and these articles hold significant importance in the field. This further confirms that the intersection of artificial intelligence and consumer social responsibility communication is becoming a focal point of attention for both academia and industry.

Figure 9
Cited references burst



Source: Author's work

There is an increasing acknowledgement that the design, implementation, and effectiveness of CSR initiatives are not merely internal management concerns; rather, they necessitate robust communication and collaboration with stakeholders. These stakeholders include employees, customers, suppliers, investors, government agencies, and local communities, among others. They have direct or indirect impacts on the actions and decisions of the corporation. Therefore, establishing good communication channels with them and actively listening to their opinions and feedback are crucial for the success of CSR initiatives. Only through effective communication with stakeholders can their needs and expectations be better understood and considered in CSR planning, ensuring that the design, implementation, and success of CSR initiatives align with the principles of social responsibility and have a positive impact (Crane & Glozer, 2016). The communication between businesses and users regarding CSR has been a topic of discussion for nearly two decades. However, even among the 'World's Most Admired Companies' listed by

Fortune magazine, the frequency of non-CSR messages conveyed in social media posts by companies exceeds that of CSR messages. When conveying CSR activities, companies tend to use informative strategies rather than interactive strategies, and they include activities targeting internal audiences more frequently than those targeting external audiences (Cho et al., 2017). Effective CSR communication is not something that can be achieved overnight; it requires time and strategy, which is challenging for business managers.

For the application of new technologies such as AI, as early as 2016, Doorn emphasised in their research the ability of technology to attract customers at the societal level, introducing a new concept called Automated Social Presence (ASP), which refers to the extent to which technology makes customers feel the presence of another societal entity. Based on this concept, Doorn also suggested that in response to the impact of new technologies on consumers, companies should focus on the application of technology in relation to customer relationships, the tendency for technological anthropomorphism, and technological readiness (van Doorn et al., 2017), which aligns with the previous discussion on the timeline of keywords and reflects the focus and trends of research in recent years and the future.

Conclusions

Contributions

The purpose of this study is to provide an overview of the application of AI in the field of CSR communication and its relationship with consumers. Through bibliometric analysis of literature, we can identify patterns, and characteristics within relevant thematic research, highlighting current areas and potential future directions. CiteSpace (V6.2.R3) is a widely used tool for this purpose; therefore, we selected it for our analysis. We searched the WOSCC database using keywords "AI," "Corporate social responsibility communication," and "Consumer," applying specific criteria that resulted in 1094 articles published over a span of 24 years (from 2000 to February 2024). After categorising the 158 disciplines, we identified the top five key disciplines as business, management, environmental studies, engineering, electrical engineering, and environmental sciences.

Firstly, in terms of publication volume, before 2012, scholars showed limited interest in this field, with very few focusing on the application of AI in CSR communication and its impact on consumers. With the introduction of the AI concept, from 2013 to 2018, there was a noticeable increase in the number of articles published. In contrast, from 2019 to 2023, the research related to this topic saw a sharp increase, with not only theoretical studies but also more scholars analysing problems encountered by businesses in the market and providing relevant recommendations through experimental methods, which indicates that research in this field has received increasingly widespread attention in the academic community. At the same time, we expect the number of publications in 2024 to be approximately 378.

Secondly, the authors conducted an in-depth analysis and identification of key contributors and collaborators in the field. Cheng Yang as one of the most influential authors in the field, with the publication of 8 articles. Following closely are Lu Yaobin, Dong Tianqing, and Cui Yuanyuan (Gina), each with 6 articles published in the field. Moreover, besides individual contributions, prominent institutions such as the University of London, Copenhagen Business School, and Auckland University of Technology have also made significant literature contributions in this domain.

In country/region analysis, the United States leads in research publications, followed by China and the United Kingdom, respectively, reflects the strong research

capabilities of these countries in the field and their high level of attention and investment in related issues. It is worth noting that there are many other countries or regions globally that actively participate and make significant contributions, which may become even more active and prominent players in the future.

Thirdly, the analysis of keyword distribution in the field of AI application in CSR communication and relationship with consumers reveals that "social media," "impact," and "management" are the top three contributing keywords. In order to make the analysis clearer, the software generated 12 clusters with different names. For example: #0 social media, #1 corporate social responsibility, #2 corporate communication, #3 artificial intelligence, #4 deep learning, #5 CSR communication, #6 annual reports, #7 customer satisfaction, #8 service experience, #9 internet of things, #11 consumer behaviour. After clustering these 12 groups, the authors classified them into three research directions based on their content, namely research related to corporate CSR communication, research on AI and its applications and learning, and research on consumer behaviour.

Fourthly, when classified according to the timeline of keywords, it was found that the research in this field is relatively recent, with scholars only beginning to research and organise it from 2017 systematically. Over these 7 years, the research can be divided into three stages: 2017-2019, 2020-2022, and 2023. Overall, during these 7 years, this field remains in the developmental stage. Particularly, with the increasing adoption and popularisation of new technologies such as AI, more and more researchers are focusing on addressing trust issues and improving AI's service to CSR communication for consumers. Ethical issues, particularly those related to trust, have garnered attention from practitioners and scholars alike.

Finally, in burst word analysis, "management" has been the longest burst word in the past 24 years. Other keywords with lasting impact include "business" and "social responsibility". As CSR communication and consumer relations are inherently part of the disciplines of management and business, many scholars use disciplinary classification as a key criterion. 'Privacy', 'Service', 'Perceived value', and 'Online' are newly emergent keywords this year, indicating potential directions for future research. It also proves that issues of trust and ethics have always been issues that urgently need to be addressed and paid attention to in this field (Gonçalves et al., 2023; Du & Xie, 2021). At the same time, we found through research that some scholars have given relevant and effective suggestions (Buhalis & Moldavska, 2022; Etter et al., 2016). Researchers and businesses increasingly focus on the impact of businesses on consumers when utilising artificial intelligence for CSR communication. Particularly, there is a growing emphasis on using new technologies such as artificial intelligence to improve service, enhance consumer perceived value, better protect consumer privacy, and consequently alleviate consumer concerns about artificial intelligence.

Through visual analysis of knowledge graphs, we can gain insights into the application of artificial intelligence in corporate social responsibility communication and consumer relations, which helps to understand the knowledge structure of this field comprehensively and provides valuable references for related research. Firstly, we can summarise the trends and distribution of contributions in the articles to demonstrate that the application of artificial intelligence in corporate social responsibility communication is a continuous and highly valued research direction. This is significant as it impacts consumers. Secondly, we can delineate the foremost contributors—namely, the authors, institutions, and nations—that significantly impact this domain. Furthermore, we shall delve into an intricate analysis of keyword clusters and explore the most frequently cited articles. This information will help us better understand the current research status. Thirdly, during the visual analysis of knowledge

graphs, we can uncover the topics and themes of great interest, guiding future related research. Fourthly, after delving into the evolution of research on the impact of artificial intelligence on corporate social responsibility communication to consumers, it is necessary to classify and elaborate on it according to content. Additionally, analysing and summarising future research directions based on highly cited articles will assist future scholars in finding relevant statistical data and analytical materials, thus promoting further development in this field.

In practical terms, firstly, scholars provide more reflections on corporate social responsibility communication strategies, encouraging companies to leverage social media to increase the frequency and content of CSR communication. Simultaneously, regarding the development and application of technologies like AI, emphasis should be placed on AI's simulation of human emotions. Moreover, when companies utilise AI-related products and services targeting consumers, ensuring consumer convenience should be a priority. Additionally, adequate pre-promotion efforts are essential, potentially fostering greater consumer acceptance of AI-related services and products. Regarding ethical concerns and privacy issues, companies should adhere to responsible AI principles to better serve consumers and the market.

Limitations and future studies

Research on the impact of artificial intelligence on CSR communication with consumers still has certain limitations. Apart from the limitations of bibliometric analysis, there are other aspects to consider. Firstly, due to the continuous development and changes in artificial intelligence technology itself, research results may vary at different time points. Secondly, during the data collection process, factors such as sample selection bias and data quality may affect the accuracy and reliability of research conclusions. Additionally, relevant literature may be omitted when searching for keywords. For example, not all fields or specialised terms related to corporate social responsibility communication and artificial intelligence are covered. Therefore, in future research, it may be beneficial to use broader search strategies to obtain more relevant literature and consider introducing other databases for comparative analysis to improve data coverage. The application of AI in CSR communication involves multiple fields, such as ethics, law, and business, thus necessitating interdisciplinary research and collaboration. For instance, in the ethical domain, artificial intelligence may impact consumer privacy, while in the legal realm, it requires clarity on relevant responsibilities and regulations. Moreover, businesses need to enhance their communication skills and methods to convey their social responsibility better and enhance consumer awareness of their actions. Additionally, at the consumer level, there are divergent attitudes toward the use of artificial intelligence in CSR communication. Some consumers are concerned that artificial intelligence may lead to job losses or replace traditional service methods, while others value the convenience and efficiency it brings. Therefore, when engaging in CSR communication, it is crucial to consider the needs and concerns of different groups and seek more effective communication methods. Addressing these issues, academia and businesses can strengthen collaborative research efforts to explore how new technologies, such as artificial intelligence, can improve CSR communication and alleviate consumer concerns about ethical implications.

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Exploring the Link between Sustainable Practices and Corporate Performance Across Industries

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Abstract

Background: The adoption of the Sustainable Development Goals (SDGs) has set a global standard for promoting sustainable practices. However, manufacturing companies need help in adopting these practices due to differences between industries, the need for research and development, and variations in corporate sizes.

Objectives: This analysis aims to study sustainability practices and their impact on corporate performance across different industries. It seeks to identify whether there is a relationship between sustainability practices and corporate performance in manufacturing companies and if the type of industry affects this relationship.

Methods/Approach: To achieve this goal, a multivariate analysis was conducted using hierarchical regression. **Results:** The research indicates a direct connection between sustainability practices and corporate performance. It highlights the importance of creating distinctive sustainability practices that cater to the specific needs and characteristics of each industry. **Conclusions:** Developing corporate strategies around sustainability is imperative. Additionally, public policies should be implemented to encourage the adoption of such practices, reinforcing the need for industry-specific approaches to enhance both sustainability and corporate performance.

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Introduction

Manufacturing companies have adopted various approaches to achieve competitive advantage in recent years: downsizing, benchmarking, outsourcing, quality management, shared value, and outplacement, and although all function according to the organisational goal, none has promoted a fundamental factor for the corporate future, like the idea of sustainability. Each approach has solved difficulties in terms of costs, management, quality, and service. Still, a fundamental fact in the competitive environment began to draw severe attention: the environmental agony that the planet is experiencing, which is evident in climate change, arid soils, melting of the poles, prolonged droughts, and unprecedented atmospheric variations, among many others. Therefore, the concern to include sustainability practices in business activities has become not only an approach but a necessity that forces companies to develop competitive strategies that associate the value of environmental impact within their products.

Some organisations have worked in the short term (Haessler, 2020) with the replacement of plastic bags with cloth bags, recycling, better packaging design, and reduction of additives and preservatives; these solutions, however, are not enough, so organisations must redesign their production processes to modify the industrial habits that have positioned companies for decades. To achieve this, some companies have had to invest in research and development, technology, specialised human capital, and even share information with their competitors to improve certain processes to benefit competitive industries.

This concern requires industrial organisations to consider sustainability practices (Batista & Francisco, 2018) as a better way to achieve superior corporate performance and the possibility of combining these sustainability practices with their competitive strategy to reach long-term competitive advantages. Thus, in the present study, five industries have been grouped to recognise their sustainability practices and understand the impact of these practices on corporate performance, with the industries being a moderating variable that allows explaining whether this relationship is stronger or weaker according to the type of industry. The following industries have been selected for the study as they are the industries that offer the greatest contribution in economic terms to the industry: food and textile products, wood and paper, oil, pharmaceutical, chemical and rubber, metallurgy and electronics, machinery, and transport.

Some previous studies have established the importance of these practices and the organisations' ability to create value from the environmental axis (Tapaninaho & Heikkinen, 2022), while others have established that environmental activities are negatively affected by other factors (Miroshnychenko & De Massis, 2022; Disli et al., 2022); therefore, these diverse results must be investigated in a specific context like the Colombian one, where each industrial company presents specific behaviours associated with sustainability, according to the subsector in which it is located.

Theoretical Framework

Sustainability practices are all those actions carried out with the objective of reducing the environmental damage caused by business activities. In the early years of the environmental movement, many organisations considered recycling and reducing paper use as responsible environmental practices. However, as more research, information, and natural phenomena became evident, organisations found that water use, energy intensity, large amounts of waste, and the low environmental awareness of companies and consumers broadly affected nature—the unique source

of indispensable resources for corporate operation. Therefore, the environmental awakening, as it might be called, initiated a broader and faster movement, moving from simple sustainability practices to practices in the production processes that involved better inputs, reduction in the intensive use of some resources, or their shift to other alternative sources, as well as a change in the conception of consumption, the economic cycle, and therefore, what it means to be sustainable (Oriade et al., 2021). However, corporate performance (De Steur et al., 2020), derived from the sales of traditional and non-ecological industrial products, did not stop; on the contrary, companies increased their profitability indices with the same products and minor changes. Organisations have demanded more from managers in situations of great environmental uncertainty (He et al., 2021). Therefore, the concern for being sustainable did not modify the intention of the large corporations: to create more products, more consumption, and therefore higher levels of sales.

Manufacturing organisations have implemented various sustainability practices, but finding the practices suitable for the type of organisation and industry becomes a challenge for both resources and capabilities. To reach suitable sustainability practices, organisations should go through research processes that lead the company to develop innovations in their production processes, reducing the use of scarce resources and improving the use of resources that are less polluting to the environment. There are multiple contradictory studies regarding the effects of sustainability policy (Böttcher & Müller, 2016), some showing positive effects (Chuang & Huang, 2018; Naidoo & Gasparatos, 2018), others with negative effects (Dahlmann et al., 2019; Lin et al., 2007). Thus, sustainability and its effects on performance must be studied in this context, which clarifies whether corporate concern for sustainability, associated with appropriate practices, can impact performance (see Figure 1). Including, for example, defining new strategies for developing new products, entering new markets, proposing modifications to their processes, and achieving a sustainable competitive advantage. Therefore, the following hypothesis is proposed:

- *H1a. The sustainability practices of manufacturing companies positively affect their corporate performance.*

Manufacturing Industries

The manufacturing industry is as varied as the types of products offered; therefore, for the present research, it is important to recognise the moderating role of the different subsectors that make up the industry. Previous studies (Rahman et al., 2022; Malesios et al., 2018) have examined the manufacturing industry. However, only some studies have identified groups of industries and their interaction between sustainability practices and corporate performance.

Each economic industry is distinct and, therefore, should have sustainability practices in accordance with its specific characteristics; in the present study, the subsectors have been grouped into 5 main categories that will be studied subsequently. This will allow an understanding of whether the relationship between sustainability practices and corporate performance is moderated by the type of industry in which the organisation is located.

Food and Textile Products Industry

Sustainability in the food industry has been highly controversial over the last 15 years, especially because the industry is considered to be the creator of various environmental problems due to waste generation (Küberling-Jost, 2021; Yngfalk, 2019), indiscriminate disposal, and the intensive use of natural resources. Therefore, the

company's value chain matters significantly in establishing good sustainability practices.

On the other hand, quality activities and customer contact can be fundamental, according to previous studies by Rahmani et al. (2018), for successful sustainability management; other studies show that sustainability is not just an organisational matter but requires an intensive review of the value chain (Vu et al., 2017). However, an additional challenge for the food industry is to create a cooperation system for the company combining sustainability and innovation (Rabadán et al., 2019; León-Bravo et al., 2017); other authors add to this condition for the competitiveness of the industry and state that this cooperation must also be based on appropriate governmental regulations (Ben Amara & Chen, 2020; Guliyeva & Lis, 2020) that allow improving processes to build what is known as eco-innovation. Moreover, the food industry presents a condition in various studies, in entirely different contexts, it has been established that sustainability practices and specifically eco-innovation, which would be the result of these practices, can generate a significant performance improvement (Yurdakul & Kazan, 2020; Cucchiella et al., 2017; Maletič et al., 2016). Therefore, in this study, it is necessary to understand the dynamics of the Colombian food industry sustainability practices and verify if they are positive, as in other contexts.

Meanwhile, the Colombian textile industry is competitive internationally and widely recognised for its quality of fabrics. However, it faces a marked trend towards green fashion (Brewer, 2019), or the trend that seeks to recycle fashion to avoid excessive consumption of clothes and textiles that become pollutants. Some companies have opted to design garments that have multiple uses, or that can later be donated in an attempt to maintain sales but also to slowly implement sustainability policies (Feng & Ngai, 2020) and a culture of proper consumption for customers (Balconi et al., 2019).

It has also been shown that sustainability can improve an organisation's performance (Pedersen et al., 2018). Therefore, sustainability practices can help organisations in the industry develop valuable assets such as reputation and even improve their value chains.

In the food industry, some Colombian companies have a sustainability policy. Companies like Frisby, dedicated to producing chicken products and fast food offered at sales points, have created a sustainability policy emphasising the use of ecological inks, recyclable packaging, and zero use of bleachers (Frisby, 2019). Organisations in these industries should have a greater relationship between sustainability practices and performance. Therefore, the aim is to explain whether:

- *H1b. The food and textile products industry moderates the relationship between sustainability practices and the performance of Colombian manufacturing organisations.*

Wood and Paper Industry

Wood and paper are possibly the industries that have developed the most social responsibility since the Millennium Goals. Its dependence on natural resources has consistently led it to create procedures to restore soils used for the industry and ensure sufficient long-term inputs. This has led to the creation of plastic woods with finishes similar to more expensive and hard-to-obtain woods in the short and medium term.

Some government policies have helped the industry generally establish certain standards (Scordato et al., 2018), although one of the major concerns is the utilisation of waste within the production process (Molina-Sánchez et al., 2018); the application of new technologies (Jiang et al., 2018) to facilitate sustainability practices has also become a concern due to the scope and benefits for a few competitors with enough resources to include them in the entire value chain. However, finding a fair balance

between nature and performance has become the central focus of companies in the industry; some studies (Hurditch, 2018) show that sustainability can help the industry create better practices and continue to be successful.

The wood and paper industry in Colombia is making great efforts to diversify paper production from other resources such as sugarcane bagasse. In Colombia, Grupo Carvajal, especially its company Propal, has developed innovations that, using waste, have managed to position itself in the market as an ecological paper derived from sugarcane crops (Propal, 2019). The company has managed to expand to more than 15 countries and diversify into packaging from the same input, allowing the industry to be widely recognised as highly profitable. Therefore, this study seeks to establish whether:

- *H1c. The wood and paper industry moderates the relationship between sustainability practices and the performance of Colombian manufacturing organisations.*

Oil, Pharmaceutical, Chemical, and Rubber Industry

The Colombian pharmaceutical and chemical industry is very competitive internationally, exports important inputs to different countries, and has consolidated its quality and good practices. However, it faces large competitors with greater research and development capabilities. In sustainability practices, the international pharmaceutical industry works on sustainable packaging (Chaturvedi et al., 2017; Raju et al., 2016), reduction in the use of some raw materials, and especially by generating a sustainability culture that improves its reputation and helps it perform better.

On the other hand, the oil and rubber industry, following the crisis generated by the COVID-19 pandemic, has been seriously affected; according to Dinero (2020), there is currently a demand shortage, generating a possible short-term production drop. However, other oil substitutes in Colombia, such as bioethanol and palm biodiesel, which are developed by mills like Manuelita (Manuelita, 2020), have established themselves as more ecological alternatives with significant results in the industry. The so-called biofuels (Bibi et al., 2017) have become an alternative for fuel production with a lower impact on the ecological environment, which can also be profitable and, in the long term, displace the demand for traditional fuels derived exclusively from oil.

The pharmaceutical, chemical, oil, and rubber industries are highly specialised and competitive and require large investments. These industries have developed essential skills that position them as highly profitable creators of a large number of jobs and significant economic mobilisers. Their value cycle, accompanied by appropriate sustainability practices, can improve firm performance (Hasheminasab et al., 2018), followed by social practices such as improvement in work safety (Huurdeeman & Rozhkova, 2019) for the thousands of employees, would constitute a significant advancement that would improve the industry reputation and therefore its long-term performance. Consequently, it is necessary to establish whether this industry presents better sustainability practices than other industries, establishing the following hypothesis:

- *H1d. The oil, pharmaceutical, chemical, and rubber industries moderate the relationship between sustainability practices and the performance of Colombian manufacturing organisations.*

Metallurgy and Electronics Industry

The electronics industry in Colombia has a particular dynamic, especially dedicated to the assembly of automobile parts. It has been extensively linked to large

multinationals investing in the industry, with Colombian companies becoming their specialised suppliers. This industry globally has had to face radical changes in the consumption and recycling of various types of products, as well as the search for cooperation to make the business more competitive and sustainable (Flygansvæ et al., 2018) while seeking a reduction in the use of raw materials (Ho et al., 2019).

Within the metallurgical industry, the constant concern to improve extraction and subsequent processing methods has created advanced production, distribution, and export policies. This industry is considered a supplier to others in the manufacturing industry and requires intensive study in terms of more responsible practices both environmentally and towards employees. Some authors have made various proposals so that each subsector within metallurgy can improve its ecological impact (Rankin, 2017), especially because it is well-known that the practices of some companies globally are not the most appropriate (Goode, 2018; Lamm & Lips-Wiersma, 2018).

Within the metallurgical industry in Colombia, one of the most representative industries is the steel industry. In Colombia, Acerías Paz del Río, originally Colombian, consolidated as the second most important in the country, although in 2007, it was acquired by a Brazilian company. It has stood out for having a policy on society and the environment, covering the management of water, air, and waste (Paz del Río, 2020). It is important to recognise that while this industry has developed some environmental practices, it still has a long way to go, especially because all decisions organisations make regarding extraction and processing directly affect employees. Additionally, establishing sustainability practices can help the organisation improve its productivity (Sun et al., 2017), which can lead to improvements in its performance. In the Colombian case, sustainability practices in the metallurgy and electronics industry are expected to be broader than in other industries. Therefore, this study seeks to establish whether:

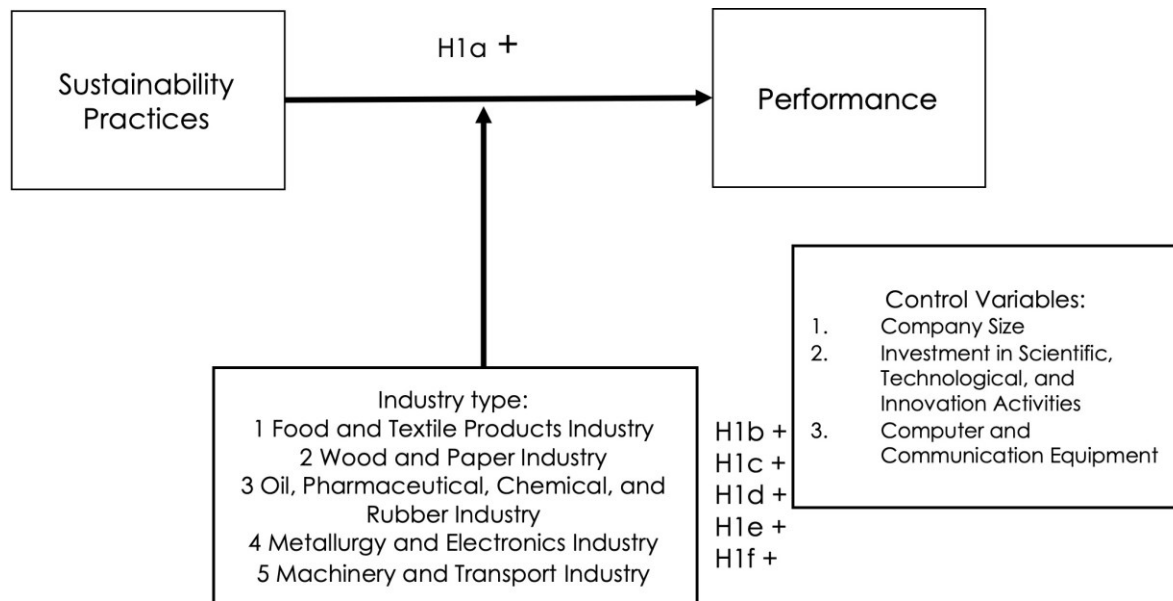
- *H1e. The metallurgy and electronics industry moderate the relationship between sustainability practices and the performance of Colombian manufacturing organisations.*

Machinery and Transport Industry

The Colombian industry includes various groups that trade and assemble machinery and transport vehicles with foreign and national capital. Most of these organisations present sustainability policies derived from the country of origin of these inputs or the consumer's use of the final product. One of the most recognised companies in the industry is Sofasa (Renault, 2020). Although there are few companies in this market niche, it turns out to be an industry that energises the economy thanks to the productive chain behind these types of companies. Sustainability practices for these companies have become a challenge in their production process, especially due to highly polluting inputs, high energy consumption, and little study regarding this industry and its environmental effects (Li et al., 2017). It is important to recognise that companies in the transport industry have different performances in terms of sustainability (Kumar & Anbanandam, 2019) and implement various practices according to their type of business and context (Banerjee & Puneekar, 2020). Therefore, this study seeks to establish whether:

- *H1f. The machinery and transport industry moderates the relationship between sustainability practices and the performance of Colombian manufacturing organisations.*

Figure 1
Research model



Source: Author's illustration

The model of this research tries to explain the positive relationship between the variables sustainability practices and performance in the manufacturing industry; the "+" sign indicates that an increase in one variable is expected to cause a corresponding increase in another variable. According to the model, the connection between sustainability practices and performance is influenced by the industry type. This means that the impact of sustainability practices on performance may vary across different industries depending on their unique characteristics and external pressures. Each industry may respond differently to sustainability practices, and as a result, the strength or direction of the influence may differ. However, all the hypotheses suggest that sustainability practices positively impact performance within particular industries.

Methodology

A sample of 1570 Colombian manufacturing companies from the Survey of Technological Development and Innovation (EDIT) with data from 2017 - 2018 created by the National Administrative Department of Statistics (DANE) was taken (Velez, 2023). For the analysis, a hierarchical regression analysis was performed, which allows the introduction of variables, noting the impact and interaction between variables in each model. The independent variable corresponds to sustainable practices (Pham et al., 2021; Pereira et al., 2021; Zhu et al., 2016), which takes the arithmetic mean of three variables: reduction in energy consumption (Hepburn et al., 2018; Tang & Tan, 2014), waste utilisation (Gupta et al., 2019; Ajemigbitse et al., 2019; Qi et al., 2018), and reduction in the use of raw materials (Lenzo et al., 2018; Sameer & Bringezu, 2019; Sicoli et al., 2019).

The control variable used was company size (Forés & Camisón, 2016), followed by investment in scientific, technological, and innovation activities in millions of pesos, according to the survey (Velez, 2023, Kihombo et al., 2021; Liu et al., 2019; Biswas et al., 2018; Saidani et al., 2017) adopted from previous studies on innovation. The third

control variable corresponds to investment in machinery and communication equipment in millions of pesos (Liang et al., 2022; Wu et al., 2015; Gawer & Cusumano, 2014). Natural logarithm was applied to both variables: investment in scientific, technological, and innovation activities and investment in machinery and communication equipment.

The dependent variable, a robust measure of performance that adds national and international sales, has been widely adopted in the literature of previous studies (Jha et al., 2017; Tan et al., 2017; Chandran & Rasiah, 2013), giving confidence in its validity and applicability.

The moderating variable used is the type of industry, recognising if differences between industry subsectors can influence performance (Hasan et al., 2022; Fok et al., 2021; Lützner et al., 2016; Betts et al., 2015; Wu, and Chiu, 2015).

Results

The assumptions of multiple regression analysis were taken care of for the analysis, and the maximum value of the variance inflation factor was 3.6. Table 1 presents the descriptive statistics, and Table 2 the correlation matrix.

Table 1
Descriptive statistics

Research variables	Code	Mean	SD
Log Performance	(1)	7,14	0,85
Control Variable Company Size	(2)	251,56	421,59
Log Investment in Scientific, Technological, and Innovation Activities	(3)	1,79	2,41
Log Computer and Communication Equipment	(4)	2,88	2,65
Sustainability Practices	(5)	1,7	0,57
Industry1 - Food and Textile Products	(6)	0,37	0,48
Industry2 - Wood and Paper	(7)	0,07	0,25
Industry3 - Oil, Pharmaceutical, Chemical, and Rubber	(8)	0,26	0,44
Industry4 - Metallurgy and Electronics	(9)	0,16	0,36
Industry5 - Machinery and Transport	(10)	0,15	0,36

Source: Author's work

Table 2
Correlation analysis

Code	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	1								
(2)	0,668**	1							
(3)	0,495**	0,461**	1						
(4)	0,446**	0,349**	0,380**	1					
(5)	0,140**	0,084**	0,098**	0,153**	1				
(6)	0,051*	0,128**	-0,125	-0,003	-0,077**	1			
(7)	-0,078**	-0,059*	-0,033	0,013	-0,025	-0,207**	1		
(8)	0,052*	-0,063*	0,072**	-0,017	0,047	-0,447**	-0,159**	1	
(9)	-0,035	-0,049	0,066**	0,021	0,047	-0,328**	-0,117**	-0,252**	1
(10)	-0,042	-0,004	0,036	-0,005	0,014	-0,323**	-0,115**	-0,248**	-0,182**

Source: Author's work

Note: ** statistically significant at 1%; *5%

Table 3 presents the regressions for the dependent variable corporate performance and the moderating effects of industry types. Control variables are introduced in

model 1; in this first model, it is explained 52.1% of the variance of corporate performance; the company size variable is positive and significant, indicating that a change in the size of the organisation can affect its corporate performance, especially if it has sustainability practices. The investment variable in research and development activities (R&D) is positive and significant, which is of interest to manufacturing companies; in this second model, research and development prove to be useful for improving the organisation's overall performance in its industry. On the other hand, investment in machinery and equipment is positive and significant; in the first model, it also had the same effect, which can help organisations consider investment in machinery and equipment as a necessity to improve their performance in the long term, and not as an inefficient expense.

Table 2
Hierarchical regression analysis

	Model 1	Model 2	Model 3	Model 4
Control Variable Company Size	0,001*** (0,000)	0,001*** (0,000)	0,001*** (0,000)	0,001*** (0,000)
Log Investment in Scientific, Technological, and Innovation Activities	0,064*** (0,007)	0,063*** (0,007)	0,063*** (0,007)	0,063*** (0,007)
Log Computer and Communication Equipment	0,063*** (0,006)	0,061*** (0,006)	0,062*** (0,006)	0,062*** (0,006)
Sustainability Practices		0,075*** (0,026)	0,073*** (0,026)	0,016 (0,049)
Industry1 Food and Textile Products			.	.
Industry2 Wood and Paper			-0,149** (0,061)	-0,171 (0,187)
Industry3 Oil, Pharmaceutical, Chemical, and Rubber			0,091** (0,039)	0,209* (0,117)
Industry4 Metallurgy and Electronics			-0,069 (0,045)	-0,058 (0,147)
Industry5 Machinery and Transport			-0,106** (0,045)	-0,198 (0,143)
Interaction Industry1_ Sustainability Practices				0,068 (0,065)
Interaction Industry2_ Sustainability Practices				0,081 (0,110)
Interaction Industry3_ Sustainability Practices				.
Interaction Industry4_ Sustainability Practices				0,061 (0,084)
Interaction Industry5_ Sustainability Practices				0,121 (0,084)
Constant	6,582*** (0,023)	6,462*** (0,047)	6,479*** (0,050)	6,460*** (0,075)
R²	0,521	0,523	0,530	0,530
R² Change		0,002	0,007	0,000

Notes: Dependent Variable Log Performance; *p < 0.10, **p < 0.05, ***p < 0.01; Standard error in parentheses.

Source: Author's work

In model 2, the independent variable of sustainability practices is included, being significant and positive, confirming hypothesis H1a. Thus, companies with practices associated with the reduction of energy use, reduction of raw materials, and waste utilisation have better corporate performance in the market.

Model 3 consists of all the main effects, and model 4 introduces the moderating effects between sustainability practices and industry types. Model 4 explains 53.0% of the variance in corporate performance. Industry 1, food and textile products (H1b) does not contribute to the model. The interactions with the industries, such as Industry 2, wood, and paper (H1c), were not significant. Also, the coefficient for the wood and paper industry itself was negative and significant, suggesting a negative impact; Industry 3, oil, pharmaceutical, chemical, and rubber (H1d), was not significant. However, the industry had a positive coefficient, indicating some direct positive impact; Industry 4, metallurgy, and electronics (H1e), was not significant, and the coefficients for the industry were negative and not significant; and Industry 5, machinery and transport (H1f), was not significant. Also, the coefficients for this industry were negative. Therefore, the effect of sustainability practices is direct and does not depend on the industry exclusively but on the company's intention to carry out sustainable practices. These practices, in turn, help it to have better corporate performance.

The industry types as a moderating variable help recognise two fundamental aspects of implementing sustainability practices. The first is that an organisation intending to carry out sustainable practices can do so regardless of its competitive industry and will, in return, achieve better corporate performance. However, the second element is that some industries may benefit more from these practices if their organisation is in an industry that can sacrifice the lesser use of natural resources and replace them with other materials or resources that have less impact on the environment.

Discussion

In the analysis of sustainability practices, multiple factors have been studied regarding causes that allow for better practices and the effects of such practices that help the organisation establish a competitive advantage (Braccini & Margherita, 2018). However, recent studies present a fundamental limitation; they need to include the economic industries to which organisations belong as a variable of analysis. This study advances in this direction, recognising the permanent effects of sustainability practices in different industries and describing a fundamental situation, the significant differences in investment, and the intention of industries to develop sustainable practices, explaining that each industry carries out sustainability practices that affect performance. However, the industry under analysis does not necessarily imply a modification in this relationship. In other words, the diversity of industries does not affect the relationship between sustainability practices and performance. Rather, it is the practices themselves and the intention to develop these practices that allow the organisation to achieve superior market performance.

From the resource and capabilities theory perspective, sustainability can be considered as a capability stemming from the good use of human and technological resources that allows for the development of practices to reduce specific resources (water, electricity, lands for farming and livestock, among others), creating a virtuous circle in the development of sustainable practices. Recent studies show that the development of capabilities can become a complete management system (Yoshikuni et al., 2021), requiring mostly intangible resources for creating value from ecological sustainability.

Moreover, recent studies implied that the organisation had to be sustainable in ecological terms (Angelakoglou & Gaidajis, 2015) but did not necessarily have investment levels in research, technology, and development, investment in machinery and equipment as a determining factor for advancement in sustainability practices and therefore in corporate performance. This analysis advances in this direction, showing how organisations that have sustainability practices and also appropriate investments in research and development, technology, machinery, and equipment can achieve this superior performance, breaking the paradigm of sacrificing sustainability for technology and recognising the need to have both perspectives (Oláh et al., 2020) to achieve organisational success.

Sustainability has gradually become the substantial axis of corporate social responsibility, not only as a determinant in the acquisition and maintenance of natural resources, the unique source of creating products and services but also because of its immediate effect on consumers' and employees' quality of life. In other words, sustainability becomes the goal of value creation for any organisation seeking to preserve a growth cycle that not only generates economic value but also social value for the communities it serves.

Therefore, returning to corporate social responsibility is fundamental to understanding the concept of sustainability and its implications on firm performance (Choongo, 2017). It is important to remember that the source of what we know as sustainability derives from a principle of responsibility of business activity, where organisations, once they carry out activities of resource exploitation, develop goods that different consumers purchase, and in each of the economic industries in which the companies of this study are located, the creation scheme is the same, the problem for all has been the scarcity of resources, which offers us the resource-based view. This theory establishes that organisations must face and deal with uncertainty (Ren, 2018) and the growing scarcity of natural resources, particularly created resources, in general. This concern looms over companies in both the production process and at the point of sale, which must ensure two fundamental factors: first, that the organisation, with the economic resources it obtains, can recreate these resources or at least invest in recovering the exploited resource, and second, that this responsibility, therefore, is no longer exclusive to governments, non-profit organisations, environmentalists, but a kind of shared responsibility that ensures that both the company and all its stakeholders (Hadj, 2020) have a fundamental job to develop processes and products that respect and reduce the ecological effect (Stock et al., 2018).

However, ensuring that organisations always consider this responsibility before designing products and manufacturing processes differs for industries of all industries. For example, in the machinery and transport industry, developing technology equipment already implies a high use of energy, which is generally electrical, translating into greater water consumption. However, other mechanisms have developed, such as using solar panel filters to reduce air pollution, sensors to prevent accidents in production plants, and alternating practices to balance the environmental effect. In the pharmaceutical industry, a large-scale ecological impact is sacrificed for small environmentally useful modifications, such as packaging modifications and amounts of plastic use, with continuous scientific development for improving the quality of life of patients and future patients. This comparison demonstrates that each industry will have different outcomes in terms of sustainability practices, but this does not necessarily mean that they will be less profitable. The study highlights that it is important for each industry to act responsibly according to their unique characteristics and invest in ecological practices that are specific to their

industry. Doing so will enable them to establish appropriate relationships with stakeholders and co-create more environmentally friendly products as they continue to learn and improve.

It is also important to discuss the significant role of corporate size in companies with sustainability practices and, therefore, superior performance; smaller companies may consider corporate success offered by sustainability practices as a path to continue growing in the market. Strengthening their market positioning and developing at the same time an economic cycle that allows them to grow and be recognised for good sustainability practices, they can invest more in research and new ecological practices, making the customer buy their products by considering them more ecological. In small and medium-sized enterprises, this incentive can be used by public policy entities to generate incentives for organisations that include sustainability activities in their manufacturing process. For example, mobilising resources for the development of these practices, tax reduction, business alliances, or, as demonstrated by the present study, managing greater investment in research, development, and technology activities that can build a business dynamic focused on the creation of activities within the production process and in the development of products, more responsible with the environment, which in the long term benefit the whole society.

In addition, it is important to highlight the management implications; corporate managers will observe that the implementation of sustainability practices in the company is not a cost but a medium-term investment that will grant the company better performance results, especially because they are associated with a genuine concern for the reduction in the use of very expensive resources such as water, electricity, and the proper management of waste derived from their corporate activities, which also generates a public policy concern, to develop legal frameworks (Salimova et al., 2020) that encourage more sustainable corporate practices, helping the entire business ecosystem to apply certain common practices that benefit both communities, customers, and stakeholders in general.

Finally, it is necessary to establish two fundamental elements for future research: first, technology and the ecological environment seem to go along different paths for industrial companies; reconciling both perspectives for environmentally responsible technology will be a short-term challenge for the manufacturing industry worth studying. Second, investments in research and development at the industrial level should not only be made to develop technology-based innovation but also to recognise other paths of innovative development with corporate social responsibility, which can be analysed through the connection between public policy and the business industry.

Conclusion

Manufacturing organisations have been developing better sustainability practices through an accelerated decrease in the use of resources such as water and energy. However, each industry is distinct in these practices; some industries may achieve better results than others as they can sacrifice the intensive use of some resources that do not necessarily generate direct value in their products. In this study, it has been established that the type of industry does not affect the relationship between sustainability practices and corporate performance, which can be explained as a direct relationship that does not depend exclusively on the industry but on the mere fact of having sustainability practices associated with energy use, water use, and waste utilisation. This result is a significant incentive for industrial organisations looking

to establish specific strategies regarding the best forms of sustainability, as well as the development of more ecological and innovative products.

In the past, some organisations considered sustainability a costly element to implement in the company, and intervening to carry out cleaner production processes seemed impossible. However, it can be established that these organisations obtain better corporate results that translate into higher sales and better financial indicators in the long term. Moreover, from the public policy perspective, better incentives exist to develop businesses that consider environmental sustainability a fundamental element of competitive strategy. This research can help managers and public policy developers establish business processes with sustainability practices and convince entrepreneurs who still need to join environmental initiatives to build environmentally sustainable companies.

It is also important to consider that this research significantly contributes to the theory by illustrating how sustainability practices in manufacturing firms can be integrated as a strategic decision across various industries to enhance performance. With the hierarchical regression model, the approach adds sophistication to our understanding of sustainability, highlighting the moderating role of industry types in the relationship between sustainability practices and corporate performance.

This contribution is particularly valuable in environmental management and sustainable development. It provides empirical evidence that supports customising sustainability strategies based on sector characteristics, thus pushing the theoretical boundaries beyond a one-size-fits-all approach to corporate sustainability.

Besides, the study has certain limitations as it is limited to a specific geographic region. Therefore, the findings may not be an accurate representation of companies in other regions or economic conditions. This implies that the results may differ significantly in countries with different regulatory environments and market dynamics.

Another limitation of the study is the need for qualitative information. Analysing the qualitative aspects of how sustainability practices are implemented and their impact on different aspects of an organisation could help better understand the differences between industries.

Furthermore, it is important to recognise that future studies should address other possible variables that affect the relationship between sustainable practices and performance, such as variables associated with corporate age, country of origin, corporate performance in international markets, and social and environmental innovations, which can add to the explanation of the relationship between these variables.

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Influence of Demand on Supplier Selection Using the Analytic Hierarchy Process: A Case Study Validation in the Textile Industry

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Abstract

Background: Supplier selection has emerged as an important activity regarding strategic purchasing with implications for the operational efficiency of both organisations and supply chains. Given the need to evaluate both qualitative and quantitative criteria for different supply alternatives, the decision-making process became more complex. **Objectives:** In the present work, an adapted Analytic Hierarchy Process model is proposed for supplier selection, which is being validated within the context of a textile company. The multi-criteria decision support model was coded in Python and encompasses criteria, cost, quality, delivery time, sustainability, and history. **Methods/Approach:** This model allocates weights to individual suppliers based on the diverse criteria considered. Four alternatives were considered as the chemical fabric dyeing pigment suppliers. Two different scenarios were considered to understand the influence of demand on the supplier selection problem. **Results:** The cost is the most valued criterion in the supplier selection (0.493 for Scenario 1 and 0.426 for Scenario 2). The second most important criterion for regular demand is quality (0.224), whereas, for the increased demand scenario, delivery time (0.301) is the second most impactful criterion. **Conclusions:** The application of the AHP for both tested scenarios resulted in a different priority, highlighting the adjustment capacity of the implemented model to different search parameterisations.

Keywords: Supplier Selection; Multicriteria Decision Model; AHP; Textile Industry

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Introduction

As companies strive to stay ahead of their competitors, they have come to realise that procurement is not just a cost-saving mechanism but also a strategic enabler of growth and sustainability (Aslani et al., 2008). Consequently, strategic purchasing assumes great relevance in any business, whether in the context of industrial, retail, or service. With the increased complexity of supply chains, more businesses have recently come to understand the critical role that procurement and strategic purchasing play in their operations (Aslani et al., 2008). Thus, it is important to understand the relationship between Procurement and Strategic Purchasing. Both concepts are closely related within the broader scope of supply chain management and are often used interchangeably (Bäckstrand et al., 2019; Ondoro et al., 2013).

While procurement primarily deals with operational tasks such as buying products and services, strategic purchasing emphasises a more strategic outlook involving market analysis, assessing supplier capabilities, identifying opportunities for collaboration and innovation, and optimising the supply chain to gain a competitive edge (Endo et al., 2017). Thus, it can be said that Procurement conventionally focuses on transactional activities, ensuring that a company obtains the required inputs at the right price, quality, and quantity. In contrast, strategic purchasing emphasises long-term partnerships with suppliers, innovation, risk management, and value creation rather than just cost savings (Ferreira & Silva, 2022). Then, strategic purchasing, a core component of procurement, involves aligning sourcing decisions with the long-term goals and objectives of Small and Medium Enterprises (SMEs). By adopting a strategic approach, SMEs can effectively manage their purchasing processes and drive sustainable growth (Bäckstrand et al., 2019; Klasa et al., 2018; Schütz et al., 2020). Key aspects include:

- Market Research and Analysis: Strategic purchasing begins with in-depth market research and analysis. Understanding market trends, supplier capabilities, and industry dynamics empowers SMEs to make informed purchasing decisions.
- Supplier Evaluation: Thorough evaluation of potential suppliers based on criteria such as quality, reliability, financial stability, and environmental practices ensures that SMEs partner with suppliers who share their values and vision.
- Long-term Cost Savings: By strategically negotiating contracts and building supplier relationships, SMEs can achieve long-term cost savings. This strategic foresight enables SMEs to be competitive while offering cost-effective products.

Supplier selection is a critical phase in the procurement process, where SMEs carefully evaluate and choose suppliers who can meet their specific needs and requirements. Key considerations for successful supplier selection include:

- Quality Assurance: Selecting suppliers with a proven track record of delivering high-quality goods and services ensures that SMEs can maintain consistent quality standards and meet customer expectations (Zimon & Zimon, 2019).
- Supply Chain Efficiency: Suppliers play a pivotal role in ensuring smooth supply chain operations. Selecting reliable and efficient suppliers contributes to the timely delivery of materials, reducing lead times and minimising disruptions (Gupta & Barua, 2017; Taherdoost & Brard, 2019). Also, the environmental sustainability of supply chains has gained a relevant weight (Huang et al., 2024).
- In today's rapidly evolving market, SMEs' sustainability hinges on their ability to innovate and adapt. This is where supplier selection plays a crucial role. Collaborating with innovative and adaptable suppliers allows SMEs to respond quickly to changing market demands and embrace new technologies, thereby ensuring their survival in the competitive business landscape.

Considering the increasing globalisation of markets, the supplier selection process is, therefore, a critical step of strategic purchasing because it requires ensuring quality, cost efficiency, reliability, risk management, innovation, and sustainability in developing partnerships between companies in the same supply chain. By carefully evaluating potential suppliers based on these criteria, companies can make informed decisions that support their strategic goals and drive overall success (Konys, 2019). This problem has a greater weight in the context of SMEs.

Supplier selection requires the identification of suitable suppliers whose services will be contracted and supplier evaluation, which rates the effectiveness of the selected suppliers (de Araújo et al., 2017). It should be considered a systematic process used to request and evaluate quotes and process the approved purchasing orders. The sourced suppliers should be compared based on qualitative and quantitative criteria (Fayos et al., 2022). It holds great importance in the overall SME supply chain management, allowing for the optimisation of resources, reducing costs, and maintaining an uninterrupted flow of materials, thereby enhancing their operational efficiency (Bienhaus & Haddud, 2018; de Araújo et al., 2017; Hernandez & Garcia, 2006). A key point to consider is cost optimisation since it allows SMEs to negotiate favourable terms with suppliers, securing cost-effective inputs and raw materials (Bevilacqua & Petroni, 2002). This cost optimisation contributes significantly to the financial health of SMEs, allowing them to allocate resources strategically and invest in growth areas (Endo et al., 2017). It also allows for improving supplier relationship management. Building strong and collaborative relationships with suppliers fosters mutual trust and encourages long-term partnerships. Close collaboration with suppliers enables SMEs to access innovative products, better terms, and early insights into market trends (Ellegaard & Andersen, 2015). Also, supplier diversification enhances supply chain resilience, mitigates disruptions and safeguards SMEs from unforeseen market fluctuations (Hawkins et al., 2020).

In the literature, several works focus on the relevance of integrating the supplier selection process in strategic purchasing. Based on the Kraljic Matrix, Garzon et al. (2019) created a green procurement technique for selecting and evaluating suppliers for a case study in the chemical industry. The purchasing strategy is based on the selection of suppliers that can contribute to the sustainable objectives preconised by the company. According to these authors, the selection criteria are mostly based on identifying environmental and social risks (Garzon et al., 2019). In Logistics 4.0, Hasan et al. (2020) suggested that a resilient supplier selection technique with heterogeneous information should be implemented by using simulation-based methods under different scenarios. The proposed method performs better than conventional methods in terms of robustness and adaptability to uncertain and dynamic situations.

According to Olanrewaju et al. (2020), the supplier selection decision is affected by key criteria such as pricing and discount quantity, delivery and lead time, commitment and capacity of the suppliers to accommodate the client requirements and the transport cost. Ferreira & Silva (2022) in their study, concluded that the most relevant criteria in supplier selection are (1) the quality of goods, (2) the compliance with delivery times, (3) price/cost, (4) supplier reputation and/or market positioning, (5) suppliers location, and (6) supplier performance history. Stevic (2017) have systematised the most noteworthy criteria that are commonly used in supplier selection. Criteria such as price, quality and delivery time still play a notorious role in the evaluation of suppliers. However, integrated approaches and computational methods need to be used to include a larger number of factors and criteria in the supplier evaluation process.

In this sense, SMEs require robust decision-making methods to identify the most suitable suppliers as well as other operational and tactical management decisions. Due to the increase in technology in companies, the entrepreneurial behaviour of managers has been reported in the literature, opening the possibility for companies to include support decision frameworks (de Freitas Michelin et al., 2023). The textile industry, the industrial sector under analysis in this work, is not an exception. The need to integrate data and information has resulted in the adoption of real-time production planning tools, considering the required resources and the timing in which they are needed for production. Therefore, decision support systems in this sector are crucial (Ćirković et al., 2022).

There are several decision-making approaches applied in supplier selection, including the Multiple-criteria Decision-Making (MCDM)/Multiple-criteria Decision Analysis (MCDA), Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy Logic and Metaheuristics (Joy et al., 2023; Menon & Ravi, 2022). MCDM/MCDA refers to a family of methods developed in the 1960s and 1970s, including AHP, TOPSIS, and others. These methods offer SMEs a structured and consistent approach to evaluating potential suppliers based on diverse criteria, helping them make more informed and rational supplier selection decisions (Azhar et al., 2021). Most decision problems involve multiple, often conflicting, criteria or objectives, including quantitative, e.g., cost, time, and quality, and qualitative criteria, e.g., environmental impact or logistics integration. MCDM methods often involve sensitivity analysis to assess the robustness of decisions to changes in criteria weights or preferences (Al Hazza et al., 2022; Hamdan & Cheaitou, 2017).

The AHP, developed by Thomas L. Saaty in the 1970s, is a widely adopted method in decision-making and supplier selection processes (Saaty, 1987). AHP helps structure complex problems hierarchically, breaking them down into criteria and sub-criteria. Decision-makers compare these criteria and alternatives through pairwise comparisons, assigning numerical values to their relative importance. In SMEs, AHP provides a systematic approach to evaluate potential suppliers based on multiple criteria, enabling informed decisions and ranking suppliers according to overall performance. Parthiban et al. (2012) applied AHP to rank the suppliers of a group of components in the automotive manufacturing industry. Based on factors prioritisation, the suppliers' qualification and final selection were performed. Haldar et al. (2012) combined AHP, Quality Function Deployment (QFD), and Pre-emptive Goal Programming (PGP) techniques in supplier selection, considering a multi-objective criteria problem. The authors concluded that the three-method approach is applicable to decision-making processes in which the prioritisation of requirements must be conducted objectively. This scenario is prevalent in the majority of situations.

Gandhi et al. (2016) used the AHP technique to determine the relative importance/priorities of the success factors of SFs in green supply chain management adoption in manufacturing. The suggested framework was developed to assist industrial managers in crafting adaptable decision strategies for both short and long-term sustainable supply chain management. An MCDM approach was also introduced by Al Hazza et al. (2022) for suppliers' selection. The framework combines the application of the Delphi technique as a means of gathering data, along with the AHP application for data analysis. It allowed us to select the main criteria and assess the trade-offs among the feasible options based on those primary criteria.

TOPSIS, introduced by Hwang and Yoon in 1981, is a multi-criteria decision-making method that assesses alternatives based on their distance from the ideal and worst solutions (Jadidi et al., 2010). In the context of supplier selection, the TOPSIS method allows for identifying the supplier that best matches the ideal criteria while minimising the distance from the worst solution. By offering relative closeness scores for each supplier, it is possible to rank suppliers based on their similarity to the ideal solution (Hamdan & Cheaitou, 2017). Fuzzy logic, developed by Lotfi Zadeh in 1960, is a computational approach that handles uncertainty by allowing the assignment of degrees of membership to suppliers for each criterion. Unlike traditional binary logic, fuzzy logic accommodates vagueness and imprecision, making it valuable when dealing with qualitative and imprecise information in supplier evaluation for SMEs. Lima Junior et al. (2014) presented a comparative study between Fuzzy AHP and Fuzzy TOPSIS methods in the context of decision-making for supplier selection.

Methods were compared considering seven parameters, the most relevant the adequacy to changes of criteria and a number of criteria and alternative suppliers. It was verified that both techniques are adequate to deal with imprecision and subjectivity in supplier selection problems. There are other hybrid decision-making approaches that combine fuzzy logic and multicriteria analysis, allowing a holistic view of supplier performance, considering both qualitative factors, such as reputation, and quantitative factors, such as cost and delivery time. Metaheuristics are optimisation algorithms derived from principles such as evolutionary computation, swarm intelligence, and simulated annealing. For SMEs, metaheuristics provide a powerful and flexible approach to supplier selection, efficiently exploring large solution spaces to identify top-performing suppliers in a timely manner (Chen et al., 2020; Garg, 2021).

In this work, the AHP technique was selected since it is particularly used when there is an inherent subjectivity of the decision agent. The AHP model was adapted and programmed in Python to select the most suitable supplier in a company that operates in the textile sector for a specific dyeing pigment. The decision-making agents make their judgments by considering two different scenarios with distinct demand requirements presented at the time that the case study data was collected. The paper is divided into five sections. After an introduction, the AHP method for supplier selection is presented, and the description of the case study is provided in the material and methods section. The third section regards the implementation and validation of the AHP model. The last two sections correspond to the main results and discussion and the conclusions, respectively.

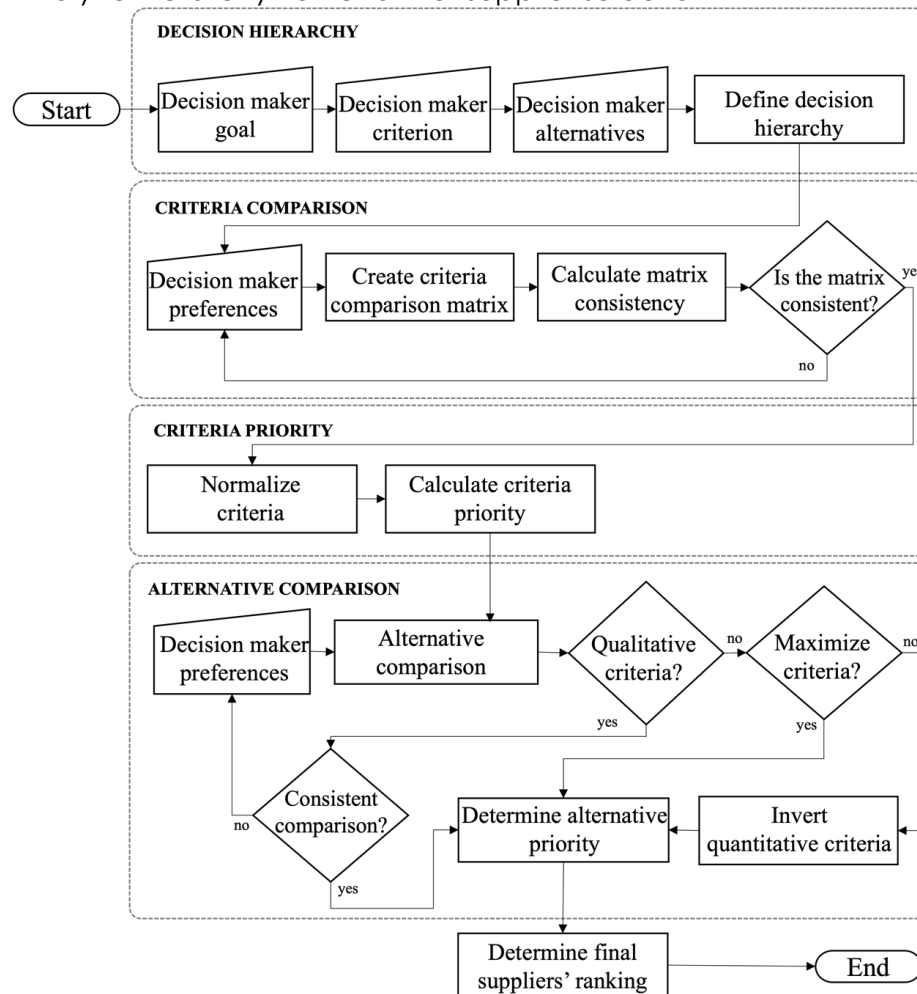
Methodology

This section describes the method used in supplier selection of fibre-reactive dye chemicals in a Portuguese textile company, which served as the case study for adapting the AHP method developed in the study.

Supplier Selection Analytic Hierarchy Process

In industry, problems are of great complexity, even for decision-makers with a high level of experience in the management and operational areas. AHP is a method that helps decision-making, allowing for a more informed decision. It is a multi-criteria decision method allowing the simultaneous consideration of well-defined (quantitative) and more subjective (qualitative) criteria. The AHP model used in this article is summarised, with calculations abstraction, in the flowchart exposed in Figure 1.

Figure 1
Analytic hierarchy flowchart for supplier selection



Source: Author's illustration

For a problem modelled by three levels to be correctly defined, it is necessary to create a well-structured Decision Hierarchy that considers the main objective of the problem (first level), the main criteria to consider (second level), as well as the available alternatives (third level) at the time of the decision. To do this, it is necessary to ask the decision-making agent what is the main objective (Who is the most suitable supplier to be selected?), what criteria should be taken into consideration when selecting a suitable supplier (cost, quality, delivery time, response flexibility or others), and also what alternatives (suppliers) are available at the time of the decision since the moment in which the decision is made usually has a great influence on the final decision.

The moment at which the decision is made will influence the criteria comparison made by the decision agent. In this phase, a comparison matrix is created based on the preferences established by the decision agent. To make the comparison, the decision-maker uses a Saaty scale (Saaty, 1987), also known as the comparative preference scale, which is a technique used in multi-criteria analysis to evaluate and compare the relative importance of different criteria or alternatives in a decision-making process. It allows decision-makers to express their preferences comparatively between pairs of criteria or alternatives, assigning numerical values that represent the intensity of the relative preference. To check whether the expressed preferences are stable and logical, without contradictions, the matrix consistency is verified to ensure greater reliability in the presented decision suggestions. If the matrix is not consistent, it is necessary to request a review from the decision-making agent.

If the matrix is mathematically consistent, a vector with the criteria priority is created. In this phase, a relative priority is created for each criterion, and the criteria are normalised so that the sum of their values corresponds to the unit value.

Then, the alternative comparison is made, allowing a pairwise comparison of the different suppliers for each of the defined criteria. At this stage, it is necessary to understand the type of criterion and its objective so that the decision maker can make the comparison as precisely as possible. If the criterion is qualitative, the comparison between alternatives is performed similarly to the comparison between criteria. When the criterion is quantitative, it is necessary first to check whether the objective is minimisation or maximisation to adjust the normalisation of the criterion in the defined direction. In other words, for example, if the delivery time of an item is to be minimised, the supplier with the shortest delivery time must be the one with the highest weight in the respective criterion, normalising the respective inverse value. If the criterion aims to maximise, the numerical values are normalised so that the respective sum totals the value one. A priority vector is then created for each of the different criteria.

Finally, the result of multiplying the priority vectors of each criterion (as columns of the matrix) and the priority matrix of the alternatives leads to a final classification of alternatives, where the highest value corresponds to the most suitable supplier for the objective defined by the agent of decision.

Case study description

To evaluate the performance and sensitivity of the implemented AHP model for the supplier selection problem, a case study was used in an industrial context where two different scenarios of demand for a pigment are addressed. This was obtained through a real case of an SME located in the north of Portugal, which has 77 employees and has operated in the textile area for over twenty years. It is dedicated to textile dyeing, more specifically in the business areas of home decor, swimwear, and sportswear, among others. Dyeing is a chemical process that changes the colour of the textile fibre through the application of coloured materials. One of the products most used by the company, which was selected for this study, consists of a fibre-reactive dye, which is mostly used in dyeing cotton or linen fabric.

The company has four specific suppliers to provide the pigment; however, for reasons of confidentiality, these will be identified with the letters A to D. The company's decision-maker selected five criteria to analyse which supplier would be most suitable to supply the company decision. Table 1 presents a definition and parameterisation of the criteria defined by the company's decision-making agent. Cost (monetary units) and quality of the product, history/relationship with the company (years), delivery time (days) and the sustainability conditions under which the pigment is produced are the criteria indicated by the decision agent to be included in the decision support model.

Criteria can be quantitative or qualitative. In qualitative criteria, it is possible for the decision-maker to define a level of preference between two different suppliers. For example, for the sustainability criterion, supplier B may be a little more suitable than C (preference level). In quantitative criteria, it is possible to obtain exact information about a given criterion since known numerical values, such as the cost of the pigment in each period for different suppliers, represent them. It is also possible to define a maximisation or minimisation objective that is associated with a specific criterion. An example is the cost since a supplier that charges a lower cost is more attractive than others that have higher costs if the objective is finding a product with a competitive cost. However, this parameterisation only refers to an individual criterion, not considering the behaviour of other criteria.

Table 1

Criteria to select a more suitable supplier for textile pigment

Criteria	Type	Objective	Definition
Cost			Cost is defined as the amount the company is willing to pay to acquire a unit of pigment, including all acquisition and transportation costs.
Quality			Quality refers to the level of quality of the product delivered by the supplier. Several aspects classify the level of quality, trying to categorise products by their level of compliance with quality requirements defined by customers and the company.
Delivery time			Delivery time is the effective time between ordering the pigment from the supplier and the moment it is delivered to the company.
History			History refers to the number of years that a given supplier has collaborated with the company. Longer collaborations are an indicator that the supplier is trustworthy and offers quality products. This indicator is used to assess reliability and consistency over time.
Sustainability			Sustainability refers to the set of good practices and techniques that suppliers follow in the production of pigment, namely care in creating more sustainable and environmentally friendly packaging, use of renewable energy sources, and selection of renewable materials.
 Quantitative  Qualitative  Minimise  Maximise  Preference level			

Source: Authors

Two different scenarios were considered to understand the sensitivity of the AHP model. The comparison of alternatives will not be changed, as they are close in time, and there is no variation in the quantitative criteria and the comparison between alternatives. Only the criteria comparison will be changed.

In the first scenario (Scenario 1), the company has low customer demand and, therefore, enough time to acquire the pigment, so cost will be the most important criterion. In an alternative scenario (Scenario 2), the company received an urgent request from an important customer with whom it had a long-term relationship, and demand for the pigment consequently increased.

Although the company continues to prioritise cost when making the decision to avoid production delays, it already manages its preferences regarding delivery times differently. The data concerning these scenarios are presented in more detail in the validation of the case study (Section 3) and in the discussion of the results (Section 4).

Model Implementation and Validation

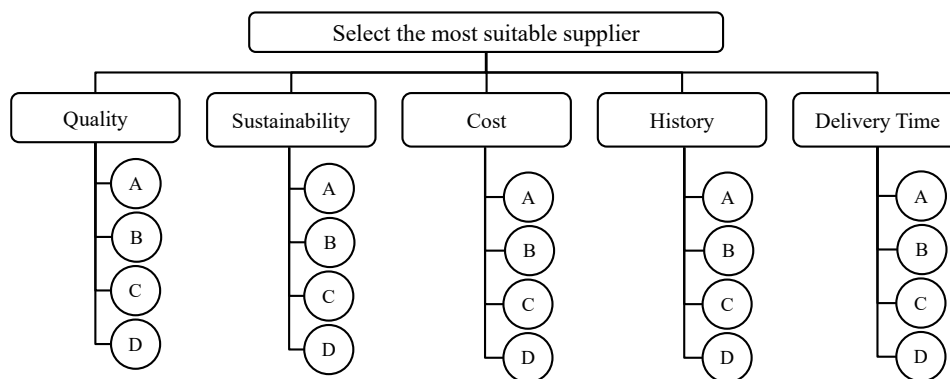
In this section, the developed AHP model for the supplier selection problem will be presented and validated. This model will be applied to both, as detailed in Section 2.2. The practical validation of the AHP method will be divided into the different phases depicted in the Figure 1 flowchart for a clearer presentation of the results.

The implemented model was developed in Python programming language without using any specific Python library regarding the AHP model. Indeed, this decision enabled the definition of the entire algorithm instead of relying on a previously developed framework that could be used as a black box, and the focus would be the result, disregarding how it was achieved. For a better discussion and clarification of intermediate results, an exploratory analysis of the data and mathematical representations will be used. In this way, it is possible to highlight the relationship between the different criteria and alternatives attributed by the decision agent for the different analysed scenarios.

Decision Hierarchy

The main objective in defining a decision hierarchy is to visualise the problem in an integrated manner while simultaneously addressing the sub-problems in a more detailed way. This allows for a global view of how sub-problems at lower levels affect higher levels in the hierarchy. The defined hierarchy is shown in Figure 2.

Figure 2
AHP Hierarchy for suppliers' selection scheme



Source: Author's illustration

The first level of the hierarchy allows for defining the global objective of the model, in this case, the selection of the most suitable supplier according to the preferences of the decision-maker for the acquisition of the preferred pigment. For the second level, five distinct criteria are defined that were considered the most relevant by the company's decision-making agent, namely cost, product quality, history with suppliers, delivery time and the sustainability conditions that suppliers consider in the pigment production.

The last level of the three-level hierarchy defines the alternatives available at the time of decision-making. In this case, it refers to the different suppliers available to supply the company with the pigment referred to.

For reasons of confidentiality, these are referred to as suppliers A, B, C, and D. It is important to highlight that to make a fair comparison between levels and elements of the hierarchy, it is necessary to use a common unit of measurement, such as a weighting factor.

Criteria Comparison

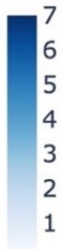
To enable a comparison between each criterion and establish a priority among all selected criteria by the decision agent, one needs to assign a preference level between criteria pairs. By using such comparative attributes, it is possible to establish the priority and understand which criteria the company most values.

Based on Saaty's fundamental scale (Saaty, 1987), the decision agent uses values between 1 and 9 to establish the qualitative relationship among all criteria. Thus, 1 indicates that both criteria are equally important, 3 indicates that the first is slightly more important than the second, and 5 sets a higher importance level. This qualitative measure grows up to 9, where one criterion is extremely important compared to the other.

Nevertheless, intermediate values are also allowed. Figure 3 presents a criterion pairwise comparison where the intensity of the colour (dark blue) indicates a more important criterion. In the opposite direction, the inversed value is used. Indeed, as observable in the figure, the pair Cost-Sustainability has a value of 7, meaning that the cost is very important when compared to sustainability. In the opposite pair, Sustainability-Cost, the presented value is 0.143 ($\approx 1/7$ rounded by three decimal places).

Figure 3
Criteria pairwise comparison matrix for Scenario 1

	Quality	Sustainability	Cost	History	Delivery Time
Quality	1	4	0.333	2	3
Sustainability	0.25	1	0.143	0.333	0.5
Cost	3	7	1	4	5
History	0.5	3	0.25	1	2
Delivery Time	0.333	2	0.2	0.5	1



Source: Author's illustration

By analysing the comparison matrix presented in Figure 3, it is observable that the Cost is an important criterion since it has values greater than 1 when compared to the remaining criteria. Quality is also an important criterion since all values are greater than 1 for all criteria, with cost being the only exception.

On the other hand, sustainability may be seen as the least important criterion since all comparison pairs have values smaller than 1. This comparison matrix demonstrates the criteria comparison for scenario 1, in which the company had low customer demand and sufficient time to obtain the pigment.

Figure 4 represents the comparison matrix for the second scenario. Here, the customer demand for the pigment was higher. The cost criteria continue to be the most important since they have greater values than the remaining criteria. Due to the need to get the pigment quicker to satisfy the demand, in this scenario, the Delivery Time is the second most important criterion, surpassing the Quality (of scenario 1). Sustainability continues to be a minor valuable criterion.

Figure 4
Criteria pairwise comparison matrix for Scenario 2

	Quality	Sustainability	Cost	History	Delivery Time
Quality	1	4	0.333	2	0.333
Sustainability	0.25	1	0.143	0.5	0.167
Cost	3	7	1	5	2
History	0.5	2	0.2	1	0.25
Delivery Time	3	6	0.5	4	1

Source: Author's illustration

By analysing Figure 3 and Figure 4, one may observe that in both scenarios, cost is the most important criterion from the decision-maker's perspective. However, the urgent need for pigment from suppliers to fulfil the customer's needs makes the difference in the second most important criterion, the Delivery Time for Scenario 2, whereas, in the first scenario, it is the Quality of the supplied pigment.

Criteria Priority

In the previous section, an empirical comparison was made to identify the most important criteria for each scenario. Indeed, in this section, the goal is to numerically define the relative priority of each criterion on a scale from zero to one. Under the linear algebra subject, this procedure corresponds to determining the highest eigenvalue and its corresponding eigenvector. Then, this vector is normalized. An approximation may be performed with good results to mathematically simplify the process of calculating the eigenvalue and eigenvector.

For such a process, it is necessary to do a column-wise sum for the matrix defined in Figure 3, and then each element of a column is divided by its sum. To obtain the eigenvector approximation, the arithmetic mean is calculated in a line-wise format of the normalised correlation matrix, obtaining the priority vector for the criteria. As an example, one needs to do the sum of each column, which is 5.083 for the first column ($5.083 \approx 1 + 1/4 + 3 + 1/2 + 1/3$), as depicted in Table 2.

Table 2
Criteria normalisation process for Scenario 1

Criteria	Quality	Sustainability	Cost	History	Delivery Time
Quality	1	4	0.333	2	3
Sustainability	0.25	1	0.143	0.333	0.5
Cost	3	7	1	4	5
History	0.5	3	0.25	1	2
Delivery Time	0.333	2	0.2	0.5	1
Sum (column)	5.083	17	1.926	7.833	11.5

Source: Authors

Then, each element of this example column is divided by its sum, obtaining 0.197 for the first element ($0.197 \approx 1/5.083$). After performing these steps for the entire matrix, the obtained results are presented in Table 3.

Table 3
Criteria eigenvector approximation for Scenario 1

Criteria	Quality	Sustainability	Cost	History	Delivery Time	Mean (line)
Quality	0.197	0.235	0.173	0.255	0.261	0.224
Sustainability	0.049	0.059	0.074	0.043	0.043	0.054
Cost	0.590	0.412	0.519	0.511	0.435	0.493
History	0.098	0.176	0.130	0.128	0.174	0.141
Delivery Time	0.066	0.118	0.104	0.064	0.087	0.088

Source: Authors

After normalising and determining the preference vector, it is necessary to check if the matrix is consistent, i.e., ensure that the matrix complies with a mathematical indicator named consistency ratio. This ratio validates if the performed comparison is adequate. According to Saaty's definition, this ratio should not be greater than 0.1. Let us consider the matrix *A* with the criteria preferences and a vector with the corresponding priorities (Saaty, 1987).

Equation (1) may be used to approximate the highest eigenvalue λ_{max} associated with the eigenvector.

$$A \times w = \lambda_{max} \times w \quad (1)$$

The consistency index (*CI*) is defined through Equation (2), which uses the obtained λ_{max} and the number *n* of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

To determine the consistency ratio, one needs to calculate the ratio between *CI* and a pre-defined random consistency index (*RCI*). The *RCI* was defined by Saaty, (1987). According to the author, these values may only be used when the comparison is done on three or more criteria. Indeed, the AHP method intends to support a multi-criteria decision. The consistency ratio (*CR*) is calculated according to Equation (3).

$$CR = \frac{CI}{RCI} \quad (3)$$

Using the Root Mean Squared Error, where x_i is *i*th value in vector *w* and y_i is the *i*th value of the eigenvector associated to the highest eigenvalue, the error can be obtained, as presented by Equation (4).

$$RMSE = \sqrt{\frac{1}{n} (\sum_{i=1}^n (x_i - y_i)^2)} \quad (4)$$

This process to evaluate the matrix consistency was then applied as presented in Table 4. Thus, the matrix *A* with the criteria preferences and the vector *w* with the corresponding priorities were used to calculate λ_{max} . By replacing the values, a value of $\lambda_{max} = 5.079$ was obtained. For *n* = 5 (number of defined criteria) and $\lambda_{max} = 5.079$, the value of *CI* is approximately 0.02. The calculation of *CI* used an approximation of the highest eigenvalue, which was obtained from the calculated eigenvector.

Table 4

Consistency of criteria matrix evaluation for Scenario 1

Procedure steps	Application of the mathematical procedure
Identification of criteria preferences and priorities	$A = \begin{bmatrix} 1 & 4 & 1/3 & 2 & 3 \\ 1/4 & 1 & 1/7 & 1/3 & 1/2 \\ 3 & 7 & 1 & 4 & 5 \\ 1/2 & 3 & 1/4 & 1 & 2 \\ 1/3 & 2 & 1/5 & 1/2 & 1 \end{bmatrix} \quad w = \begin{bmatrix} 0.224 \\ 0.054 \\ 0.493 \\ 0.141 \\ 0.088 \end{bmatrix}$
Calculation of the highest eigenvalue	$\begin{bmatrix} 1 & 4 & 1/3 & 2 & 3 \\ 1/4 & 1 & 1/7 & 1/3 & 1/2 \\ 3 & 7 & 1 & 4 & 5 \\ 1/2 & 3 & 1/4 & 1 & 2 \\ 1/3 & 2 & 1/5 & 1/2 & 1 \end{bmatrix} \begin{bmatrix} 0.224 \\ 0.054 \\ 0.493 \\ 0.141 \\ 0.088 \end{bmatrix} = \lambda_{max} \begin{bmatrix} 0.224 \\ 0.054 \\ 0.493 \\ 0.141 \\ 0.088 \end{bmatrix} \Leftrightarrow$ $\Leftrightarrow \lambda_{max} = average \left\{ \frac{1.148}{0.224}; \frac{0.271}{0.054}; \frac{2.544}{0.493}; \frac{0.713}{0.141}; \frac{0.439}{0.088} \right\} \approx 5.079$
Calculation of CI	$CI = \frac{5.079 - 5}{5 - 1} \approx 0.02$
Calculation of CR	$CR = \frac{0.02}{1.12} \approx 0.018$

Source: Authors

By using the open-source *Scilab* software, it is possible to calculate the eigenvector associated to the highest eigenvalue using the `spec` command. The obtained values will be {0.392; 0.093; 0.870; 0.243; 0.150} with an eigenvalue of 5.078.

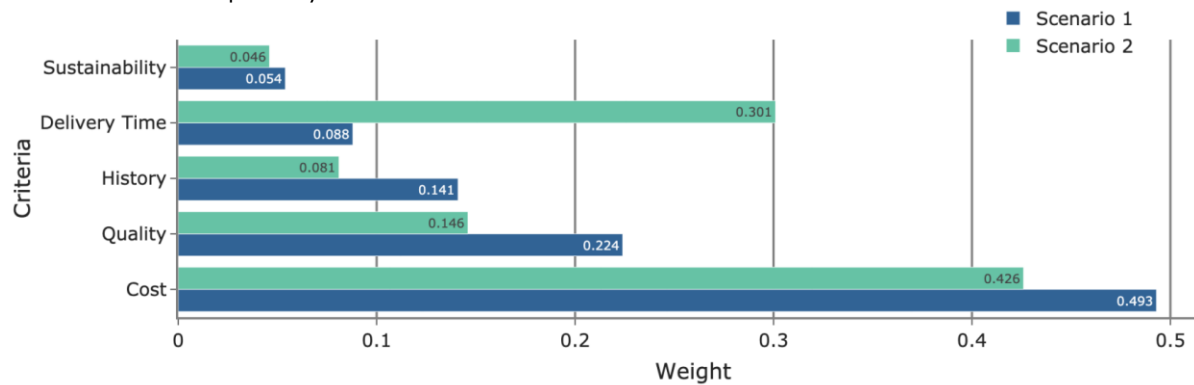
For this example, all remaining (four) eigenvalues are complex numbers, whereas associated eigenvectors also have complex numbers. By normalising the eigenvector, the final vector is {0.224; 0.053; 0.499; 0.139; 0.086}.

Based on the pre-defined values of RCI established by Saaty (1987), for five criteria with a cap R, cap C, and cap Iteria with a $RCI = 1.12$, CR is approximately 0.018, which is less than 0.1. Thus, the criteria comparison matrix is consistent. Using the Root Mean Squared Error, the obtained error is about 0.003 (0.3%). The complexity of determining such values is a disadvantage in computational terms since the results will be approximately the same.

The same procedure is applied for the second scenario (Scenario 2). The criteria relative priority results for both scenarios are presented in Figure 5.

Cost is the most important criterion in both scenarios. Regarding Scenario 1, Cost is followed by Quality. The least important criterion is Sustainability, with a relative importance of 5.4%. For Scenario 2, due to the need to acquire pigment to fulfil the orders, cost continues to be the most important criterion, but with a small decrease in its importance. Delivery Time becomes the second most important, surpassing Quality. Sustainability is the least important criterion, and its importance has decreased.

Figure 5
Criteria relative priority for Scenario 1 and Scenario 2



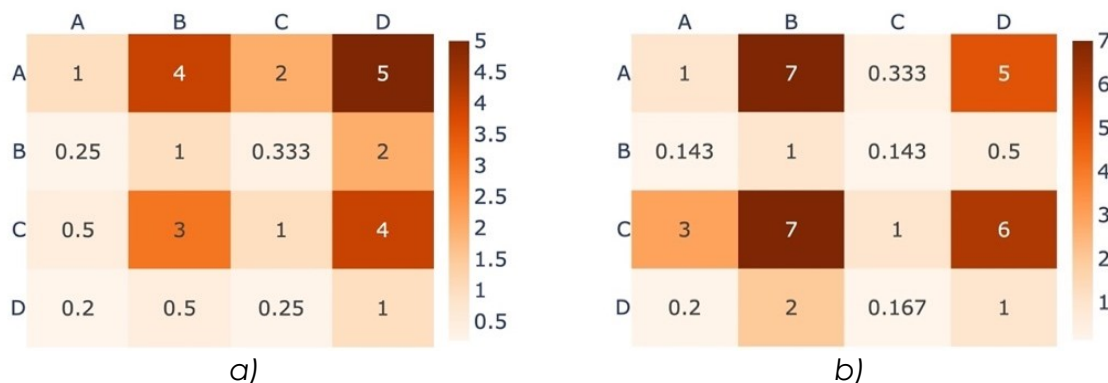
Source: Author's illustration

Alternative Comparison

In the alternative comparison phase, the aim is to compare the selected alternatives through all criteria. According to each type of criterion, there are different methods to do this alternative comparison. Indeed, for qualitative criteria (like quality or sustainability), the process is equivalent to the comparison of criteria presented in the previous step. Thus, for this type of criteria, the decision-maker needs to set values in a comparison matrix that, instead of having the criteria, has all alternatives. According to Saaty's scale, comparison values are set and normalised, and an alternative vector is obtained. For both scenarios 1 and 2, the selected alternatives presented the same characteristics.

Figure 6a and Figure 6b present the qualitative comparison matrices for the quality and sustainability criteria, respectively. For quality, it is observed that supplier A has the highest values, being above 1. Supplier C is, for the quality criterion, the second most suitable supplier since it only loses to supplier A (the only value that is below 1). In contrast, for the Sustainability criterion, this order is reversed, with C being the more suitable supplier. Both matrices are consistent since their consistency ratio is 0.018 and 0.058, respectively, meaning that both values are smaller than 0.1.

Figure 6
Qualitative alternative pairwise comparison matrices: a) Quality; b) Sustainability.



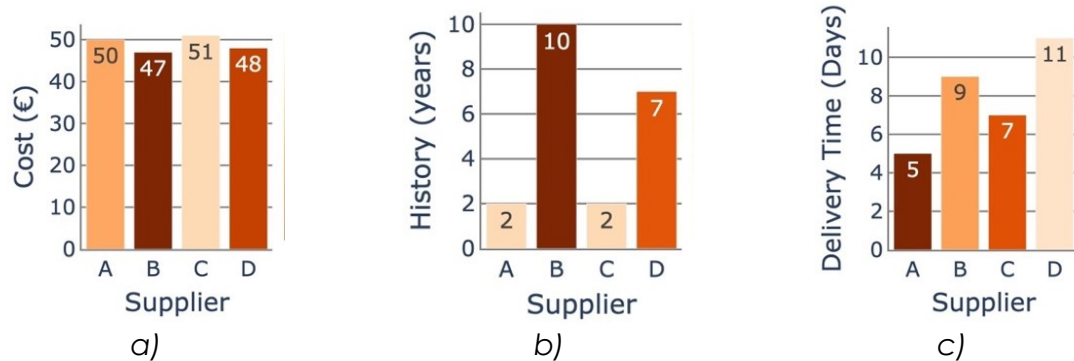
Source: Author's illustration

For quantitative criteria, the process for creating a comparison vector is slightly different since, for such types of criteria, there is no ambiguity from the decision agent.

Indeed, for these criteria, a numerical value is known and used to make a comparison. For each criterion, there is also the need to understand if the goal is to maximise or to minimise the results. In the case of, for example, History, the goal is to valorise suppliers that have a longer commercial relationship with the company. Thus, the goal is to maximise this criterion. Cost and Delivery Time are examples of minimisation criteria, i.e., the goal is to increase the importance of suppliers that have lower costs and lower Delivery Times. The quantitative criteria are presented in Figure 7.

Figure 7

Quantitative alternative comparison by: a) Cost; b) History; c) Delivery Time.



Source: Author's illustration

The process for defining the comparison vector within quantitative criteria is to execute the normalisation of values. Bigger values mean that such a supplier (alternative) has better results than those with lower ones. However, when the goal is to minimise, there is an initial step to invert the defined values.

Taking the Delivering Time as an example, by inverting the highest value, it becomes 1 over 11, almost equal to 0.091 and the same for the lowest 1 over 5, almost equal to 0.200. With this intermediate step, smaller values have higher importance after normalisation.

Final Ranking

After determining all comparison vectors between suppliers for each criterion, the goal is to create a global ranking system to understand who the most suitable supplier is for satisfying the pigment company's needs. Indeed, the result is a ranking defined according to the decision agent preferences of selected criteria and alternatives.

To obtain such a final ranking, it is necessary to create a matrix where each column contains the priority vector for the alternatives for each criterion. This matrix is then multiplied by the criteria comparison vector determined in the first step. The alternative comparison matrix is represented as M , where lines are suppliers A, B, C, and D, and columns are the criteria Quality, Sustainability, Cost, History, and Delivery Time, in this order. Vector w represents the criteria importance vector for Scenario 1.

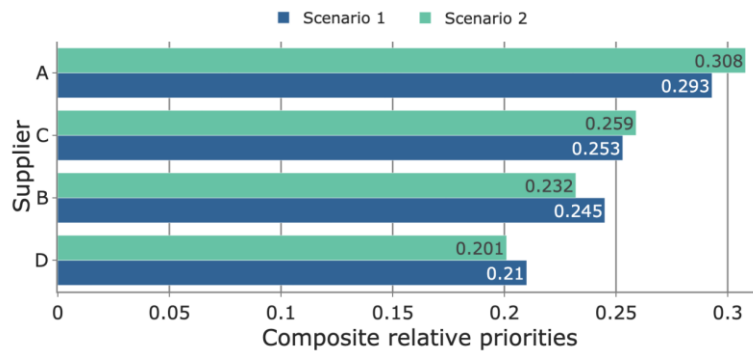
By multiplying matrix M by vector w , it is obtained the final ranking vector RS1, as presented by Equation (5). For Scenario 2, the same process is executed to obtain the final alternative ranking vector.

$$RS1 = M \times w \quad (5)$$

Figure 8 depicts the results for both scenarios. Despite the difference between both cases, the final order to select suppliers has not changed. However, the company's need for the pigment intensifies the rank of supplier A to the detriment of the remaining ones since, in this second scenario, Delivery Time is the second most important

criterion, and the Cost differences to other suppliers are not very different, since the variation coefficient is low (being Cost the most important criteria). For Scenario 1, supplier A obtained the highest priority with a relative value of 0.293. This is followed by supplier C with 0.253. Supplier D is close to C with a relative value of 0.245. Finally, Supplier B is in the last position with a relative priority of 0.201.

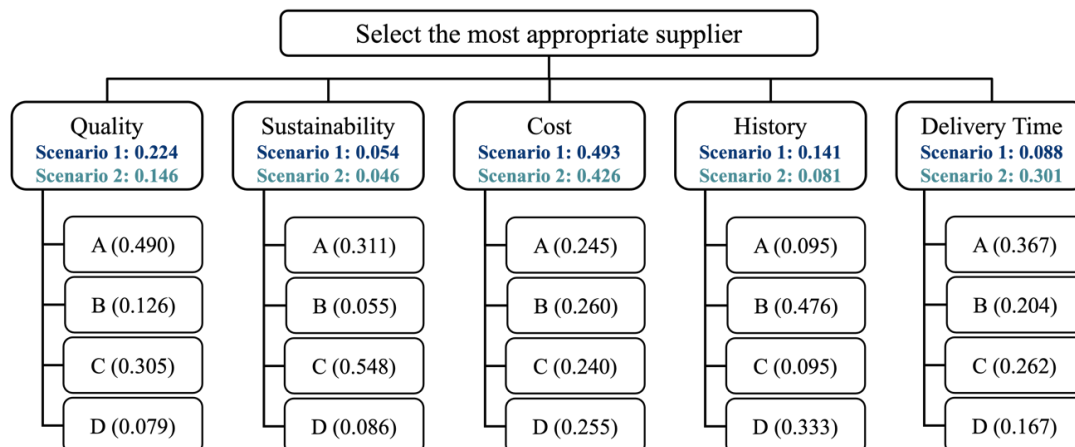
Figure 8
Final suppliers' ranking for Scenario 1 and Scenario 2



Source: Author's illustration

For Scenario 2, the final order remains the same, but the relative priority values change. Indeed, supplier A distances itself from the others since, in this scenario, this supplier stands out by providing the shortest delivery time. By applying the AHP to support the decision of the decision agent, which considers the preferences and requirements of the decision agent, the most suitable supplier is supplier A. According to the selected criteria, this is the one that better satisfies the pigment company's needs. In Figure 9, the final AHP hierarchy is presented with the relative importance values for criteria and alternatives.

Figure 9
Final weighting AHP hierarchy for suppliers' selection



Source: Author's illustration

Despite the final supplier rank, the results being the same, there are some differences related to each scenario-specific requirement, as highlighted in Figure 9. Indeed, the most important criterion, Cost, was reduced by 13.6% between scenarios. Delivery time, which changes from the 4th to the 2nd position between scenarios, was

increased by 242%. Quality, on the other hand, went from the 2nd position to the 3rd with a percentual decrease of 34.8%. History was also decreased, in terms of its importance, by 42.6%. Finally, Sustainability maintained the same last position, but its importance decreased by 14.8%.

Results

Although the result is slightly different, supplier A is the most suitable supplier for the pigment above for both presented scenarios according to the decision maker's preferences. In this section, a critical analysis of the results will be carried out to demonstrate how the criteria and demand influence the final decision to recommend supplier A.

It is important to highlight that the AHP model is a multi-criteria method that presents decision-making recommendations, allowing the decision-maker to achieve more informed and well-founded decisions within the organisation. In the first phase, and after normalising the criteria to allow a fairer comparison, it is possible to observe the values of the different criteria for the different suppliers without considering any weighting. At this stage, a comparison is made without considering the influence of demand at the time of the decision (Figure 10), as described in the two presented scenarios. In other words, the sum of the weighting of each criterion must total one.

Figure 10

Final suppliers' ranking comparison without criteria weighting



Source: Author's illustration

For the Cost criterion, it is possible to verify that all suppliers present a normalised value between 0.2 and 0.3, which in practice represents an average and median of €49 per industrial unit of pigment, a population standard deviation of €1.581, and a low coefficient of variation (about 3.2%).

In the Sustainability criterion, supplier C stands out as the supplier with the most sustainable practices in pigment manufacturing, with a value between 0.5 and 0.6, while supplier B is the one with the least sustainable practices, with a value below 0.1. It is also possible to verify that supplier A stands out from the others due to its Quality (approximately 0.5) and Delivery Time (between 0.3 and 0.4).

On the other hand, customer D presents the lowest Quality values (less than 0.1) and Delivery Time (less than 0.2). In terms of Delivery Time, suppliers have an average median of 8 days for delivery and a standard deviation of 2.236 days, which is reflected in a coefficient of variation of approximately 28%.

Regarding the History that the supplier has with the company, it is possible to verify that suppliers A and C are suppliers with a very young relationship with the company (approximately 0.1).

In contrast, suppliers B and D have a more mature and long relationship with the company, meaning their value is higher, between 0.3 and 0.4 and approximately 0.5, respectively. This difference in years of partnership is evidenced by the high coefficient of variation (65.1%). The history/relationship criterion with the supplier presents an average of 5.25 years, a median of 4.5 years, and a standard deviation of 3.419 years. Please note that the standard deviation of the population was used since all suppliers (A to D) selected by the decision agent to be part of the model were analysed (Table 5).

Table 5

Measures of dispersion and central tendency of quantitative criteria

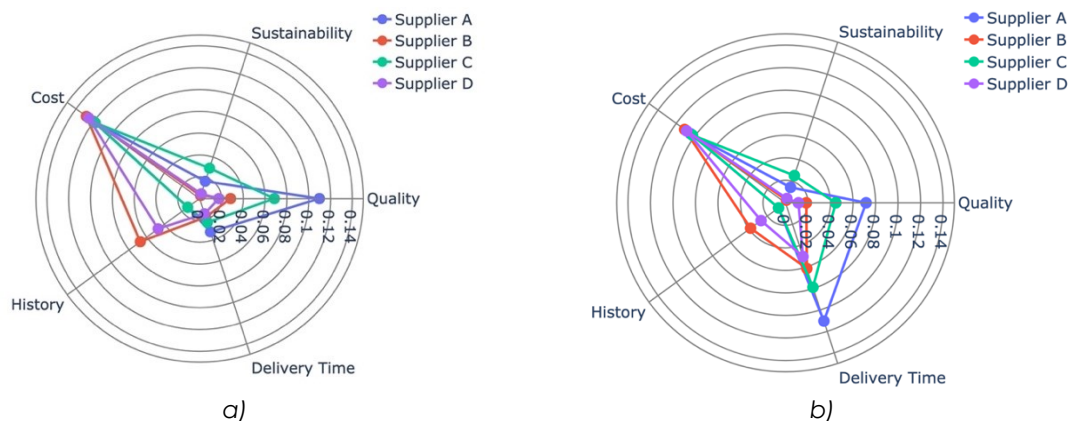
Quantitative Criterion	Median	Mean	Std. Dev.	Min	Max	Variation Coefficient
Cost (€)	49	49	1.58	47	51	0.032
History (years)	4.50	5.25	3.42	2	10	0.651
Delivery Time (days)	8	8	2.24	5	11	0.280

Source: Authors

The radar graphs presented in Figure 11 consider not only the comparison between different suppliers but also the weight attributed to the criteria by the decision agent in the two presented real scenarios. In other words, the sum of the weighted criteria and the weighted alternatives must be equal to one. In the first scenario (Figure 11a)), Demand is relatively low, so the company's main objective is to acquire a very good quality pigment at the lowest possible Cost. In a second scenario with greater demand ((Figure 11b)), Cost continues to be a highly valued criterion, as does Quality. However, the Delivery Time becomes more important when selecting the most suitable supplier. The Sustainability criterion, even for the supplier most concerned about sustainable practices, now has a small weighting (less than 0.04) for both scenarios as it is not yet one of the company's biggest concerns, complying with the stipulated requirements.

Figure 11

Final suppliers' ranking with criteria weighting: a) Scenario 1; b) Scenario 2.



Source: Author's illustration

In both scenarios, Cost is a highly valued criterion. However, the company is now slightly more willing to prioritize the Delivery Time criterion over Cost (less than 0.12 to less than 0.14). When demand is higher, the company is willing to purchase pigment from suppliers of slightly lower quality (less than 0.08 instead of 0.12) if it continues to meet quality requirements.

It should be noted that the decision agent only included in the decision model suppliers that meet the requirements imposed by the company and customers for all criteria. Hence, a reduction in them never implies non-compliance with the proposed requirements. The number of years of partnership between the company and suppliers becomes slightly less important (less than 0.06 to less than 0.04) since one of the most priority criteria becomes the Delivery Time.

Despite the mentioned observations, supplier A proves to be the most suitable to supply the company, despite being a supplier with a relatively young partnership with the company. This decision makes sense since supplier A is strong in the three main criteria valued by the company: Cost, Quality and Delivery Time. Supplier A is the most suitable of the four alternatives in terms of Quality and Delivery Time, and despite not being the one with the cheapest Cost, it has a competitive cost. This result may be an indicator that companies, to become competitive today, cannot only have the reduction of the Cost as their main objective but also criteria such as Quality and Delivery Time.

Conclusion

In this paper, a multi-criteria AHP model is implemented for the supplier selection problem. This model allows deciding which supplier is most suitable according to the preferences of the decision-maker of a company that operates in the textile area and intends to acquire a specific textile pigment for its production process. Two demand scenarios were analysed in a real application case to understand the influence of demand on decision-making through the proposed model.

In Scenario 1, the company's demand was low, meaning that Cost and Quality were prioritised as the main criteria for decision-making. For Scenario 2, demand was greater, and customer orders were more urgent. Hence, the Delivery Time criterion had to be prioritised, resulting in a slight reduction in the prioritisation of Quality and Cost. Thus, the main outcome resulted in Cost being the most valued criterion in the supplier selection (0.493 for Scenario 1 and 0.426 for Scenario 2). Nowadays, it may no longer make sense to use Cost reduction as the main or only criterion to achieve competitive solutions in the selection of suppliers since customers around the world have increasingly valued the criteria of Quality and Delivery Time due to fluctuations in demand triggered by customers' needs and consequently felt by companies. Despite the differences in demand, supplier A proved to be the most suitable for satisfying both scenarios. Notwithstanding being a supplier with a young relationship with the company, it is strong in the three criteria most valued by the company, that is, Cost, Quality, and Delivery Time.

Regarding the practical and scientific contribution of the present work, this study aims to implement a mathematical approach based on the adaptation of one of the most used methods from the literature, the AHP method, to be used as an adjusted decision support system that deals with many criteria and supplier alternatives. This will allow adequate management choices and justify decision-making in the industrial environment.

The main limitation of the implemented approach relies on subjective judgments from decision-makers, which can introduce bias into the process. Thus, in the next iteration of the work, a framework will be created, allowing different evaluators to

assign different weights to the considered criteria. Another limitation concerns the difficulty in obtaining accurate data, especially for qualitative factors like supplier reliability or responsiveness. Lastly, as the number of criteria and alternatives increases, the complexity of pairwise comparisons grows exponentially, making the process more time-consuming and resource intensive.

In future research, it will be important to create software with a user-friendly interface that allows effective and efficient communication with the decision agent, autonomous characterisation and parameterisation of the problem, and the analysis and visualisation of the decision process in real time. On the other hand, the decision process deals with subjective data determined by the decision agent that may present inconsistencies. At this point, these inconsistencies are solved by requesting changes to the comparison matrix provided by the decision agent, which will be the natural process if it is not possible mathematically and automatically to make the matrix consistent. In other words, it would be important to try to make the matrix consistent through mathematical procedures, when possible, before requesting the change to the decision agent.

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How did Hotels Measure Performance during Covid-19? Insights from Central and Eastern Europe

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Abstract

Background: One of the industries that was among the most disrupted by the Covid-19 pandemic was the tourism industry. Hotel owners and managers needed guidelines on how to combat the “new normal” and enable the sustainable economic operation of the hotels they managed. **Objectives:** This paper addresses the problem of identifying performance management (PM) indicators hotel managers turned to during the pandemic and the factors which motivated them to do so. **Methods/Approach:** Managers of hotels in winter destinations in Serbia and Bosnia and Herzegovina were surveyed on the performance measures they implemented in the hotels they managed. **Results:** The results of the research show that in the era of the Covid-19 pandemic, hotel managers relied on both organisational and operational measures but found operational indicators more useful. The characteristics of managers, such as business position in the hotel, age, level of education and level of work experience, are related to the choice of indicators and levels of their implementation. Also, the hotel's characteristics, such as size, revenue, and growth rate, proved to have an impact on the level of PM indicators measured. **Conclusions:** In times of crises, such as pandemics, organisational PM indicators that rely mainly on financial results are not as useful as operational ones. The reliance on operational measures of indicators increased the resilience of hotels.

Keywords: performance measurement; hotel industry; winter destinations; Covid-19 pandemic; Serbia; Bosnia and Herzegovina

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Introduction

In the last decade, the tourism industry has grown steadily and has had a strong impact on sustainable economic development in the countries of the Central and East European (CEE) region. Significant levels of investment by both the public and private sectors in the tourism industry of the CEE region have been recorded (The Travel & Tourism Competitiveness Report, 2019). The global Covid-19 pandemic has profoundly impacted societies and economies worldwide, creating significant hurdles for individuals, governments, and businesses alike (Pejić-Bach, 2021). Zhao et al. (2020) consider that the Covid-19 pandemic has caused an unprecedented recession in the tourism industry, particularly affecting the hotel sector. Various studies emphasise that the hotel industry was one of the most vulnerable sectors at the time of the Covid-19 pandemic (for example, Radygina & Oshkordina, 2020; Fatima & Elbanna, 2020; Magnini et al., 2021). Given the length of the Covid-19 pandemic, hotel managers were looking for new strategies that would be an adequate response to emerging business circumstances (Lai & Wong, 2020). The question that has occupied the attention of the scientific and professional community was how to mitigate the adverse effects of the Covid-19 pandemic on the performance of the hotel industry and enable the sustainable economic business of the industry.

The role of the sustainability dimension in the business processes attracted the attention of the scientific and professional community before the start of the pandemic, and interest further deepened during the Covid-19 pandemic. Numerous studies have pointed to the importance of performance management (PM) implementation in terms of sustainability (Hristov & Chirico, 2019; Dočekalová & Kocmanová, 2016; Amrina & Yusof, 2011; Martínez-Perales et al., 2018). At the same time, the process of developing sustainable business strategies in the hotel industry is closely related to performance measurement (Zigan & Zeglal, 2010; Haktanir & Harris, 2005; Fatima & Elbanna, 2020). PM systems in the hotel industry are associated with business process innovation and profitability (Phillips et al., 2005; Pnevmatikoudi & Stavrinoudis, 2016; Sainaghi et al., 2013; Zigan & Zeglal, 2010; Pingitore et al., 2010). Measuring performance in companies is at the core of business strategy, influencing their competitiveness and sustainable economic development (Hristov & Chirico, 2019). Given the efficiency of the PM system in terms of economically sustainable hotel business, increasing attention is being paid to the PM system, even in the era of the Covid-19 pandemic (Magnini et al., 2021). Sharma et al. (2021) considered that measuring the effects on the hotel industry during the Covid-19 pandemic is a priority. At the time of the Covid-19 pandemic, the key question was which indicators should be measured within the PM system of the hotel industry (Radygina & Oshkordina, 2020). Hotel service metrics, guest metrics, employee metrics and digital marketing metrics became key tools in hotel management in the era of a pandemic (Shin et al., 2021; Kilgore, 2020; Chaturvedi, 2020).

Winter tourism in the Central and Eastern Europe (CEE) region is recognised as a strategically important activity and generator of the development of national economies (Vanat, 2022). Recognising the importance of tourism development, CEE governments developed and are developing strategic tourism plans and investing significant resources in tourism development (The Travel & Tourism Competitiveness Report 2019). Serbia and Bosnia and Herzegovina (Bosnia) are distinguishable as regions with exceptional natural and geographical potential for the development of winter tourism (Vanat, 2022). This region is recognisable in the field of winter tourism, given the fact that the mountains Jahorina and Bjelašnica hosted the Winter Olympics in 1984 (Begic & Duman, 2013) as well as organised the Winter Youth Festival (EYOF) in 2019 (European Youth Olympic Festival-EYOF, 2019). In addition to the natural

potential for the development of winter tourism, significant investments in the development of hotel infrastructure have been recorded (Vanat, 2022). At the time of the Covid-19 pandemic, the issue was how to mitigate the consequences of the crisis and enable the sustainable economic business of the hotel.

This study aims to identify indicators used by hotel managers in Serbia and Bosnia during the Covid-19 pandemic. Having in mind that differences between countries are apparent in the response to the Covid-19 pandemic (Pejić-Bach et al., 2023), the question of which indicators to measure in the era of the Covid-19 pandemic has interested both the scientific community and hotel managers. Also, within this study, the factors that influence the levels of indicator implementation were examined. In accordance with the relevant literature, this study examined whether the levels of implementation of the PM system are related to factors such as hotel characteristics (hotel size, hotel revenue, sales growth, and levels of investment) and characteristics of the hotel manager (position in the hotel, age, level of education, and level of work experience). Additionally, managers' attitudes on the usefulness of various indicators in hotel management during the Covid-19 pandemic were analysed. To provide answers to the raised questions, a survey was conducted among winter hotel managers in Serbia and Bosnia. Furthermore, with respect to the subject of the research, this study updates the literature in the field of PM systems in the hotel industry of the CEE region during the Covid-19 pandemic. The presented PM systems' measurement can be a basic framework for the development of a performance measurement system in the CEE region, given the fact that specific indicators that hotel managers measured during the Covid-19 pandemic have been identified within this research. Given the fact that the CEE region is a homogeneous area in terms of business objectives and legislation, the exchange of practices in the field of PM systems in the hotel industry is desirable. The research results can be useful for understanding and implementing the PM not only during the Covid-19 period but also in the post-Covid period.

The presented study is structured as follows: In section two, we provide a literature review on PM systems in the hotel industry and on PM systems in the hotel industry during the Covid-19 era. The next section presents the research methodology and the sample characteristics. Section four is related to the results, while section five discusses the obtained results in depth. Finally, in section six, the conclusion is provided.

Literature review

PM systems in the hotel industry

The PM systems of the hotel industry started to develop in the late 1990s (Phillips et al., 2005). The increasing competitive pressure caused by the globalisation of the market required the application of PM systems to assess and improve business strategies, procedures, and functions (Jevtić et al., 2018; Střiteská & Svoboda, 2012; Phillips et al., 2005). Fatima and Elbanna (2020) consider PM systems to be vital for the survival and sustainable economic business of the hotel. Additionally, PM systems enable efficient management of high hotel business costs and complex hotel services (Atkinson & Brander Brown, 2001). In addition to pointing out the efficiency of the PM system in hotel management and the compliance of the PM system with hotel services, many papers indicate the need to modify the PM system in hotels (Chenhall & Langfeld-Smith, 2007; Zigan & Zeglát, 2010; Odar et al., 2012; Hansen & Schaltegger, 2016). Unlike traditional PM systems that rely on financial measures, modern performance measurement systems are based on the equal application of financial and non-financial measures. Zigan and Zeglát (2010) indicate that PM systems are effective

when they are based on the equal implementation of financial and non-financial criteria. Buhovac and Groff (2010) believe that the need to redesign traditional PM systems in the CEE region is imperative. Widz et al. (2022) consider that the improvement of non-financial performance is a must for the hotel sector, given the fact that non-financial performance is the driver of companies' competitiveness. Atkinson and Brander Brown (2001) state that hotels that do not use balanced PM systems and are more focused on financial rather than non-financial indicators measure the wrong aspects of business, which may lead to problems with future performance. Katsikeas et al. (2016) consider that the division of indicators into financial and non-financial indicators is outdated. Within the framework of their research, they divide the indicators into organisational and operational indicators. Financial and non-financial metrics are equally represented within the group, as well as organisational and operational indicators. Organisational indicators represent aggregate values of the performance of various operational activities of the business, which are measured using operational indicators.

A small amount of research focuses on the specific choice of indicators in specific industries (Hristov & Chirico, 2019; Hristov et al., 2019), such as the hotel sector of winter destinations. Buhovac and Groff (2010) consider PM systems to be unique. Mapping PM systems between different regions and industries is not the best solution (Wadong et al., 2010). Dai and Kuosmanen (2014) believe that the exchange of practices in the field of PM systems requires the homogeneity of the hotels in terms of size, number of employees, market share and similar characteristics. Magnini et al. (2021) consider that it is impossible to use the same indicators within the PM system in crises such as the Covid-19 pandemic and regular business conditions. In accordance with the previous statements, one of the research questions within this paper is what indicators hotel managers in Serbia and Bosnia measured in the era of the Covid-19 pandemic.

Relevant studies suggest that managerial attitudes are a key factor in the development and implementation of PM systems (Wadong et al., 2010; Modell, 2003). Performance measurement systems should be seen as an initiative to improve and achieve a corporate goal rather than as a control instrument, which facilitates their introduction into formal business processes. The positive attitude of managers towards performance measurement systems is extremely important because it enables the contribution of managers in the implementation of measures and improves the interpretation of the obtained results (Groen et al., 2012). Research in this paper will focus on the attitudes of hotel managers in CEE region countries regarding the usefulness of certain types of indicators in hotel management. In accordance with the previous statements, the following research hypothesis was defined:

- *H1: There is a link between the level of use of certain operational and organisational indicators and the attitudes of hotel managers about their usefulness.*

Various studies show that hotel size, hotel revenue, sales growth in hotel services, and the level of hotel investment are related to the choice of indicators and levels of their implementation (Hudson et al., 2001; Garengo et al., 2005; Odar et al., 2012). Managers of larger hotels implement several financial and non-financial indicators, which are reflected in savings, efficient resource management, and improved service quality (Bohdanowicz et al., 2011). Smaller hotels which do not have developed PM systems and measurement processes are limited to legally required financial criteria (Pereira-Moliner et al., 2015), indicating that large hotels which use several non-financial parameters achieve better performance and have a strong impact on the market by improving service quality. Sharma and associates (2021) consider that performance measurement is related to the revenues that hotels generate. The

implementation of non-financial metrics in the hotel industry is reflected in the growth of hotel services sales, hotel revenues and levels of investment in hotels (Bendle et al., 2015; Pnevmatikoudi & Stavrinoudis, 2016). Therefore, this research examines the relationship between hotel characteristics (hotel size, hotel revenue, sales growth in hotel services, and the level of hotel investment) and the level of PM system implementation. In accordance with the previous statements, the following research hypotheses were defined:

- *H2: The size of the hotel affects the level of implementation of organisational and operational indicators.*
- *H3: There are differences in the levels of implementation of organisational and operational indicators based on hotel revenues.*
- *H4: There are differences in the levels of implementation of organisational and operational indicators based on the growth of hotel sales in the past three years.*
- *H5: There are differences in the levels of implementation of organisational and operational indicators based on the level of hotel investment in the past three years.*

A question that has also attracted the attention of the scientific community is whether managerial characteristics such as education, position held in the hotel, work experience and age influence the choice of indicators and the level of their application (Jogarathnam et al., 2004; Todorović et al., 2015; Jugović et al., 2022). de Waal and Kourtit (2013) consider that the lack of resources and skilled labour are the main limiting factors for the implementation of the PM system. Wadong et al. (2010) consider that the level of education of managers and the lack of analytical skills of managers are the key limiting factors in the implementation of PM systems. In contrast to this statement, Todorović et al. (2015) believe that the characteristics of managers do not affect the choices and levels of implementation of the PM system. In accordance with the previous statements, the following research hypotheses were defined:

- *H6: The characteristics of the manager position in hotels have an impact on the implementation of the PM system.*
- *H7: The characteristics of managers' age have an impact on the implementation of the PM system.*
- *H8: The characteristics of managers' level of education have an impact on the implementation of the PM system.*
- *H9: The characteristics of managers' levels of work experience impact the implementation of the PM system.*

PM systems in the hotel industry during the Covid-19 era

Magnini et al. (2021) consider PM systems to be a key strategic instrument in hotel management during the Covid-19 pandemic. Implementing PM systems enables the development of sustainable economic strategies related to cost reduction, service innovation, competitiveness, and increased sales, which is what hotel managers strive for, especially during the Covid-19 pandemic (Radygina & Oshkordina, 2020).

At the beginning of the crisis, managers of tourism companies focused on the analysis of financial performance. The goal was to reduce the cost of hotel services and stimulate sales. As the duration of the epidemiological crisis lengthened, these strategies proved ineffective (Kukanja et al., 2020). In addition to relying on financial performance at the beginning of the Covid-19 pandemic, managers tried to use PM systems to predict trends in the hotel industry (Magnini et al., 2021). However, the

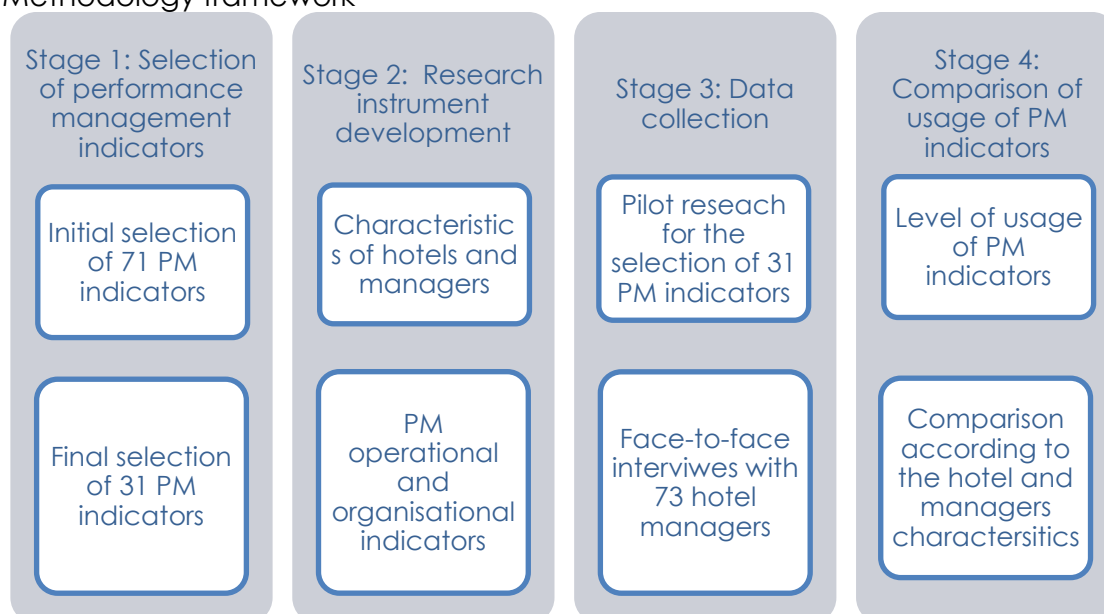
results show that even the most sophisticated predictions have large errors due to the radical disturbances in the market.

Client insecurity during the pandemic period caused a greater need for information and communication. Travel decisions were strongly influenced by information from the news and social media (Villacé-Molinero et al., 2021). Neuburger and Egger (2021) claim that media coverage plays a crucial role in the relationship between risk perception and travel intention. Hotel managers then focused on marketing activities (Lai & Wong, 2020). Marketing activities and the use of digital media are becoming primary for communication and attracting guests, which is why managers are increasingly interested in measuring the performance of digital advertising (Neuburger & Egger, 2021; Villacé-Molinero et al., 2021; Lai & Wong, 2020). Improving service in line with epidemiological standards is becoming significant in the hotel industry during the Covid-19 pandemic, with hotel managers increasingly interested in measuring performance related to guest satisfaction and protection (Yu et al., 2021). Since the costs of employees in the hotel industry make up 50% of the total costs, managers are also interested in the performance of employees in order to reduce costs and ensure efficient personnel management during the Covid-19 pandemic (Kukanja et al., 2020). Post-Covid-19 research reveals a continued trend in the hotel industry toward prioritising non-financial indicators. Several authors stress that the Covid-19 pandemic has been a catalyst for the development of non-financial analytics and the recognition of its significance in terms of hotel profitability (Németh & Gyurácz-Németh, 2022; Widz et al., 2022; Hao et al., 2020).

Methodology

The research process was conducted in 3 stages: (i) stage 1, which included the selection of performance management indicators; (ii) stage 2, which included the development of the research instrument based on the stage 1 results; (iii) stage 3, which included the data collection, and (iv) stage 4 that included comparison of the usage of PM indicators according to managers' and hotels' characteristics. Figure 1 presents the methodology framework.

Figure 1
Methodology framework



Source: Authors' work

Stage 1: Selection of performance management indicators

A review of the relevant literature identified 79 indicators of hotel performance (Rust et al., 2004; Bendle et al., 2015; Pnevmatikoudi & Stavrinoudis, 2016; Davis, 2007; Paine, 2007; Magnini et al., 2021; Lai & Wong, 2020; Fatima & Elbanna, 2020) used within the PM system. These indicators aim to measure the sustainable operation of the hotel, as they consider the key dimensions of sustainability (epidemiological, social and economic sustainability) (Obrenovic et al., 2020; Hristov & Chirico, 2019).

After defining a preliminary list of 79 indicators, a pilot study was conducted to determine the final list of indicators. Based on the pilot study, 31 indicators were selected, which were divided into two groups: organisational and operational indicators. The division into operational and organisational indicators is increasingly represented in the scientific literature and practice (Katsikeas et al., 2016). This division enables easier operationalisation of research. Operational indicators measure operational business activities related to user, service, advertising, and direct marketing indicators, while organisational indicators measure achieved financial, market, price, capacity utilisation and employee performance. Organisational indicators represent the cumulative values of the performance of various operational activities within business processes (Katsikeas et al., 2016). Within operational and organisational performance, both financial and non-financial indicators are represented. The list was modified in accordance with the strategic intentions of the hotel in the observed region, the business circumstances caused by the Covid-19 pandemic, the available resources, and the expectations of stakeholders. Table 1 presents the organisational and operational indicators examined in the research.

Table 1

Organisational and operational indicators selected for the research

Organisational indicators	Operational indicators
Net Profit	Customer retention rate
Return on Investment (ROI)	Customer Satisfaction
Return on Sales (ROS)	Net Promoter Score
Earnings Before Interest Taxes Depreciation Amortization (EBITDA)	Health Index of Client (HIC)
Market Demand	Customer Effort Score
Market Growth	Quality of Service
Occupancy Rate	Impressions
Average Daily Room Rate	Click
Revenue Per Available Room (RevPAR)	Reach
Room Cleaning	Click To Rate- CTR
Employee Satisfaction	Cost per Click- CPC
Sales Force Effectiveness	Conversions
Compensation	Rates of Conversion
Health Index of Employee (HIE)	Value of Conversion
	Cost of Direct Marketing Activities
	Percentage Sales with Direct Marketing
	Return of Marketing Investment ROMI

Source: Authors' work

Stage 2: Research instrument development

Four groups of questions were used in the survey.

- The first group referred to the characteristics of the hotel (size of the hotel, level of income, sales growth, and level of investment) and characteristics of the

hotel manager (age, level of education, work experience, and position in the hotel).

- The second group of questions was related to the level of implementation of chosen organisational and operational indicators. The questions within this group were formulated as follows: Do you implement the following indicator with answers Yes and No?
- The third group of questions refers to the attitudes of hotel managers about the usefulness of certain indicators in hotel management. On a scale of 1 (completely useless) to 5 (completely useful), managers rated the usefulness of each indicator.
- Within the fourth group of questions, hotel managers independently identified indicators not included in the survey but considered helpful in managing hotels during the Covid-19 pandemic.

Stage 3: Data collection

The empirical research presented in this paper is divided into two parts. First, the pilot research aimed to refine the list of performance indicators through interviews conducted with seven hotel managers. Second, the hotel managers of winter destinations in Serbia and Bosnia were interviewed face-to-face. Criteria for selecting managers who participated in creating the final list of indicators were their level of education, work experience in the position of strategic manager in the hotel industry, the size of the hotel they managed, and the financial results achieved in managed hotels. The research was conducted from December 2020 to February 2021.

The research involved 73 hotel managers who operate in winter destinations (Jahorina, Bjelašnica, Trebević, Vlašić, Kupres (Bosnia), and Kopaonik, Zlatibor, Tara, Divčibare (Serbia)), in Serbia and Bosnia. In Bosnia, 38 hotel managers were interviewed, while in Serbia, 35 hotel managers participated. Each manager represented one hotel, following the first-respondent research approach. Given the structure of the indicators used in this study, only hotel managers could provide answers because they have insight into the different areas of hotel business to which the selected indicators refer. Thus, a face-to-face survey with hotel managers was completed in each of the 73 hotels. The number of managers who participated in this study was influenced by the following factors: busyness of hotel managers and lack of free time to fill out the questionnaire, inability to establish face-to-face contact due to the epidemiological situation, inability to answer certain questions and reveal business secrets, weather and terrain configuration which prevented access to certain locations, seasonal business, and the presence of hotel managers only in certain periods. Also, it is necessary to take into account that the hotel industry in Bosnia and Serbia is in the process of rebuilding existing capacities and developing new capacities (hotels), especially after the destruction of the war. The number of 73 hotel managers makes up about 69% of the total market of the hotel industry of winter destinations in Serbia and Bosnia.

The characteristics of hotel managers who participated in the study are presented in Table 2. Descriptive data is provided for Serbia and Bosnia, as well as for the overall sample. Among the executives, 40 hotel owners (54.8%) and 33 hotel top managers (45.2%) were involved. There were 45.2% of hotel managers under the age of 45 and 54.5% of managers over the age of 45. The threshold of 45 was chosen for two reasons: to have equal groups to compare and to divide respondents into Generation X and Generation Y. Most managers have a university education. In contrast, when it comes to work experience, most hotel managers have less than 10 years of work experience in the hotel industry.

Table 2

Sample descriptive data Serbia, Bosnia and for the overall sample

Characteristics	Categories	Serbia		Bosnia		N	%
		N	%	N	%		
The position of the respondents in the hotel	Hotel owner	22	56.4	18	52.9	40	54.8
	Hotel top manager	17	43.6	16	47.1	33	45.2
Age of the respondent	Less than 45 years (Generation Y)	20	51.3	13	38.2	33	45.2
	45 years and more (Generation X)	19	48.7	21	61.8	40	54.8
Educational attainment of the respondents	High school	3	7.7	/	/	3	4.1
	College degree	10	25.6	8	23.5	18	24.7
	Master's degree	15	38.5	16	47.1	31	42.5
	PhD	11	28.2	10	29.4	21	28.8
Work experience of the respondents	Less than 10 (years)	5	12.8	4	11.8	9	12.3
	From 10 to 20 (years)	10	25.6	13	38.2	23	31.5
	More than 20 (years)	24	61.5	17	50.0	41	56.2

Source: Authors' work

The characteristics of the hotels whose managers participated in this research are shown in Table 3. In total, 50 (68.6%) hotels generated revenue greater than \$500,000, and less than \$500,000 was generated by 23 (31.5%) hotels. Most hotels had sales growth of 1 to 3% in the last three years. When it comes to hotel investment levels, most hotels have invested less than \$ 25,000 in the last three years. When it comes to the size of hotels on the market in Bosnia and Serbia, small hotels operate the most.

Table 3

Features of the hotels whose managers participated in the study

Hotel features	Categories	Serbia		Bosnia		N	%
		N	%	N	%		
Hotel income (yearly)	Less than \$500,000	11	28.2	12	35.3	23	31.4
	More than \$500,000	28	71.8	22	64.7	50	68.6
Sales growth (yearly)	Less than 1%	8	20.5	10	29.4	18	24.7
	from 1 to 3%	19	48.7	11	32.4	30	41.1
	More than 3 %	12	30.8	13	38.2	25	34.2
The level of investment in the hotel in the last three years	Less than \$25,000	7	17.9	5	14.7	12	16.4
	from \$25,000 to \$50,000	9	23.1	9	26.5	18	24.7
	More than \$50,000	23	59.0	20	58.8	43	58.9
Number of rooms in the hotel	Less than 25	8	20.5	8	23.5	16	21.9
	from 25 to 50	10	25.6	7	20.6	17	23.3
	More than 50	21	53.8	19	55.9	40	54.8
Number of hotel employees	Less than 25	8	20.5	9	26.5	17	23.3
	From 25 to 50	9	23.1	7	20.6	16	21.9
	More than 50	22	56.4	18	52.9	40	54.8

Source: Authors' work

Stage 4: Comparison of the usage of PM indicators according to managers' and hotels' characteristics

In stage 4, the use of PM indicators was compared using the Mann-Whitney and Kruskal-Wallis tests according to the characteristics of managers and hotels.

Results

Level of PM indicators usage

The research identified organisational indicators used by hotel managers (Table 4). The most used indicators are Net profit, Average Daily Room Rate, Compensation, Occupancy Rate, Return on Sales (ROS), and Market Demand.

Table 4

Levels of usage of organisational indicators in surveyed hotels

Organisational indicators	# of hotels	%
Net Profit	73	100
Return on Investment (ROI)	64	87.7
Return on Sales (ROS)	68	93.2
Earnings Before Interest Taxes Depreciation Amortization (EBITDA)	33	45.2
Market Demand	68	93.2
Market Growth	53	72.6
Occupancy Rate	69	94.5
Average Daily Room Rate	70	95.9
Revenue Per Available Room (RevPAR)	48	65.8
Room Cleaning	64	87.7
Employee Satisfaction	44	60.3
Sales Force Effectiveness	59	80.8
Compensation	70	95.9
Health Index of Employee (HIE)	38	52.1

Source: Authors' work

The research also observed operational indicators used by hotel managers (Table 5). The most used operational indicators are Customer Satisfaction, Return of Marketing Investment (ROMI), Customer Effort Score, Quality of Service, and Click.

Table 5

Levels of usage of operational indicators in surveyed hotels

Operational indicators	# of hotels	%
Customer retention rate	59	80.8
Customer Satisfaction	70	95.9
Net Promoter Score	50	68.5
Health Index of Client (HIC)	43	58.9
Customer Effort Score	68	93.2
Quality of Service	65	90.4
Impressions	58	79.5
Click	64	87.7
Reach	62	84.9
Click To Rate- CTR	39	53.4
Cost per Click- CPC	34	46.6
Conversions	40	54.8
Rates of Conversion	46	63.0
Value of Conversion	47	64.4
Cost of Direct Marketing Activities	55	75.3
Percentage Sales with Direct Marketing	54	74.0
Return of Marketing Investment ROMI	69	94.5

Source: Authors' work

Relationship between the usage level and attitudes about the usefulness of PM indicators (H1)

The research analysed managers' attitudes towards the usefulness of organisational and operational indicators during the Covid-19 pandemic. On a scale from 1 (completely useless) to 5 (completely useful), hotel managers rated each indicator (Table 6). Based on the presented results, it can be concluded that hotel managers at the time of the pandemic considered operational indicators more useful than organisational indicators.

Table 6

Managers' attitudes about the usefulness of organisational and operational indicators

Type of indicator	Indicator	Mean $\pm$ Std
Organisational indicators	Net Profit	2.73 $\pm$ 0.769
	Return on Investment (ROI)	2.71 $\pm$ 0.735
	Return on Sales (ROS)	2.75 $\pm$ 0.795
	Earnings Before Interest Taxes Depreciation Amortization (EBITDA)	2.98 $\pm$ 0.841
	Market Demand	3.76 $\pm$ 0.589
	Market Growth	3.76 $\pm$ 0.589
	Occupancy Rate	4.26 $\pm$ 0.500
	Average Daily Room Rate	4.43 $\pm$ 0.477
	Revenue Per Available Room RevPAR	4.41 $\pm$ 0.641
	Room Cleaning	4.79 $\pm$ 0.408
	Employee Satisfaction	4.43 $\pm$ 0.577
	Sales Force Effectiveness	4.58 $\pm$ 0.573
	Compensation	3.71 $\pm$ 0.824
	Health Index of Employee (HIE)	3.63 $\pm$ 0.677
Operational indicators	Customer retention rate	4.19 $\pm$ 0.461
	Customer Satisfaction	4.89 $\pm$ 0.393
	Net Promoter Score	4.71 $\pm$ 0.513
	Health Index of Client (HIC)	3.90 $\pm$ 0.819
	Customer Effort Score	4.38 $\pm$ 0.679
	Quality of Service	4.93 $\pm$ 0.304
	Impressions	4.30 $\pm$ 0.638
	Click	4.30 $\pm$ 0.660
	Reach	4.34 $\pm$ 0.628
	Click To Rate- CTR	4.24 $\pm$ 0.662
	Cost per Click- CPC	4.27 $\pm$ 0.629
	Conversions	4.36 $\pm$ 0.634
	Rates of Conversion	4.38 $\pm$ 0.637
	Value of Conversion	4.35 $\pm$ 0.631
	Cost of Direct Marketing Activities	4.65 $\pm$ 0.582
	Percentage Sales with Direct Marketing	4.65 $\pm$ 0.582
	Return of Marketing Investment ROMI	4.72 $\pm$ 0.583

Source: Authors' work

We also observed whether there are differences between hotel managers' attitudes on the usefulness of certain organisational and operational indicators and the level of their implementation, as shown in Table 6 and Table 7. To explore the differences, the Mann-Whitney (MW) test was employed in both cases.

For organisational indicators, differences were found in Return on Sales (ROS), Revenue Per Available Room (RevPAR), Employee Satisfaction, and Sales Force Effectiveness (Table 7).

Table 7

Difference in the attitudes of managers about the usefulness of organisational indicators based on their implementation

Organisational indicators	Mann-Whitney test	Mean $\pm$ Std.	
		Use	Do not use
Net Profit	/	/	/
Return on Investment (ROI)	-1.464	2.67 $\pm$ 0.757	3.00 $\pm$ 0.500
Return on Sales (ROS)	-1.955*	2.70 $\pm$ 0.792	3.40 $\pm$ 0.547
Earnings Before Interest Taxes Depreciation Amortization (EBITDA)	-1.446	2.87 $\pm$ 0.992	3.07 $\pm$ 0.693
Market Demand	-0.618	3.77 $\pm$ 0.594	3.60 $\pm$ 0.547
Market Growth	-1.465	3.69 $\pm$ 0.540	3.95 $\pm$ 0.686
Occupancy Rate	-1.138	4.27 $\pm$ 0.511	4.00 $\pm$ 0.000
Average Daily Room Rate	-1.268	4.35 $\pm$ 0.482	4.00 $\pm$ 0.000
Revenue Per Available Room (RevPAR)	-3.262**	4.60 $\pm$ 0.494	4.04 $\pm$ 0.734
Room Cleaning	-0.109	4.79 $\pm$ 0.407	4.77 $\pm$ 0.440
Employee Satisfaction	-2.361*	4.56 $\pm$ 0.501	4.21 $\pm$ 0.629
Sales Force Effectiveness	-2.893**	4.67 $\pm$ 0.539	4.21 $\pm$ 0.578
Compensation	-1.006	3.72 $\pm$ 0.832	3.33 $\pm$ 0.577
Health Index of Employee (HIE)	-1.844	3.76 $\pm$ 0.633	3.48 $\pm$ 0.677

Note: *p<0.05, ** p<0.001

Source: Authors' work

For operational indicators, there is no link between managers' attitudes about their usefulness and the level of their implementation in Customer retention rate, Health Index of Client (HIC), and Customer Satisfaction (Table 8). However, it was found that there is a link between the level of use of certain operational indicators and the attitudes of hotel managers about their usefulness.

Table 8

Differences in the attitudes of managers about the usefulness of operational indicators based on their implementation

Operational indicators	Mann-Whitney test	Mean $\pm$ Std. Deviation	
		Use	Do not use
Customer retention rate	-0.159	4.18 $\pm$ 0.472	4.21 $\pm$ 0.425
Customer Satisfaction	-1.722	4.91 $\pm$ 0.329	4.33 $\pm$ 1.154
Net Promoter Score	-3.928**	4.86 $\pm$ 0.404	4.39 $\pm$ 0.583
Health Index of Client (HIC)	-0.322	3.93 $\pm$ 0.827	3.86 $\pm$ 0.819
Customer Effort Score	-3.666**	4.67 $\pm$ 0.588	4.12 $\pm$ 0.656
Quality of Service	-1.140	4.95 $\pm$ 0.209	4.71 $\pm$ 0.755
Impressions	-3.512**	4.44 $\pm$ 0.535	3.73 $\pm$ 0.703
Click	-2.827**	4.39 $\pm$ 0.607	3.66 $\pm$ 0.707
Reach	-2.297*	4.41 $\pm$ 0.588	3.90 $\pm$ 0.700
Click To Rate- CTR	-3.755**	4.51 $\pm$ 0.601	3.94 $\pm$ 0.600
Cost per Click- CPC	-4.784**	4.64 $\pm$ 0.485	3.94 $\pm$ 0.559
Conversions	-4.910**	4.70 $\pm$ 0.464	3.96 $\pm$ 0.585
Rates of Conversion	-4.770**	4.65 $\pm$ 0.525	3.92 $\pm$ 0.549
Value of Conversion	-4.795**	4.61 $\pm$ 0.533	3.88 $\pm$ 0.515
Cost of Direct Marketing Activities	-5.266**	4.86 $\pm$ 0.404	4.05 $\pm$ 0.639
Percentage Sales with Direct Marketing	-5.418**	4.87 $\pm$ 0.390	4.05 $\pm$ 0.621
Return of Marketing Investment ROMI	-2.473*	4.79 $\pm$ 0.439	3.50 $\pm$ 1.290

Note: *p<0.05, ** p<0.001

Source: Authors' work

Comparison of PM indicators usage according to hotel characteristics (H2-H5)

The following analysis, using the Kruskal-Wallis Test, analysed whether there are differences in levels of implementation of organisational and operational indicators based on the size of the hotel (Table 9). The size of the hotel is determined based on the number of rooms and the number of employees. Small hotels had less than 25 rooms and 25 employees. Medium hotels had between 25 and 50 rooms and between 25 and 50 employees. Large hotels had more than 50 rooms and more than 50 employees.

Table 9

Differences in the levels of application of the PM system and the size of the hotel

Type of indicators	Mean $\pm$ St. Dev.			Kruskal-Wallis H
	Large hotels	Medium hotels	Small hotels	
Organisational indicators	18.10 $\pm$ 2.53	16.17 $\pm$ 1.70	14.00 $\pm$ 0.00	35.67**
Operational indicators	24.50 $\pm$ 4.93	21.29 $\pm$ 6.49	17.00 $\pm$ 0.00	29.68**

Note: ** p<0.001

Source: Authors' work

The results show that there are differences in the levels of organisational and operational indicators applied based on the size of the hotel. Large hotels used the most performance indicators, followed by medium-sized hotels and small hotels. The Man-Whitney U Test was again employed to examine whether there were differences in the levels of application of organisational and operational indicators based on hotel revenues. The results show that hotels with higher revenues measure more indicators compared to hotels with lower revenues (Table 10).

Table 10

Differences in the levels of application of the PM system based on annual hotel revenues

Type of indicators	Mean $\pm$ St. Dev.		Mann-Whitney test
	More than \$500,000	Less than \$500,000	
Organisational indicators	19.52 $\pm$ 2.10	15.48 $\pm$ 1.70	-5.872**
Operational indicators	27.60 $\pm$ 5.12	19.58 $\pm$ 3.75	-5.697**

Note: ** p<0.001

source: authors' work

Using the Kruskal-Wallis Test, it was examined whether there are differences in the levels of application of organisational and operational indicators based on hotel sales growth over the past three years. The results show that hotels that achieved higher sales growth rates measure more indicators compared to hotels that achieved lower sales growth rates (Table 11).

Table 11

Differences in the levels of application of the PM system based on hotel sales growth

Type of indicators	Mean $\pm$ St. Dev.			Kruskal-Wallis H
	More than 3 %	From 1 to 3%	Less than 1%	
Organisational indicators	19.68 $\pm$ 1.74	15.93 $\pm$ 1.41	14.05 $\pm$ 0.23	55.48**
Operational indicators	26.76 $\pm$ 3.73	21.16 $\pm$ 5.68	17.22 $\pm$ 0.94	41.28**

Note: ** p<0.001

Source: Authors' work

The following analysis, using the Kruskal-Wallis Test, examined whether there are differences in the levels of application of organisational and operational indicators based on the level of hotel investment in the past three years. The results show that hotels that measured more indicators had higher levels of investment, while hotels that measured fewer indicators had lower investment (Table 12).

Table 12

Differences in the levels of application of the PM system based on investment levels

Type of indicators	Mean $\pm$ St. Dev.			Kruskal-Wallis H
	More than \$50,000	From \$25,000 to \$50,000	Less than \$25,000	
Organisational indicators	18.30 $\pm$ 2.30	14.88 $\pm$ 1.02	14.00 $\pm$ 0.00	44.42**
Operational indicators	26.23 $\pm$ 5.29	18.05 $\pm$ 2.15	17.00 $\pm$ 0.00	40.41**

Note: ** p<0.001

Source: Authors' work

Comparison of PM indicators usage according to managers' characteristics (H6-H9)

The research examined whether managers' characteristics (position, age, level of education, and level of work experience) impact the implementation of the PM system. Using the Mann-Whitney U Test, it was examined whether there are differences in the levels of application of organisational and operational indicators and positions in the hotel. The results show that top hotel managers measure more indicators than hotel owners (Table 13).

Table 13

Differences in the levels of application of the PM system based on the position of the respondent

Type of indicators	Mean $\pm$ St. Dev.		Mann-Whitney test
	The owner	Top manager	
Organisational indicators	15.85 $\pm$ 2.48	17.84 $\pm$ 2.39	-3.648**
Operational indicators	19.85 $\pm$ 4.43	24.87 $\pm$ 5.73	-4.143**

Note: ** p<0.001

Source: Authors' work

Using the Man-Whitney U Test, it was examined whether there are differences in the levels of application of organisational and operational indicators and the age of the respondents. The results show that top hotel managers under the age of 45 measure more indicators than managers over the age of 45 (Table 14).

Table 14

Differences in the levels of application of the PM system based on the age of the respondent

Type of indicators	Mean $\pm$ St. Dev.		Mann-Whitney test
	More than 45 years	Less than 45 years	
Organisational indicators	15.80 $\pm$ 2.04	17.90 $\pm$ 2.82	-3.242**
Operational indicators	20.15 $\pm$ 5.27	24.48 $\pm$ 5.17	-3.679**

Note: ** p<0.001

Source: Authors' work

Using the Kruskal-Wallis Test, it was also explored whether there are differences in the levels of application of organisational and operational indicators and the work experience of the respondents. The results show that hotel managers with less than 10 years of work experience measure more indicators than managers who have more than 10 years of work experience (Table 15).

Table 15

Differences in the levels of application of PM based on the work experience of managers

Type of indicators	Mean $\pm$ Std			Kruskal-Wallis H
	More than 20 years	From 10 to 20 years	Less than 10 years	
Organisational indicators	15.82 $\pm$ 2.24	17.08 $\pm$ 2.46	20.11 $\pm$ 1.69	18.560**
Operational indicators	20.56 $\pm$ 5.39	22.39 $\pm$ 4.94	28.44 $\pm$ 3.87	16.200**

Note: ** p<0.001

Source: Authors' work

Using the Kruskal-Wallis Test, it was analysed whether there are differences in the levels of application of organisational and operational indicators and the level of education of the respondents. The results show that hotel managers who have completed doctoral studies measure upwards of indicators, and then by measurement levels are managers who have completed master studies. Managers with a secondary education measured more indicators than managers with a bachelor's degree (Table 16).

Table 16

Differences in the levels of application of PM based on the educational attainment of respondents

Type of indicators	Mean $\pm$ Std				Kruskal-Wallis H
	High school	College	Master	PhD	
Organisational indicators	15.66 $\pm$ 1.52	14.83 $\pm$ 1.85	16.64 $\pm$ 2.44	18.71 $\pm$ 2.28	25.10**
Operational indicators	22.66 $\pm$ 5.13	18.33 $\pm$ 3.19	21.67 $\pm$ 6.01	25.90 $\pm$ 4.49	23.44**

Note: ** p<0.001

Source: Authors' work

Discussion

The following table (Table 17) shows the summary results of the research and tested set of research hypotheses. The research results show that H1 is rejected in the case of organisational indicators (there is no connection between the level of implementation of organisational indicators and managers' views on the usefulness of organisational indicators in hotel management). As part of the research results, the analyses are presented for individual organisational indicators, and the obtained values show that for most individual organisational indicators, there is no statistically significant result for these analyses. When it comes to operational indicators, with many indicators of individual operational indicators, statistically significant results were obtained,

so H1 in the case of operational indicators is confirmed (there is a connection between the level of implementation of operational indicators and the views of hotel managers about their usefulness). Hotel managers who had a more positive attitude about the usefulness of the indicators used them more than managers who had a less positive attitude. H2, H3, H4 and H5 were confirmed, which shows that there is a relationship between hotel characteristics such as size, revenues, sales growth investment level and the level of PM system implementation. H6, H7, H8 and H9 were confirmed, which shows that there is a relationship between manager characteristics such as position, age, level of education and work experience and the level of PM system implementation.

Table 17

Aggregated results of the conducted hypothesis testing

Research hypotheses	Hypothesis testing on organisational indicators	Hypothesis testing on operational indicators
Attitudes of managers		
H1: There is a link between the level of use of certain operational indicators and the attitudes of hotel managers about their usefulness.	4/14 Ø Less than half of relationships are positive	13/17 ✓ More than half of relationships are positive
Characteristics of the hotel		
H2: There are differences in levels of implementation of organisational and operational indicators based on the size of the hotel.	✓ (1%) Larger hotels	✓ (1%) Larger hotels
H3: There are differences in the levels of implementation of organisational and operational indicators based on hotel revenues.	✓ (1%) Higher revenue	✓ (1%) Higher revenue
H4: There are differences in the levels of implementation of organisational and operational indicators based on the growth of hotel sales in the past three years.	✓ (1%) Higher growths	✓ (1%) Higher growths
H5: There are differences in the levels of implementation of organisational and operational indicators based on the level of hotel investment in the past three years.	✓ (1%) Higher investments	✓ (1%) Higher investments
Characteristics of the managers		
H6: The characteristics of the manager position in hotels have an impact on the implementation of the PM system.	✓ (1 %) Top managers	✓ (1 %) Top managers
H7: The characteristics of managers' age an impact on the implementation of the PM system	✓ (1 %) Youngers managers	✓ (1 %) Youngers managers
H8: The characteristics of managers' level of education have an impact on the implementation of the PM system.	✓ (1 %) Higher education	✓ (1 %) Higher education
H9: The characteristics of managers' level of work experience have an impact on the implementation of the PM system.	✓ (1 %) Less experience	✓ (1 %) Less experience

Note: % is significance level of hypothesis acceptance

Source: Authors' work

This research shows the practice of measuring the performance of hotels in winter destinations in Serbia and Bosnia during the Covid-19 pandemic. In the first part of the research, organisational and operational indicators used by managers within hotel management were identified. The results show that the following indicators were most often used: Net Profit, Return on Sales (ROS), Market Demand, Occupancy Rate, Average Daily Room Rate, Compensation, Customer Satisfaction, Net Promoter Score, Customer Effort Score, Quality of Service, Click, Return of Marketing Investment (ROMI). Based on the presented results, it can be concluded that most managers use basic financial measures such as Net Profit, Compensation and Return on Sales (ROS) but that the application of non-financial measures such as Customer Satisfaction and Quality of Service does not lag the application of financial criteria. These results are consistent with the results presented by relevant research in the field of performance measurement (Neuburger & Egger, 2020; Villac'e-Molinero et al., 2021; Lai & Wong, 2020; Yu et al., 2021). In the age of the Covid-19 pandemic, hotel managers are increasingly relying on non-financial metrics such as service metrics, customer metrics, digital advertising activity metrics, and employee-related metrics. Also, in this study, hotel managers independently singled out indicators that they considered useful in hotel management during the Covid-19 pandemic. At the time of the pandemic, hotel managers used the following indicators: client profitability was used by 45.2% of the sample, duration of training of hotel employees by 31.5%, discounted price by 43.8%, costs of coupons, rebates, and advertising materials by 19.2%, percentage of sales with coupons, rebates 20.5% also use advertising materials. Metrics that hotel managers have independently identified as useful in hotel management further strengthen the results of this research and the results presented by the relevant literature that non-financial metrics are used more than financial metrics during the Covid-19 pandemic.

After identifying the indicators used in hotel management within this research, managers' attitudes on the usefulness of organisational and operational indicators were examined. The results of this study show that hotel managers, at the time of the Covid-19 pandemic, considered operational indicators more useful in hotel management compared to organisational indicators. Relevant literature on managerial attitudes about PM systems at the time of the Covid-19 pandemic is scarce or limited. Wang and Huang (2021) believe that the effects of the implementation of operational indicators within hotel management are exceptional and that hotel managers strive to achieve superior operational performance. The implementation of operational indicators removes the "short-sightedness" of managers, enabling the selection of areas for development and investment in accordance with market circumstances and hotel opportunities (Katsikeas et al., 2016).

This study examined whether there was a link between the attitudes of hotel managers regarding the usefulness of organisational and operational indicators and the level of their implementation during the Covid-19 pandemic. The existence of a link between managers' attitudes about the usefulness of indicators and levels of indicator implementation was determined for the following organisational indicators: Return on Sales (ROS), Revenue Per Available Room (RevPAR), Employee Satisfaction, and Sales Force Effectiveness. When it comes to operational indicators, the existence of a relationship between managers' attitudes about the usefulness and levels of implementation was found for the following indicators: Net Promoter Score, Customer Effort Score, Quality of Service, Impressions, Click, Reach, Click To Rate- CTR, Cost per Click - CPC, Conversions, Rates of Conversion, Value of Conversion, Cost of Direct, Marketing Activities, Percentage Sales with Direct Marketing and Return of Marketing

Investment (ROMI). Managers who had more positive attitudes about the usefulness of these indicators measured them more compared to managers who had a less positive attitude about the usefulness of these indicators. Various studies show that managers' attitudes are related to their analytical skills, pointing to a lack of analytical skills and the need to educate managers regarding the implementation of key performance indicators (de Waal & Kourtiti, 2013).

The research identified whether there is a link between the level of implementation of the PM system and the characteristics of the hotel, such as the size of the hotel, the level of revenue that the hotel generates, sales growth in the last three years and the level of investment in the last three years. The results showed that larger hotels use more operational and organisational indicators compared to smaller hotels. Also, the results show that hotels that measured more organisational and operational indicators within hotel management achieved higher revenues, higher sales growth and higher levels of investment. Relevant literature before the start of the Covid-19 pandemic shows that there is a link between the level of implementation of the PM system and the size of hotels, i.e., that larger hotels measure more indicators than smaller hotels (Hudson et al., 2001; Odar et al., 2012). The results of various studies have confirmed that there is a link between business results (revenue and sales growth), level of investment and level of implementation of the PM system, i.e., hotel managers who use more organisational and operational indicators have better business outcomes and invest more in hotels and hotel business (Zigan & Zeglal, 2010; Pnevmatikoudi & Stavrinooudis, 2016; Sainaghi et al., 2013; Pingitore et al., 2010). The results of this research show what represents the relevant literature that PM systems are associated with the improvement of services, innovation, competitiveness, and profitability of hotels (Sharma et al., 2021; Magnini et al., 2021; Wadongo et al., 2010; Philips et al., 2005; Jugović et al., 2022). Bendle et al. (2015) consider that PM systems represent a management instrument that allows managers to determine the current position of the company and the position where the company wants to be, as well as ways to achieve goals. To improve the level of implementation of the PM system, hotel managers are advised to use their hotel management resources (human and operational) and combine them with those of IT (digital skills), to develop business value (Klada et al., 2024; Mihajlović et al., 2024).

This study also examined whether the characteristics of the hotel manager, such as the position in the hotel, the age of the manager, the level of education, and the level of work experience, affect the implementation of the PM system. The results showed that there is a relationship between the position held in the hotel and the level of PM. Top hotel managers measured more indicators than hotel owners. Relevant research prior to the Covid-19 pandemic indicates that hotel managers use PM systems not only as instruments to control and improve business but also to justify certain management decisions before boards (Bendle et al., 2015). The results show that the age of hotel managers also influenced the levels of implementation of the PM system. Managers under the age of 45 used more indicators compared to managers over the age of 45. The existence of a connection between the level of work experience of managers and the level of implementation of the PM system was also determined. Most indicators were used by managers who had less than 10 years of work experience and the least by managers who had more than 20 years of work experience. Relevant literature indicates that PM systems are management instruments of modern management, and the beginning of their development in the hotel industry was recorded in the late twenties (Phillips et al., 2005). Traditional PMs that relied on financial results were instruments of the centralised accounting systems of communist societies and were used until the mid-1990s when the need to redesign them was

recognised. Older managers who gained knowledge and experience during the communist regimes, when management systems were based exclusively on legally prescribed financial criteria, still apply them today and find it more difficult to redesign them. Unlike older managers, younger managers recognise the importance of modern, balanced (equal application of financial and non-financial indicators) PM systems and implement them in hotel management processes (Uddin et al., 2020).

It was also examined whether there is a connection between the level of education of hotel managers and the level of implementation of the PM system. The results showed that managers with completed doctoral studies measure the most indicators, followed by managers with master's studies. After managers with master's studies are managers with a high school diploma. Managers with a university education measured the least indicators. The results of other research indicated that the level of education of the manager had an impact on the levels of implementation of certain indicators within the PM system (de Waal & Kourtit, 2013).

Conclusion

The Covid-19 pandemic has caused changes in the hotel and hospitality industry's business, for example restaurants turned to offering private dining (Slivar, 2022). The goal of hotel managers was to enable sustainable, economical hotel operations. Satisfaction, safety, guest protection and communication through digital media have become the focus of interest of hotel managers. These changes also affected the hotel industry's PM systems in the CEE region. This study presents the practice of measuring organisational and operational indicators during the Covid-19 pandemic in the CEE region (Serbia and Bosnia). The results of the research show that in the era of the Covid-19 pandemic, hotel managers relied on both financial and non-financial measures. Although various studies before the start of the Covid-19 pandemic indicated a higher prevalence of financial indicator measurements in CEE companies during the Covid-19 pandemic period, the application of non-financial indicators does not lag behind the application of financial indicators. Research conducted after the Covid-19 pandemic indicates a higher prevalence of non-financial measures in hotel management, which indicates the fact that the results of this research can serve as a basis for the development of a performance measurement system in the hotel industry in the post-pandemic period.

The research identified managers' attitudes toward the usefulness of the PM system in hotel management during the Covid-19 pandemic. The results of this study show that hotel managers in the CEE region find operational indicators more useful than organisational indicators in hotel management during the pandemic. Based on the results of this study, it can be concluded that during the Covid-19 pandemic, managers' awareness of the usefulness of operational indicators in hotel management is growing. In the framework of this research, whether there is a connection between the attitudes of managers and the levels of implementation of certain organisational and operational indicators was examined. The results showed that there is no connection between the level of implementation of organisational indicators and the attitudes of managers, so H1 is rejected in the case of organisational indicators. When it comes to operational indicators, the results of the research show that there is a connection between the level of implementation of operational indicators and the level of managers, and hypothesis H1 in the case of operational indicators is confirmed.

The efficiency of the PM system is expressed through an increase in revenue, sales growth rate and investment in hotels. This study also showed that there is a link between business performance (revenue and sales growth) and the PM system. Hotel

managers who measured more indicators achieved better business results than managers who measured fewer indicators. The results of the research also showed that managers who used more indicators invested more in hotels and hotel business processes. In accordance with the previous statements, the results of this research show that H2, H3, H4, and H5 are confirmed. The results of this study show that the characteristics of managers, such as business position in the hotel, age, level of education and level of work experience, are related to the choice of indicators and levels of their implementation, which indicates that H6, H7, H8 and H9 are confirmed.

A potential limitation of this study is the sample size. The size of the sample was determined by the structure of the sample (managers of winter destination hotels) and the fact that the owner or top manager who manages each hotel participated in the research. Opportunities to improve research were identified during this study. This study did not consider the synergistic effects of various internal and external factors on the choice of operational and organisational indicators.

Future directions of the study could be foreseen. One can explore the differences between the attitudes of managers in Serbian and Bosnian winter hotels regarding the implementation of PM systems. Another possible direction of the study could be to extend the sample and cover winter destination hotels in other CEE countries such as Montenegro and Albania. Also, it might be of interest to segment the winter hotels in CEE based on their level of PM using clustering algorithms (Nikolic et al., 2023). Also, advanced multivariate analysis and machine learning algorithms can be implemented to rank winter destinations (Maričić et al., 2019). The conducted research contributes to the field of performance measurement in tourism industry in the CEE region by providing insights on the situation within winter destination hotels.

We hope that the presented research will initiate further research on attitudes and factors that lead to the higher implementation of PM in the tourism industry in CEE.

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Integrated Communications Management in Organisations: Bibliometric Insight into Past and Future

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Abstract

Background: Integrated Communications Management (ICM) has emerged as a critical strategy in the evolving economy of organisational dynamics. This paper delves into its evolution, challenges, and thematic axes, addressing theoretical controversies and practical applications. **Objective:** This paper aims to conduct a comprehensive bibliometric analysis of ICM literature from 1989 to June 2023, scrutinising 971 publications from Elsevier Scopus. The study seeks to unveil patterns in productivity, authorship, collaboration networks, international contributions, and thematic structures. **Methods/Approach:** Employing systematic bibliometric methodology, this study analyses selected publications from the Scopus database. It integrates quantitative productivity metrics, citation analysis, qualitative mapping, and network exploration. **Results:** The findings highlight a significant surge in ICM studies since 2009, delineating thematic axes such as strategic communication, integrated marketing communications, social media, and public relations. Philip J. Kitchen is the most prolific author, while the most productive source, the Journal of Communication Management, plays a significant role in shaping the field of ICM. Remarkable collaboration networks are led by P. J. Kitchen, A. Siano, and A. Moreno. **Conclusions:** The analysis underscores the growing interest in ICM, emphasising ongoing interdisciplinary research and theoretical refinement. It advocates for further exploration to enhance both theoretical understanding and practical applications.

Keywords: Integrated Communications Management; bibliometric analysis; thematic axes; strategic communication; interdisciplinary research

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Introduction

In the dynamic landscape of the 21st century, organisations of diverse types find themselves navigating a challenging and intricate environment (Heide et al., 2018). Their pursuit of primary goals involves a nuanced understanding of stakeholders, employees, emerging markets, attractive segments, and niches (Verčič et al., 2015; Frandsen & Johansen, 2015). This endeavour is compounded by an array of contemporary challenges, ranging from the burgeoning influence of empowered customers through social media and new technologies (Šerić et al., 2014) to cyclical financial crises, global warming, and an absence of political will to address multifaceted issues.

The proliferation of information networks in society, in which every company is intricately woven, has expanded exponentially, creating a web of interactions between organisations and their public (Shumate et al., 2018). The complexity of today's society, coupled with the surge in new technologies generating vast amounts of data, signifies that significant game-changing forces are on the horizon (van Ruler, 2021; López-García et al., 2023). Much like the impact of artificial intelligence, these forces compel organisations to reassess their approach to communication management.

Organisations are now facing fundamental changes in their external environment, which is propelled by information and communication technology (ICT). Digitalisation, globalisation, and information deluge underscore the need for organisations to adapt their communication strategies (Seiffert-Brockmann et al., 2021; Globočnik Žunac et al., 2021).

In the economy of increasingly competitive marketing, a shift from traditional techniques toward more diversified approaches has become evident. The rapid evolution of industry products and services presents significant opportunities and challenges, demanding a strategic approach (Heath et al., 2018). Recognising the inadequacy of relying on the usual communication tools, organisations are embracing IC as an effective management approach to adapting to changes in the market environment (Luxton et al., 2015; Kitchen, 2017; Porcu et al., 2017).

While Integrated Marketing Communication (IMC) has gained broad acceptance since its emergence in the early 1990s, controversies persist, primarily centred on conceptual issues. Researchers continue to grapple with developing a cohesive theoretical base that aligns and applies all tools and techniques within the IMC practice. Disagreements persist regarding the theoretical robustness and practical application of IMC, contributing to a somewhat vague and uncertain theoretical position (Kliatchko, 2005; Tafesse & Kitchen, 2017).

Despite the conceptual intricacies surrounding IMC, its prominence in the marketing literature has grown significantly, fuelled by advancements in information and communication technology. Defining IMC proves challenging due to varied interpretations and values in academic and commercial spheres. A critical review of previous IMC definitions reveals five crucial attributes, emphasising the importance of directed communication, an outside-in approach, well-established relationships, holistic inclusion of communication activities, and coordination between communication disciplines (Kitchen et al., 2004).

The primary goal of this study is to conduct a comprehensive analysis of the landscape of Integrated Communications Management (ICM) using bibliometric methods. By leveraging bibliometric analysis, we aim to explore the evolution, trends, key contributors, and thematic structure of the scholarly literature on Integrated Communication (IC). The research questions stated below drive this study to investigate the productivity of research on IC, the recency and impact of published

literature, prominent countries, authors and journals, collaboration networks, thematic trends, and gaps in the existing literature.

- RQ1: *How is the evolution of scientific production on Integrated Communication (IC) in the Scopus database?*
- RQ2: *Which are the main thematic lines on the IC topic?*
- RQ3: *What are the main research gaps and future trends of IC scientific literature?*

This type of research question is often formulated in bibliometric studies on IC (Muñoz-Leiva et al., 2012; Nunhes et al., 2019; Marinescu & Cicea, 2018; Resqi, 2022; Wu et al., 2022), as their answers allow a better understanding of the topic. To address these questions, we employ a systematic bibliometric approach that integrates quantitative productivity and citation metrics with qualitative mapping and network analysis. This methodological framework enables us to provide a comprehensive overview of the field and identify areas for future research.

This paper identifies two gaps: the study of Integrated Communication Management (ICM) literature is mostly centred on IMC, not studying deeply other areas (e.g., strategic communication), and not considering Spanish literature sufficiently in their reviews (Salgado Moreno et al., 2024; Sadi & Álvarez-Nobell, 2024). The novelty of this bibliometric study lies in the evaluation of other areas of integrated communication, widening the scope of the literature analysis.

The structure of this paper is organised to facilitate a coherent presentation of our research findings and analysis. Following this introduction, the paper proceeds with a literature review section, which provides an overview of previous research on IC and clarifies key concepts, theoretical frameworks, empirical findings, and debates in the field. Subsequently, we delineate the applied research methodology employed in this study, detailing the systematic steps undertaken for bibliometric analysis. The methodology section is followed by a presentation of our results, which encompasses findings related to productivity per year, publication recency, authorship analysis, most cited authors and documents, thematic trends, and international collaboration networks.

We then discuss our findings, contextualising them within the broader scholarly discourse on IC and addressing their implications for theory, practice, and future research. Finally, we conclude the paper by summarising our key findings, highlighting this study's contributions, and outlining avenues for future research in the field of ICM. This structured approach enhances the clarity and coherence of our paper, guiding readers through the analytical journey and facilitating a deeper understanding of our research outcomes.

Literature review

With the purpose of building the foundations of a research paper and to contextualise the research questions, a literature review must be conducted in every research (Pejić-Bach & Cerpa, 2019); moreover, writing a thorough and lucid literature review is critical (Abdullah et al., 2023). Literature on IC offers a rich tapestry of definitions, theoretical frameworks, empirical studies, discussions on channel integration, critiques, as well as debates due to the evolution of Integrated Communication from a tactical communication tool to a strategic management tool and strategic business process (Schultz & Kitchen, 2004; Kliatchko, 2008; Kitchen, 2017). This literature review takes into consideration three phases: IMC, IC, and SC. Integrated Communication Management (ICM) refers to any of these specific managements (according to context/approach) and encompasses all of them as well.

Integrated marketing communication

While IC has gained broad acceptance since its emergence in the early 1990s -known as IMC for being centred in the marketing area, controversies persist, primarily on conceptual issues; Duncan and Caywood (1996) debate the challenges of evaluating IMC effectiveness, advocating for rigorous measurement frameworks. Critiques and debates regarding the conceptualisation, implementation, and evaluation of IMC add depth to the discourse. Schultz and Kitchen (2004) critique the oversimplification of IMC, advocating for a more strategic approach beyond message integration.

Organisational barriers, including a lack of horizontal communication, pose significant obstacles to its implementation. Scholars highlight issues such as resistance to change, turf battles, ego problems, and managerial parochialism as major barriers to integration (Šerić & Gil-Saura, 2012).

Kitchen and Burgmann (2010) identified challenges in organisational IMC implementation, such as siloed structures and resistance to change. Schultz (1993) advocates integrating advertising, public relations, sales promotion, and direct marketing into cohesive communication strategies. Later, Fill (2009) explores the integration of digital and traditional channels, emphasising synergy and consistency in IMC campaigns.

Disagreements persist regarding the theoretical robustness and practical application of IMC, contributing to a somewhat vague and uncertain theoretical position (Kliatchko, 2005, 2008; Šerić & Gil-Saura, 2012; Porcu et al., 2017). As markets, consumers, technologies, media, and data-handling capabilities undergo rapid transformations, marketing professionals are compelled to reassess their approaches continually. Technological turbulence drives the demand for integration, as evidenced by scholars (Porcu et al., 2017; Macnamara & Gregory, 2019), and IC brings tangible benefits, aligning short- and long-term marketing, ensuring consideration of all target audiences, encouraging individual communication, enhancing synergy and recall, and delivering financial benefits (Kitchen & Burgmann, 2010).

The literature abounds with theoretical frameworks and models pivotal for comprehending and implementing IMC and its strategies. Duncan and Moriarty (1998) propose a framework highlighting synergy, consistency, and integration across communication channels in IMC campaigns. Additionally, Kitchen & Schultz (2003) present the IMC Planning Model, delineating the strategic process for campaign development and execution.

Researchers continue to grapple with developing a cohesive theoretical base that aligns and applies all tools and techniques within the IMC practice. Its prominence in the marketing literature has grown significantly, fuelled by advancements in information and communication technology (Muñoz-Leiva et al., 2015; Wu et al., 2022). However, defining IMC proves challenging due to varied interpretations and values in academic and commercial spheres. A critical review of previous IMC definitions reveals five crucial attributes, emphasising the importance of directed communication, an outside-in approach, well-established relationships, holistic inclusion of communication activities, and coordination between communication disciplines (Kitchen et al., 2004).

Integrated communications: Toward a holistic approach

The evolution of Integrated Communication (IC) from a tactical tool to a strategic business process highlights the need for a holistic approach (Kliatchko, 2008; Thøger Christensen et al., 2008). A conceptual framework developed by Porcu et al. (2017) defines IC in four dimensions: message consistency, interactivity, stakeholder-centred strategic focus, and organisational alignment. This framework has proved to be useful

for applied research developed in the tourism and hospitality sector (Porcu et al., 2017).

Because of the rapid growth within the execution and adoption of IC tactics, earlier research suggested that further analyses are required. However, studies on IC continue to be somewhat neglected within hospitality; additionally, it also looks like buyer perceptions and viewpoints of marketing and sales communications tend to be disregarded (Šerić & Gil-Saura, 2012). In this respect, consumer perceptions of IMC ought to be considered very carefully since that is perhaps one of the most important impacts on investment effectiveness.

Nikadimovs (2019) conducted a review on IMC, revealing that not enough tourism and hospitality IMC implementation research has been carried out. Although research has increased lately, only a fraction of it was relevant to this industry, and even fewer addressed IMC implementation and evaluation issues. Following his study, some hospitality management efforts have not implemented IMC due to a lack of confidence and resources for IMC concept integration.

Distinguishing IMC from IC, Grigorescu and Lupu (2015) emphasised their differences, positioning IC as a broader discipline that encompasses marketing and extends to corporate design, culture, public relations, and corporate communication. Recognising the evolving landscape of IC, Taffese & Kitchen (2017) advocate for an integrative review, building on three alternative IC frameworks: conceptualisation at the marketing campaign level, organisation level, and the role of advertising agencies. However, no empirical studies supported by their integrative theoretical model are known so far.

Strategic communication

The growing digital content ecosystem has significantly increased the number of effective communication channels used by an organisation's customers, employees, partners, shareholders, and communities. An integrated communication strategy helps businesses deliver a cohesive message across digital and traditional channels to engage audiences, build and sustain trust and provide a positive brand experience.

Strategic communication (SC) is an important key theme of integrated communication and a distinctive approach focusing on the process of communication, offering complementary insights, and opening up new fields for interdisciplinary research. Hallahan et al. (2007) defined SC "in its broadest sense, (as) communicating purposefully to advance (the organisation's) mission". The type of organisation was not limited to businesses (for-profit) but included activist organisations, non-profits, social and civic movements, NGOs, political parties, as well as governmental entities.

Barker (2013) identified the most critical factors which provided the impetus to the core concepts of Integration, marketing and communication to ensure competence and accountability to all stakeholders and proposed the alignment of all communication based on a Strategic Integrated Communication (SIC), an alternative perspective seen as the process of strategically managing mutually beneficial organisational and stakeholders relationships where the planning recognises the added value of a strategic integrated communication approach through the integration of all functions, which is information-driven, interactive, and focused on consistency in brand, messages, knowledge creation and sharing, processes, functions and the strategic intent of the organisation.

According to Carrillo (2014), SC is closer to the organisation's management policies than to communication itself. Its foundations lie at the heart of the organisation, which would be Image and Communication Management, so in her opinion, a proper definition of SC should highlight certain aspects that have as yet not been adequately

considered: SC has to be managed communication (not all communication is SC, but all SC is managed communication); SC and communication strategies are two different things ("Strategic communication" has to put all the forms of communication available to the organisation at the service of its goals, with the result being far more than the sum of the partial communication strategies); and organisations must have an interactive relationship with all stakeholders, not just with partial target audiences or publics (its stakeholders maintain a relationship with the organisation which means they may come into contact with it through various channels and media by will and or interests).

For Grigorescu & Lupu (2015), SC is needed to adopt a new strategy subordinated to the global organisational strategy, as the informational explosion leads to the impossibility of complete processing of this information and a large part of the information is shielded and eliminated. Therefore, the answer is to send a unitary message on every channel of communication; with this, unidirectional and inefficient mass communication has been replaced by integrated communication.

Nothhaft et al. (2018) shared that SC had "emerged as a global field of communication research". They suggested that this global field was going strong by lauding the efforts of scholars from a multitude of disciplines, such as "public relations, corporate communication, organisational and internal communication, public diplomacy, political communication, advertising, marketing, health and intercultural communication".

Plowman and Wilson (2018) see that practitioners are involved in social media strategy development and tactical implementation yet see their involvement as linked mostly to their organisations' strategic rather than tactical social media activities. In addition, practitioners delineate social media strategies and tactics differently than theoretical conceptualisations. They saw practitioners view the distinction between social media strategies and tactics differently than how they are defined in the academic literature and that aspects of strategic planning that are more operational, according to theory, including focusing content on specific themes, engaging influencers, and selecting specific social media channels, were seen as strategic by practitioners. Moreover, practitioners see tactical approaches to social media engagement that are related to strategy, based on theory, such as long-term relationships and building community, as tactical.

Shumate et al. (2018) introduce a multidimensional network perspective as a theoretical and methodological touchstone for the study of SC, embracing various disciplinary traditions that are found under the SC umbrella (e.g., advertising, corporate communication, organisational communication, and public relations) and gives primacy to communication as the constitutive element through which organisations make strategic decisions about network positioning and representation to stakeholders. In this sense, SC research embraces the interconnectedness of organisations, messages, and stakeholders; this interconnectedness brings into sharp focus the constitutive role of communication in the creation, maintenance, and dissolution of complex relationships between interrelated stakeholders and organisations (similar approach to Hallahan et al., 2007; and Frandsen & Johansen, 2015).

The understanding of the concept of alignment, which has been acknowledged as a central aspect of SC but never explicitly defined, has been pointed out by Zeffass and Volk (2018). Building upon a comprehensive literature review and systematisation of concepts at the nexus of SC and management research, a working definition and an integrative conceptual framework of alignment of IC were suggested. The new framework combines the multiple perspectives and types of alignment discussed so

far, differentiating between external and internal alignment, intrafunctional and cross-functional alignment, management–strategy–activities alignment and process-structure-culture-people alignment. As there are gaps on this topic yet, Zeffass and Volk (2018) open six avenues for future conceptual, empirical, and critical research to inspire SC scholars to carry out further research on this topic.

Lock et al. (2020) see SC as an umbrella term to comprehensively address and include the different elements offered in the public relations, corporate communication, organisational communication, and communication management fields. SC is a close neighbour to many others for the –older and more established– disciplines within the social sciences, such as business management, psychology, or sociology, and a transfer of theories from these disciplines has taken place: stakeholder theory, trust models, systems theory have entered SC research providing fruitful avenues to study organisation-society relations.

According to Heath et al. (2018), scholars and practitioners approach SC from a variety of paradigmatic perspectives. At least four distinct conceptualisations can be identified: (1) SC as public relations/corporate communication, (2) SC as a comparative framework for examining processes employed across various functions, (3) SC as a structure to integrate purposeful communication functions within organisations, and (4) SC as a meta-process that amalgamates functional roles and stresses organisation-wide strategy, discursive processes, and critical analysis.

All these theoretical and empirical studies are significant for IC literature. However, this research has some limitations. First, most of these papers partially qualitatively review the integrated communication literature. Thus, they do not provide a quantitative overview of how IC literature has evolved. Second, these review papers did not provide a comprehensive outlook on the conceptual structure of IC literature separately. Considering these limitations and the substantial growth of IC literature (Taffese & Kitchen, 2017; Heath et al., 2018), it becomes necessary to quantitatively examine the different attributes of IC literature by means of a bibliometric analysis.

Bibliometric studies on integrated communication

A notable amount of information on integrated communication has been produced due to information and communications technologies (ICT) development, among them bibliometric studies. This type of research is of high importance for new investigation development, as new knowledge must be built over previous research. Among several investigations, Young et al. (2015) developed a bibliometric analysis of published articles between 1993 and 2014, where four common underlying conceptual topics were identified, and the research topics; Tackie & Anning-Dorson (2021) conducted a scientometric approach to assess IMC research's authors, literature, and countries in 1995-2020 period; and Resqi (2022) performed "Marketing Communications: A Bibliometric Study In The Use Of Technology And Social Media For Marketing", to evaluate the most relevant themes related to marketing communications from 2015 to 2022, visualising the network of authors, as well as countries and journals. Keyword analysis showed that marketing communication studies referred to marketing done through social media in 2021 and 2022, as well as the benefits of social media and technological advancements. We outline three types of research taken as antecedents on the IC topic. Their results show a wider, deeper bibliometric analysis and a stronger impact on the scientific literature in recent years (see Table 1).

Table 1

Bibliometrics of three referenced studies

Authors / Items		Wu et al. (2022)	Resqi (2022)	Muñoz-Leiva et al. (2012)
Database		WoS and Scopus	Scopus	Scopus
Study timeframe		2000-2020	1991-2020	2015-2012
Keywords		Integrated Marketing Communications; Scientometric; CiteSpace; Web of Science; Scopus	Integrated Marketing Communication s; Brand equity; IMC implementation	Integrated Marketing Communications; IMC; Bibliometric Study; Co-Word Analysis; Conceptual Evolution
Productivity	Per Years	✓	✓	✓
	Per Authors	✓	✓	✓
	Per Journals	✓	✓	✓
	Per Countries	✓	∅	✓
Citation and Co-Citation	H-Index	✓	✓	✓
	Authors Co-citation	✓	✓	✓
	Authors Citation	✓	✓	✓
	Journals Citation	✓	✓	∅
	Documents Citation	✓	✓	✓
	Documents Co-Citation	✓	✓	✓
	Countries Citation	✓	✓	✓
	Authors collaboration	✓	✓	✓
Price Index		∅	∅	∅
Authors affiliation (Organisation)		✓	✓	∅
Authors Affiliation (Country)		✓	✓	✓
Thematic Area		✓	✓	✓
Keywords		✓	✓	✓
Content Analysis (Trends)		✓	✓	✓
Gaps and Future Research Lines		✓	✓	✓

Source: Authors' elaboration

"Discovering Prominent Themes of Integrated Marketing Communication Research from 1991 to 2012: A co-word analysis approach" by Muñoz-Leiva et al. (2015) performed a bibliometric analysis of IMC (1991-2012) emphasising a co-word analytic approach. Their analysis of IMC aimed at its evolution from its inception in 1991 up to 2012 (included). The authors applied a bibliometric approach combining co-word analysis and science mapping to detect and visualise conceptual sub-domains and identify the most relevant themes. The thematic networks extracted showed associations between the main issues the IMC community was addressing, enabling

the authors to examine its intellectual structure over two decades. The quantitative analysis of a corpus of IMC manuscripts provided a structure for the conceptual sub-domains, classification of the themes showing internal associations into four groups, and identification of the main research trends forecasting its future direction. In response to the call for greater theoretical clarification of the IMC discipline, this paper provides a snapshot of the thematic evolution of IMC research over time, providing experts with a better understanding of the state of the art and suggesting future research directions.

"Marketing Communications: A Bibliometric Study in the Use of Technology and Social Media for Marketing", by Resqi (2022), is the second one. This research paper used multiple bibliometric parameters instead of a single co-word analytic approach while reviewing the whole period of IMC literature in the 1991-2020 period. H-index and citations per ratio are used to demonstrate productivity and impact; descriptive analysis and network analysis (e.g., keywords co-occurrence networks and co-citations analysis) have also been performed to identify intellectual and conceptual structure. Sources and authors were identified in the most productive countries as well. VOSviewer software for bibliometric mapping was applied using two standardised factors: the number of links and the strength of links to demonstrate the visual nodal network, allowing researchers to explore the conceptual and intellectual structures of the research field.

The third one, "Mapping the literature of integrated marketing communications: A scientometric analysis using CiteSpace", by Wu et al. (2022), identified hot research topics and the evolutionary process of IMC in the 2000-2020 period. Theory and models, brand communication, media research, customer research, and marketing strategy were the five hot research topics. In contrast, social media and brand-building research will continue to be hotspots for future trends research, and "experiential marketing" will see a growth process. Considering the regular pattern of IMC concept change and comparing the evolution of IMC concepts and research topics in different periods, the authors concluded that the content and form of "integration" are constantly changing, which should be one of the reasons why scholars have not reached a consensus on the concept of IMC.

The literature review on ICM provides a comprehensive overview of the existing knowledge landscape in this field. It encompasses definitions, theoretical frameworks, empirical studies, discussions on channel integration, and critiques and debates. These elements serve as a foundational understanding for our research endeavour. Firstly, the review clarifies the conceptual terrain by presenting various definitions and conceptualisations of IC, highlighting its strategic nature and emphasis on coordinated communication efforts with diverse stakeholders (Schultz et al., 1998; Kliatchko, 2008; Porcu et al., 2017). This sets the stage for our study to delve deeper into understanding how organisations strategically manage their communications.

Secondly, theoretical frameworks and models elucidated in the literature, such as those proposed by Duncan and Moriarty (1998) and Kitchen and Schultz (2003), offer valuable insights into the principles underlying effective IMC strategies. Our research aims to build upon and possibly extend these and other frameworks (Porcu et al., 2017; Taffese & Kitchen, 2017) by examining their applicability in contemporary organisational contexts. Thirdly, empirical studies cited in the literature review provide empirical evidence on the effectiveness and challenges of implementing IC strategies.

By synthesising these findings, our study seeks to contribute to the empirical knowledge base by exploring specific contexts or dimensions of IC effectiveness that may not have been extensively addressed in prior research. Our research aims to

address some of these gaps, particularly in evaluating the effectiveness of IC and integrating emerging communication technologies into IC strategies.

Methodology

A systematic methodology, underpinned by logical steps, guides the bibliometric analysis to unravel the landscape of ICM. The process initiates with the meticulous selection of terms to construct a comprehensive search equation aimed at identifying relevant publications on Integrated Communication.

The initial step is to select the terms of the search equation for publications on IC. The equation is defined as follows: TS= ("integrated marketing communications"); OR TS= ("integrated marketing communication"); OR TS= ("integrated communications"); OR TS= ("integrated communication"); OR TS= ("Integrated Communications Management"); OR TS= ("Integrated Communications"); OR TS= ("Strategic Communications"); OR TS = ("Gestión de Comunicación Estratégica"); OR TS= "Comunicación Integrada Corporativa (CIC)"; OR TS= ("Gestión de comunicación organizacional integrada"); OR TS = ("Gestión de comunicación integrada"), ensuring a thorough exploration of the topic across titles, abstracts, and keywords.

The bibliometric analysis, combining quantitative productivity and citation metrics with qualitative state-of-the-art mapping and social network exploration, aims to discern patterns and contributions within the scientific literature on IC in organisations. Figure 1 depicts the methodological framework, showcasing the systematic approach underpinning this research.

The search was conducted on Scopus (Elsevier), a database renowned for its substantial impact on the social sciences and encompassing 38,589 scientific journals in diverse research areas, from which a total of 971 documents from 456 sources were extracted. Extracting and processing data from more than a database makes info integration complex, as their platforms have different structures (Nunes et al., 2019). The definition of the search criteria is shown in Table 2.

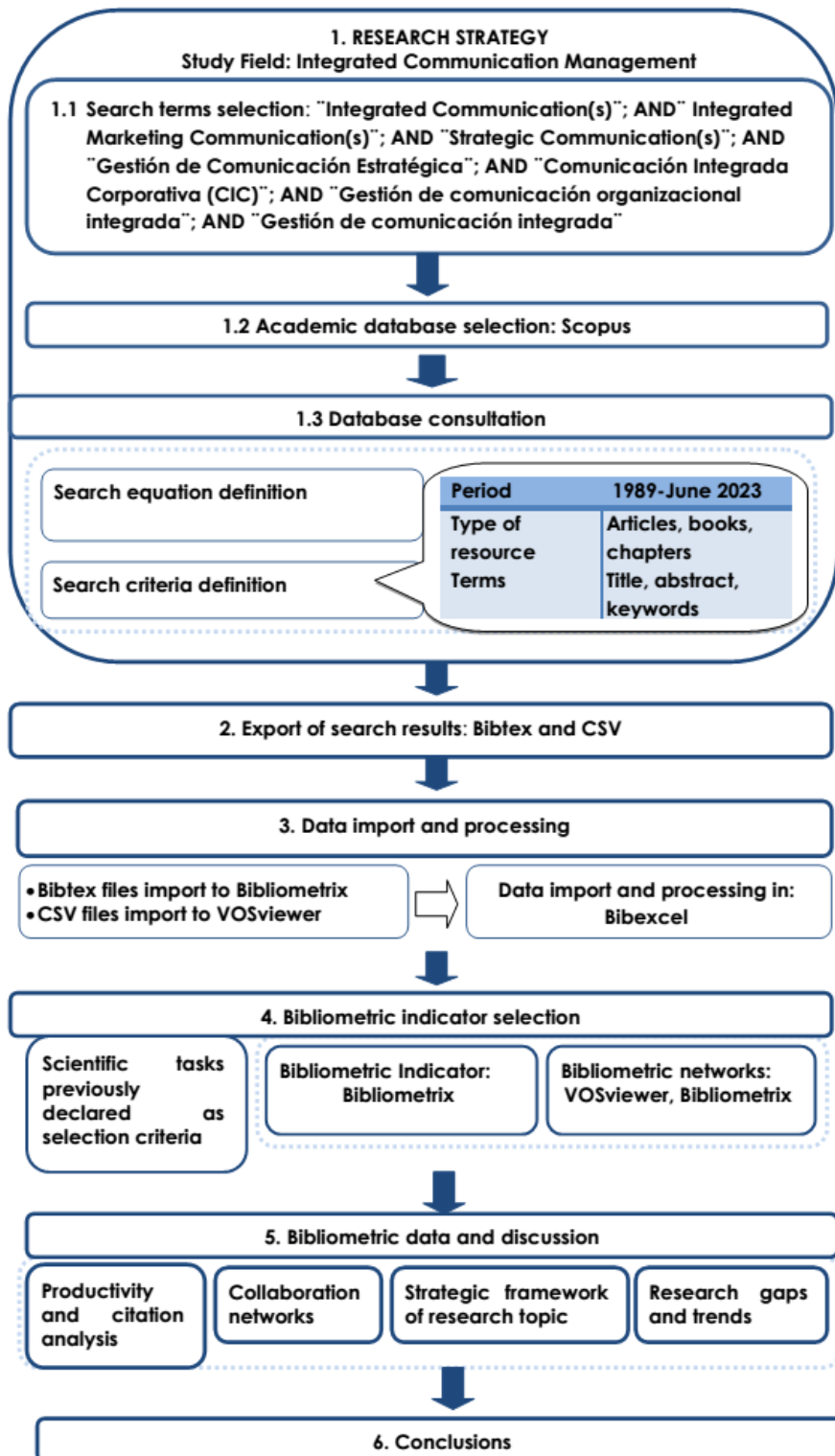
Table 2
Search Criteria

Search criteria	Search strategy
Database	Elsevier Scopus
Keywords	Integrated Communication(s); Integrated Marketing Communication(s); Strategic Communication(s); Gestión de Comunicación Estratégica; Comunicación Integrada Corporativa (CIC); Gestión de comunicación organizacional integrada; Gestión de comunicación integrada (in title, abstract and keywords)
Period	From 1989 to June 2023
Type of documents	Articles
Type of source	All articles in scientific journals, books, book chapters, encyclopaedia Social Sciences, Economics, Business, Management, Marketing,
Thematic areas	Communication
Languages	English, Spanish

Source: Authors' elaboration

Articles that meet the search criteria and data are exported in Bibtex and CSV files for further normalisation through the R's bibliometrix package (Aria & Cuccurullo, 2017), addressing any positives and duplicates.

Figure 1
Methodology for the Bibliometric Study



Source: Adapted from Ávilas Hernández et al. (2023)

Results

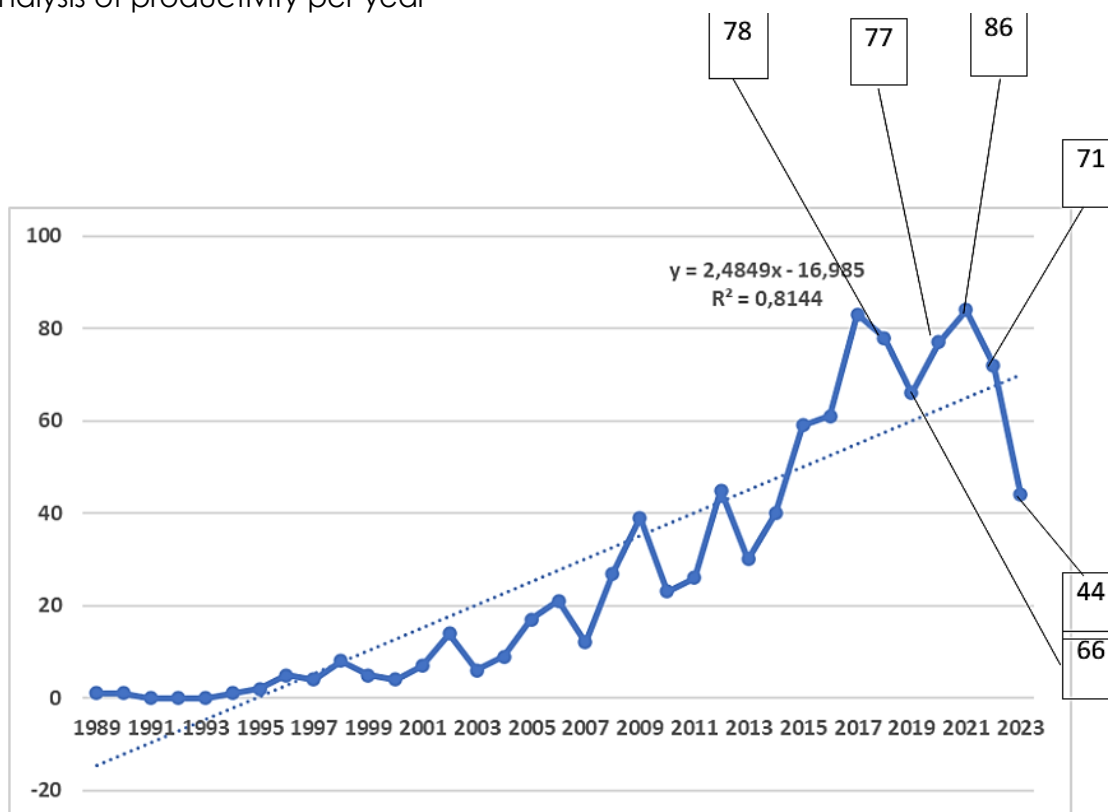
Timeline and country analysis

The productivity per year indicator is an important indicator for visualising the tendency of literature production in specific timeframes. A graph showing the number of documents per year is required as a starting point for productivity analyses. The number of published papers per year is shown on the y-axis, while the years from 1989 to 2023 are shown on the x-axis. Figure 2 illustrates a consistent productivity increase from the inception of publications on IC, with a remarkable number of published papers from 2018 to 2022.

Notably, a surge in studies is observed from 2009 onward due to the renewed interest of scholars, following an initial period of both enthusiasm and criticism. The high number of papers appearing this year, including seven papers published in the second special issue on IMC in the Journal of Marketing Communications (vol. 15, issue 2-3) and a number of conferences focused on the topic (for example, three papers presented at the 16th International Economic Conference – IECS 2009, held in Sibiu, Romania), was followed by a not so productive 2010 year (the European Journal of Marketing, the Journal of Promotion Management, and Marketing Intelligence and Planning, did show interest in IMC research, publishing only over 20 papers). Then, there was again an increasing trend of papers in scientific journals.

Figure 2

Analysis of productivity per year

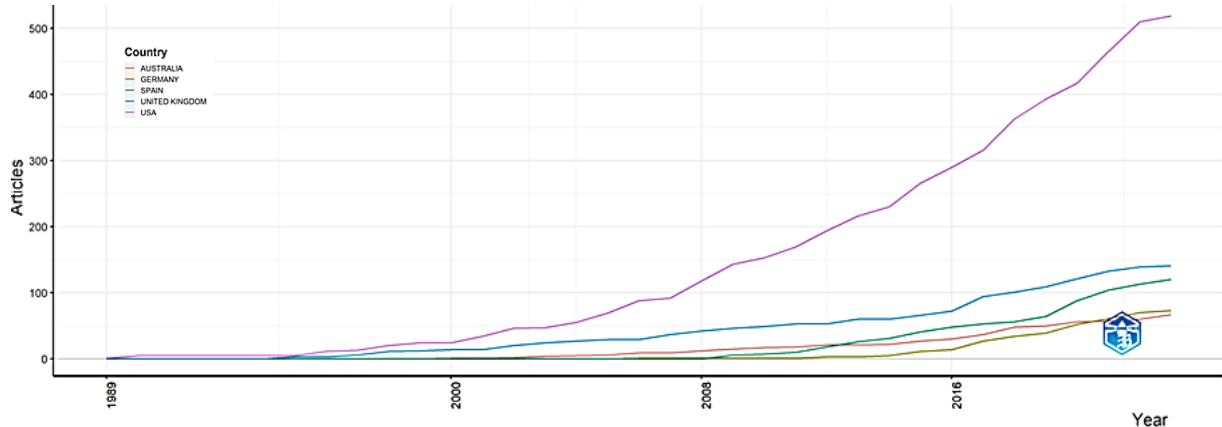


Source: Authors, based on Scopus

Figure 3 depicts the international research landscape, indicating a notable uptick in global research contributions from 2008 onward. Starting in 2012, there has been a sustained, remarkable growth of research/papers in the USA, followed far by the United Kingdom (U.K.) and Spain, showing high interest in the topic by scholars at the

international level. Germany and Australia had a minor productivity, although it was still ascendant.

Figure 3
Countries' Production Over Time



Source: Authors, based on Scopus

The Price Index is the ratio of the topicality of the available bibliography on the issue under investigation, highlighting the late papers' relevance. It is calculated from documents produced in the last five (5) years out of the total number of publications. Out of the 971 documents, 504 papers (nearly 52 % of research) were published/indexed between 2018 and 2023, for a Price Index of 0.5190.

Author, affiliation, and journal analysis

The productivity index identifies the most prolific authors in a specific topic of research to understand their contributions. According to Lotka's law, at least 60% of authors of papers in a research field make a single contribution in an analysed period. As the number of contributions (papers) of an author increases, the single-document contributors decrease. Productivity Index (I_p) determines authors' productivity, calculated by the formula $I_p = \log_{10}n$, where n is the number of publications per author. If $n \geq 10$, then $I_p \geq 1$; in case of $1 < n < 10$, then $0 < I_p < 1$; while if $n=1$, then $I_p = 0$. The productivity index analysis reveals a nuanced distribution, with only 7 authors displaying high productivity (over 0.8 index). See Table 3.

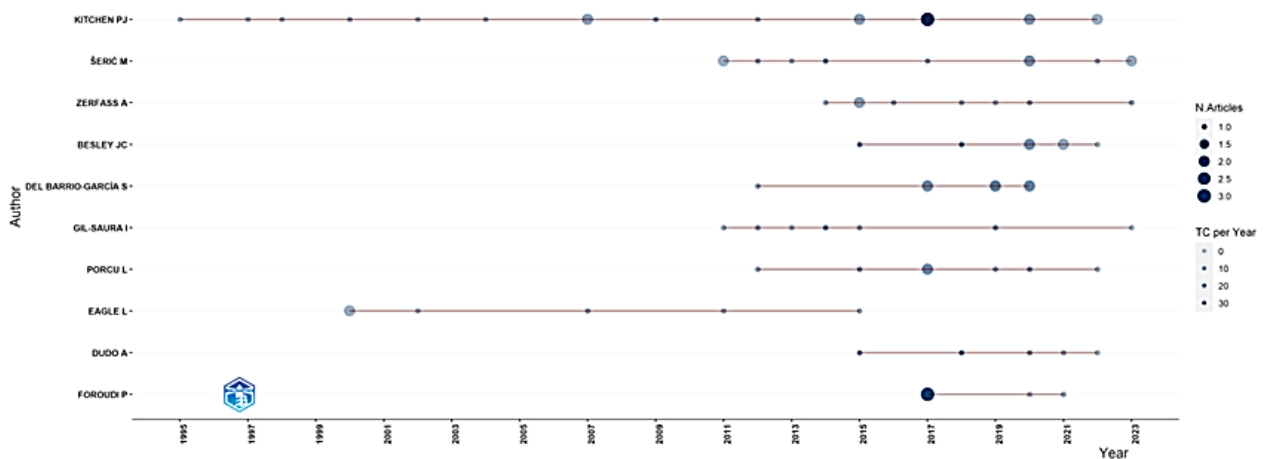
Table 3
Analysis of productivity and systematicity of authors

Authors	Number of contributions	Number of authors	Productivity Index
Kitchen, P. J.	19	1	1.28
Šerić, M.	11	1	1.04
Zerfass, A.	8	1	0.90
Del Barrio-García, S.; Gil-Saura, I.; Porcu, L.; Besley, J. C.	7	4	0.85
Eagle, L.	6	1	0.78
Kim, Y.; Dudo, A.; Foroudi, P.; Laurie, S.; Mortimer, K.; Siano, A; Smith, B. G.; Tench, R; Moreno, A.	5	9	0.70

Source: Authors, based on Scopus

Philip J. Kitchen and Maja Šerić are prolific authors, equalling or exceeding ten publications. Also, details about the author's role in the research on IC from 1989 to 2023 must be known (most consistent investigator and last year's contributors). The authors' production over time illustrates the systematic contributions of P.J. Kitchen, a key academician since 1995 (see Figure 4). The following scholars have a remarkable production: M. Šerić, A. Zerfass, J. C. Besley, S. del Barrio-García, I. Gil-Saura, and L. Porcu, in the last five years.

Figure 4
Authors' production over time



Source: Authors, based on Scopus

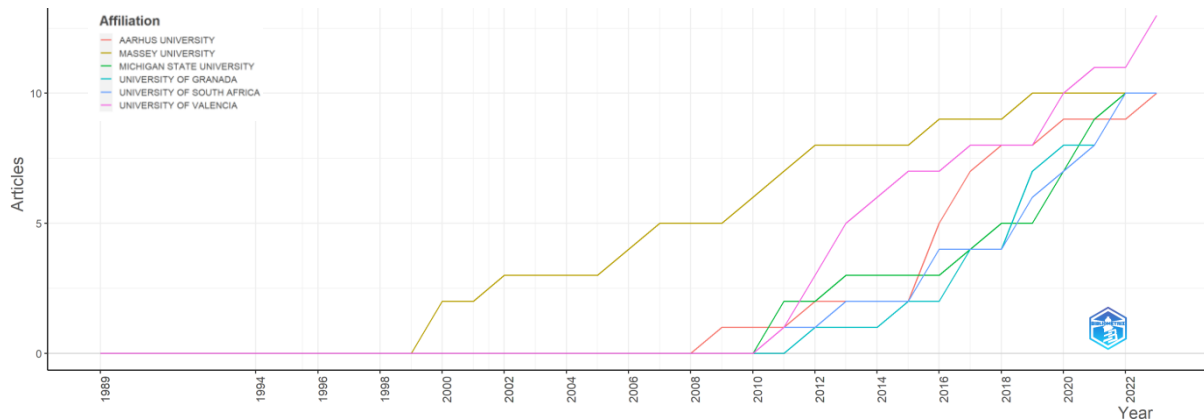
The ten most productive and influential research institutions on this topic are listed below (in Table 4); around 40 % of them are from Spain and the USA. Valencia, Massey, Aarhus, Granada, South Africa, and Michigan are the six universities that conducted the most research on integrated communication from 2011 until 2023. The first three are leading the way (see Figure 5).

Table 4
Affiliation' Production Over Time

Affiliation	Articles
University of Valencia (Spain)	13
Aarhus University (Denmark)	10
Massey University (New Zealand)	10
Michigan State University (USA)	10
University of Granada (Spain)	10
University of South Africa	10
Northwestern University (USA)	9
Leipzig University (Germany)	8
Lund University (Sweden)	8
Queensland University of Technology (Australia)	8

Source: Authors, based on Scopus

Figure 5
Affiliations' production over time



Source: Authors, based on Scopus

Table 5 lists the most productive journals, with the Journal of Communication Management, Journal of Marketing Communications, Public Relations Review, and Corporate Communications leading the way. The Journal of Communication Management, Corporate Communications, Journal of Marketing Communications, Sustainability, and Communitas published more papers on integrated communication from 2018 to mid-2023, showing higher interest in this topic.

Table 5
Most Productive Journals

Journal	1989-2023 Articles	2018-2023 Articles
Journal of Communication Management	62	38
Journal of Marketing Communications	52	12
Public Relations Review	40	6
Corporate Communications	29	14
European Journal of Marketing	24	2
Emerald Emerging Markets Case Studies	15	4
Journal of Promotion Management	12	1
Communicatio	10	2
Sustainability	10	10
Business Horizons	9	1
Communitas	9	9

Source: Authors, based on Scopus

Citation analysis

The h-index is a quality indicator of individual researchers' impact within the scientific community. It relates the number of sources to the author's productivity. Table 6 shows a relationship between the h-index and the number of citations, where local authors with 130 or more citations are selected. Philip J. Kitchen is leading the list with nearly 600 citations and high impact (14 h-index), followed by Maja Šerić, Salvador del Barrio-García, and Ansgar Zeffass.

Table 6

Most cited authors and h-index

h-index	Authors	All citations
14	Kitchen, P. J.	599
7	Šeric, M.	221
7	Del Barrio-García, S.	187
7	Zerfass, A.	134
6	Gil-Saura, I.	218
6	Porcu, L.	195
5	Besley, J. C.	199
5	Kim, Y.	190
5	Eagle, L.	133
4	Christensen, L. T.	216

Source: Authors, based on Scopus

Table 7 shows the ten most cited articles, with more than 150 citations. Surprisingly, the most cited document was not published in any of 8 most relevant journals.

Table 7

Most Cited Documents

Author	Article title, journal, online access	Citations
Mangold W. G. & D. J. Faulds (2009)	Social media: The new hybrid element of the promotion mix. <i>Business Horizons</i> , 10.1016/j.bushor.2009.03.002	2041
Keller, K. L. (2015)	Building Strong Brands In A Modern Marketing Communications. <i>Journal of Marketing Communication</i> , 10.1080/13527260902757530	524
Maznevski, M. L. (1994)	Understanding Our Differences: Performance in Decision-Making Groups with Diverse Members. <i>Human Relations</i> , 10.1177/001872679404700504	299
Welch, M. (2007)	Rethinking internal communication: a stakeholder approach. <i>Corporate Communications</i> , 10.1108/13563280710744847	
Batra, R. (2016)	Integrated Marketing Communications: New Findings, New Lessons and New Ideas. <i>Journal of Marketing</i> , 10.1509/jm.15.0419	253
Baxendale, S. (2015)	The Impact of Different Touchpoints on Brand Consideration. <i>Journal of Retailing</i> , 10.1016/j.jretai.2014.12.008	197
Kreiss, D. (2016)	The Limits of Peer Production: Some Reminders from Max Weber for the Network Society. <i>New Media & Society</i> , 10.1177/1461444814562445	182
Coombs, W. T. (2015)	The value of communication during a crisis: Insights from strategic communication research. <i>Business Horizons</i> , 10.1016/j.bushor.2014.10.003	168
Manser Payne, L. (2017)	Omni-channel marketing, integrated marketing communications and consumer engagement: A research agenda. <i>Interacting Marketing</i> , 10.1108/JRIM-08-2016-0091	163
Van den Bosch, A.L. (2005)	How Corporate visual identity supports reputation. <i>Corporate Communications</i> , 10.1108/13563280510596925	152

Source: Authors, based on Scopus

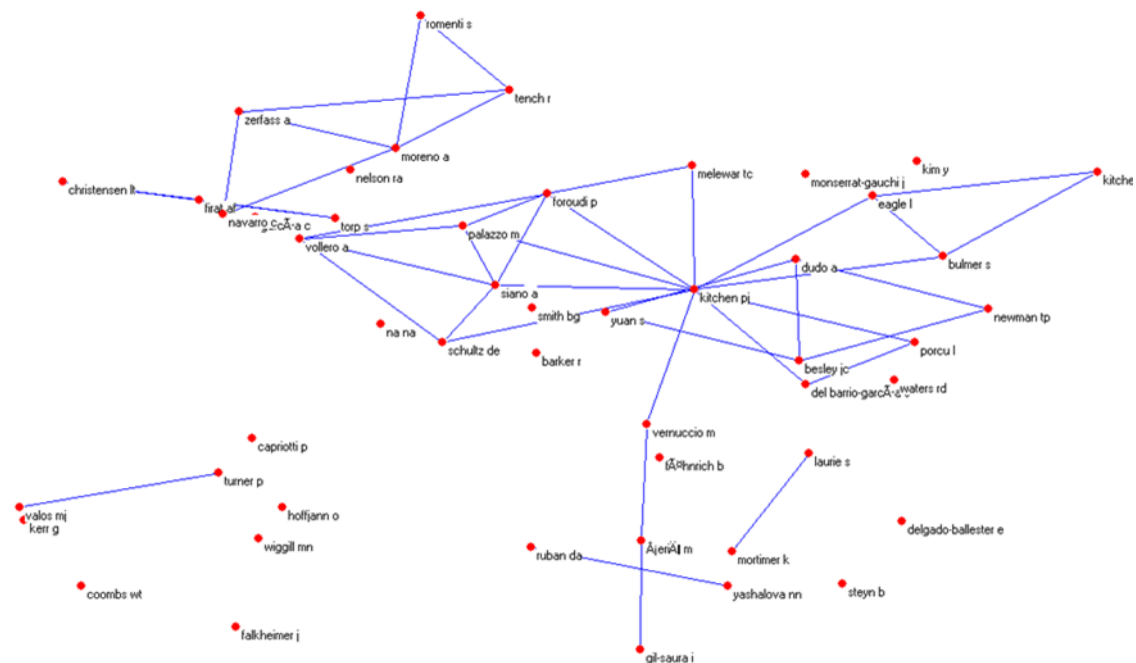
The number of citations of an article has traditionally been seen as a sign of its quality and impact on the scientific community. The most cited article about IC on the Scopus database is *Social media: The new hybrid element of the promotion mix*, by W. G. Mangold & D. J. Faulds (2009), arguing that social media is a hybrid element of promotion

mix because traditional sense, it enables customers to talk to their customers, while social media conversations are outside the direct control of managers. Methods such as providing consumers with networking platforms and using blogs, social media tools, and promotional tools to engage customers are suggested to enhance consistency with the organisation's mission and performance goals.

International collaboration

International research collaboration is crucial to scientific progress. Around 69 % of the total publications (671 papers, Scopus database) were signed by more than one author. Figure 6 delves into collaboration networks, revealing prominent collaborations led by authors like P. J. Kitchen, A. Siano, and A. Moreno, fostering a robust research community.

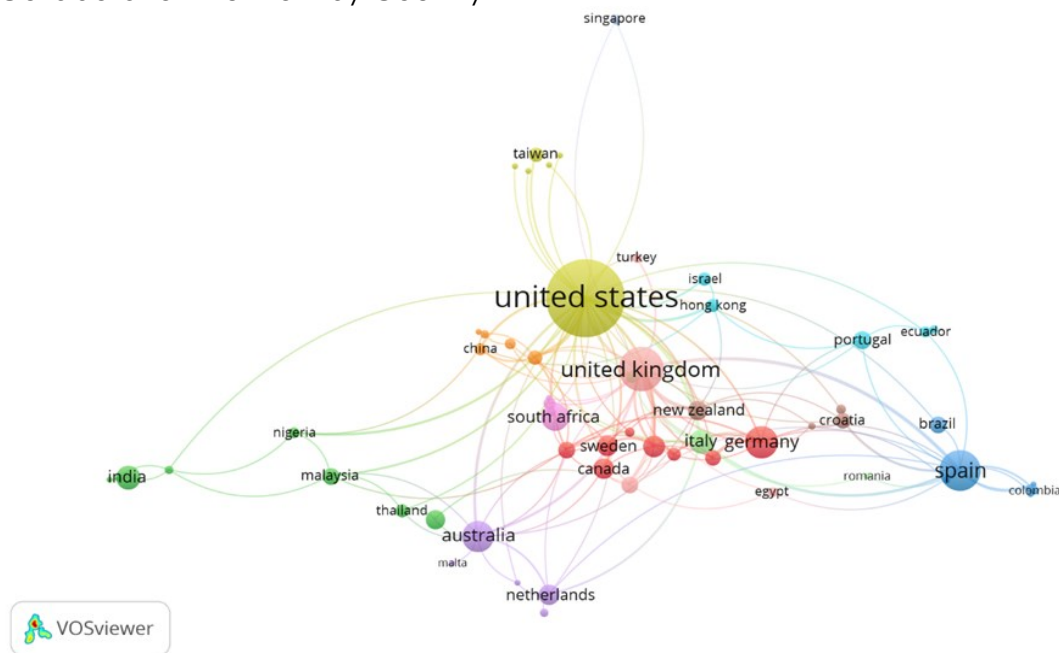
Figure 6
Collaboration Network Among Authors



Source: Authors, based on Scopus

The international collaboration network structure depicts the leading country of a network, the number of countries strongly linked to the leading country in a node, and the number and strength of links. The VOSviewer software for bibliometric mapping is applied to graphically illustrate this process by using two standardised weights: the number of links and the strength of links to demonstrate the visual nodal network (Figure 7). There are some significant collaboration networks. USA, U.K. and Spain play team leader roles, each of them with several countries: the USA, with New Zealand, South Africa, India, Sweden, China, and Taiwan; U.K., with Sweden, Canada, Germany and Italy; Spain, with U.K., Croatia, Italy, Netherlands, Portugal, Ecuador, Colombia, and Brazil. Less strong collaboration networks involve Australia, Malaysia, and Thailand.

Figure 7
Collaboration Network by Country



Source: Authors, based on Scopus; processed in VOSviewer

Significantly, the USA, the U.K. and Spain are also on the list of the most productive and influential countries.

Keywords, topics, and themes

Table 8 presents the most used keywords on IC topics. A total amount of 971 documents from 456 sources (most Scopus-registered articles in journals, some books and chapters) have been analysed, spanning from 1989 to June 2023. From this total, 49 were the most used keywords; 20, the most frequent topics in IC literature, where SC, IMCs, social media, and public relations are the four highly frequent (used ≥ 100 times) keywords over time.

Table 8
Most frequently used keywords on IC topics

Keywords	Frequencies	Keywords	Frequencies
Strategic communication	213	Crisis communication	34
Integrated marketing communications	129	IMC	34
Social media	104	Strategic communications	32
Public relations	102	Social corporate responsibility	30
Advertising	78	Corporate communication	29
Integrated marketing communication	78	Corporate communications	29
Communication	71	Branding	25
Marketing	45	Integrated communication	24
Communication management	39	Public diplomacy	23
Marketing communications	38	Brand equity	21

Source: Authors, based on Scopus

It is noteworthy that seven keywords (including public relations and advertising) -- out of the 20 most popular keywords directly refer to IMC. However, they were used in the literature with slight variations; this has implications for marketers; for example, "communication" emphasises "the act of communicating", and "communications" emphasises "the technology used for transmitting the message"; "Integrated marketing communications" is customer-centred concept (Schultz, 1993; Duncan & Caywood, 1996; Duncan & Moriarty, 1998; Fill, 2009), whereas "integrated communications" focus on all stakeholders of a company (Kliatchko, 2008; Porcu et al., 2017).

Eleven of the 20 more frequently used keywords refer to SC, which is suggested as a global research field still needing further theoretical development with the support of specific, interdisciplinary research methods. The evolving interest in key themes over the years shows that SC has emerged as the most prominent topic (see Figure 8).

After Covid-19 affected countries and international economics, SC has still been a high-frequency topic in recent years (Van Ruler, 2021; Seiffert-Brockmann, 2021), sharing an interest with stakeholder engagement, marketing mix, sustainability, and trust communication strategies as a trend, by scholars.

Figure 8
Keywords word cloud

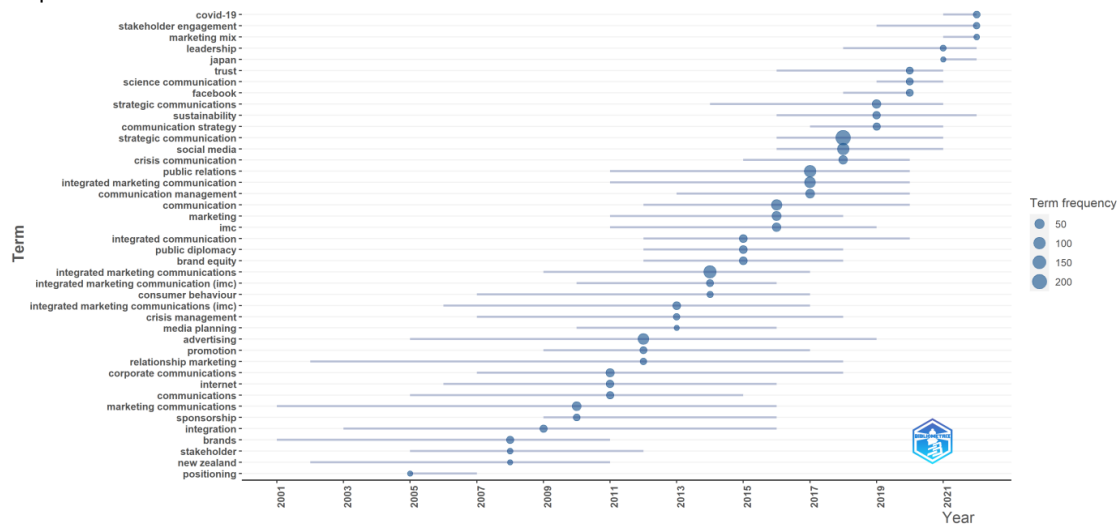


Source: Authors, based on Scopus

After processing data, topics of investigation on integrated communication (IC) over time are identified. While brands, marketing communication, corporate communication, internet, promotion, relationship marketing, and sponsorship were prevailing frequency terms in communication research between 2008 and 2012 years, there was a shift in interests in the next stage (see Figure 9). SC, social media, public relations, IMC and advertising surged as topics with higher frequency (strongest interest) in research papers from 2012 to 2019, followed by other topics, namely crisis communication, marketing, and communication management. In the case of crisis communication, the use of digital platforms is recommended, considering its simultaneous reaction and direct communication possibilities with the affected public, without the mediation of information media (Zora Rezo et al., 2021). The shift in topics research proves the evolution of communication studies from non-integrated to effective IC approach in response to an intense, more competitive global market.

After Covid-19 affected countries and international economics, SC has still been a high-frequency topic in recent years (Van Ruler, 2021; Seiffert-Brockmann, 2021), sharing an interest with stakeholder engagement, marketing mix, sustainability, and trust communication strategies as a trend, by scholars.

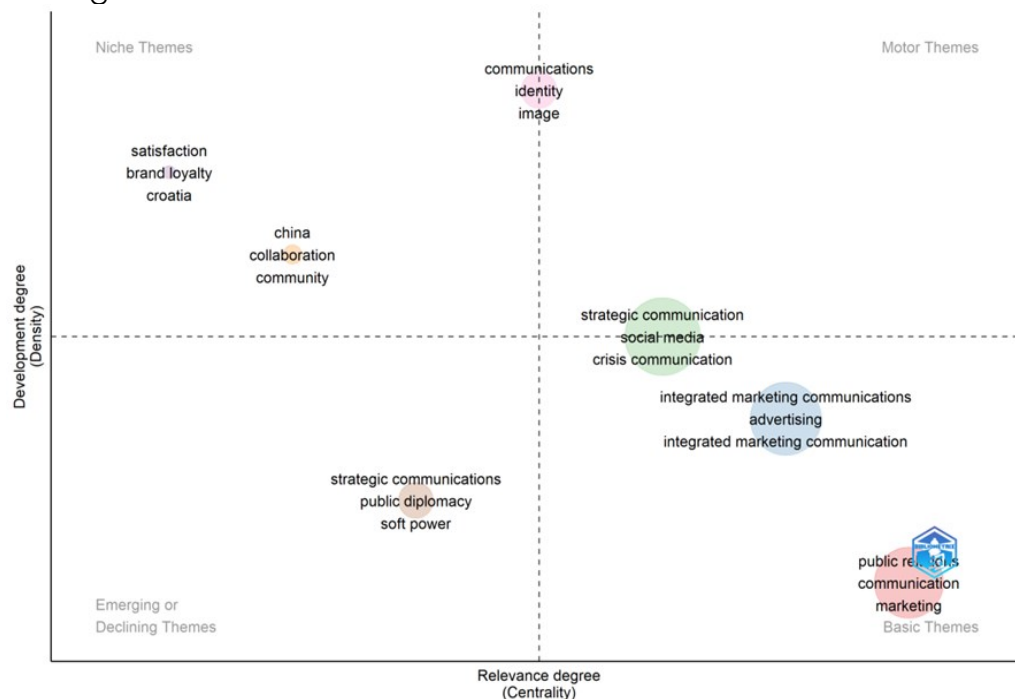
Figure 9
Topics over time



Source: Authors, based on Scopus

By delineating thematic groups and categorising them into specialised topics, motor themes, basic issues, and emerging or disappearing themes, a comprehensive thematic structure of IC is presented. The strategic framework (chart) distributes the different thematic groups into four quadrants, delimited by centrality (X) and density (Y) axes. Each labelled globe constitutes the central node of a particular network to which other thematic groups are related based on conglomeration algorithms (see Figure 10). The distribution is defined as follows: (i) 1st quartile ($>X/2$; $<Y/2$) - Specialised topics; (ii) 2nd quartile ($<X/2$; $<Y/2$) - Motor themes; (iii) 3rd quartile ($<X/2$; $>Y/2$) - Basic issues, and (iv) 4th quartile ($>X/2$; $>Y/2$) - Emerging or disappearing themes

Figure 10
Strategic Chart



Source: Authors, based on Scopus

Thematic groups in the 1st quartile (brand loyalty, satisfaction, Croatia, China, collaboration, and community) are peripheral issues (niches), as they are not of high importance for the research field. Croatia and China can be seen there as topics of specific development in ICM research, although they are not significant.

Motor themes on ICM are visualised in the 2nd quartile, which includes SC, social media, and crisis communication, representing areas of high interest for ICM studies. Identity, image, and communications are topics with the highest development degree, in need of more relevance for the scientific community; this can be achieved by proposals of theoretical and methodological designs relating these topics to SC, social media and crisis (Heide et al., 2018; O'Connor & Shumate, 2018; Lock et al., 2020; Seiffert-Brockmann et al., 2021).

The 3rd quartile includes IMC(s) and advertising, with a higher development degree than others (public relations, communication, and marketing); all these basic themes represent interesting research opportunities (Sadi & Álvarez-Nobell, 2024). Finally, SC, public diplomacy, and soft power are emerging or disappearing topics in the 4th quartile. If academicians and practitioners are interested in them, they can be considered a potential study gap.

Discussion

The bibliometric study has shed light on the multifaceted nature and evolving landscape of ICM in organisations. This analysis not only enhances the understanding of ICM but also highlights key dimensions, shaping its conceptualisation and application in practice. For instance, Porcu et al.'s (2017) conceptual framework delineating IMC across four dimensions, including message consistency, interactivity, stakeholder-centred strategic focus, and organisational alignment, offers a structured approach to understanding the core elements of ICM. By acknowledging these dimensions, organisations can better navigate the complexities of contemporary communication environments and align their strategies with broader organisational goals. Similarly, Taffese and Kitchen's (2017) advocacy for an integrative review underscores the importance of comprehensively examining IC frameworks at different levels. This recommendation highlights the need for a holistic understanding of IC, considering its implications not only at the tactical level but also at the strategic and organisational levels.

In this study several bibliometric techniques on the Scopus database were applied to provide a quantitative outline of the evolution of Integrated Communication (IC) literature and identify conceptual, intellectual, and citation and publication structures, similar objective to Al-Mamun et al. (2022) and Wu et al. (2022) researches. Additionally, the last ones took and processed data from the WoS database, too, with no significant differences in the outcomes.

IC literature has evolved through different stages of publications, and a higher amount of documents were published in the last 10 years --as stated by Al-Mamun et al. (2022) and Wu et al. (2022), similar productivity findings to this research. The evolution reveals thematic axes that provide a comprehensive view of its development. SC emerges as a crucial thematic axis, emphasising the strategic nature of communication practices in both organisational and public domains, as highlighted by Frandsen and Johansen (2015). Although clearer conceptualisation and a more realistic understanding of SC are identified as a prerequisite for maturation, progress --as opposed to sophistication, ultimately depends on the development of discipline-specific, unique, and robust methods (Nothhaft et al., 2018).

IMC forms another pivotal axis, reflecting the shift towards consumer-centric approaches and relationship marketing paradigms. Moreover, as emphasised by Plowman & Wilson (2018), the growing influence of social media underscores the need for leveraging technology in marketing communications to enhance effectiveness and reach.

Philip J. Kitchen leads the list of most productive and influential authors, according to Al-Mamun et al. (2022)'s bibliometric study. Still, Wu et al. (2022) referred to D.E. Schultz and P.J. Kitchen as the core authors of IMC studies in the WoS database. In this study, P.J. Kitchen is the most productive and influential author since 1995, followed by M. Šerić in the last 5 years.

The Journal of Marketing Communications was the most productive, influential journal (in 1st or 2nd position) –according to Muñoz-Leiva et al. (2012) and Al-Mamun et al. (2022). On the other hand, the Journal of Advertising Research was the publishing review leader on I.C., as stated by Wu et al. (2022). Comparatively, this study finds the Journal of Management Communication as the publishing review leader, not only by the total amount of articles in the 1989-mid 2023 period but also by its published papers in the last 5 years.

This research's practical implications are significant for both scholars and practitioners. SC cannot stand alone, as nested in and complementary to ICs. It searches for integration of different areas/disciplines, advancing the global strategy of organisations towards their mission fulfilment, which is Integrated Communication in essence, as several scholars have pointed out (Hallahan et al., 2007; Carrillo, 2014; The Routledge Journal of SC (2015); Holtzhausen & Zerfass, 2015; Nothhaft et al., 2018; and Heath et al., 2018).

Acknowledging the study's limitations, including its reliance on the Scopus database and focus on articles rather than broader sources, is essential. Future research should address these limitations by exploring alternative databases and considering a more diverse range of literature sources for a nuanced exploration of the subject over specific periods.

Expanding upon the existing discussion, it is imperative to critically engage with the literature by delineating differences, identifying gaps, exploring surprises, and outlining future trends in research. By scrutinising existing frameworks and theoretical insights, researchers can contribute to the ongoing discourse on ICM, fostering a deeper understanding of its complexities and implications for organisational communication strategies and practices.

Conclusions

The bibliometric analysis, supported by R software, offers crucial insights into the IC literature. Key turning points in IC research, notably 2009, 2013, and 2015, marked shifts in interest, with 2017 and 2021 emerging as prolific years, establishing IC as a hot topic in marketing and corporate communications. With 456 articles, the ascending trend of research between 2009 and 2021 demonstrates sustained interest in marketing and corporate communications, advertising, IMCs, communication management, crisis communication, social media, and SCs. Notable journals like the Journal of Communication Management, the Journal of Marketing Communications, Corporate Communications, and Public Relations Review have contributed significantly, proposing approaches and models for ICM studies. The most influential author, Philip J. Kitchen, leads the literature, followed by Maja Šerić and Ansgar Zerfass. Collaboration networks, illustrated in the strategic framework, unveil research gaps and opportunities. SC, social media, crisis communication, IMC, and advertising are identified as areas for future studies. Communication, identity, and image represent

niche themes warranting further exploration. The study unveils critical periods in Integrated Communication development and emphasises the changing nature of the concept of "integration" and the lack of consensus among scholars. Research gaps in SC, as indicated by various scholars, underscore the need for more studies on the impact of big data, automation, and the profession's transformation (Wiesenberget al., 2017). The study concludes by providing a roadmap for future research directions, emphasising the importance of advanced methods, large-scale studies communication (Heide et al., 2018; O'Connor & Shumate, 2018; Lock et al., 2020; Seiffert-Brockmann et al., 2021), and interdisciplinary collaboration to advance the field of SC.

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Scaling Up Organic Agricultural Enterprises: An Empirical Study of the Role of Associations of Micro Producers

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Abstract

Background: Development of organic agricultural entrepreneurship often requires “scaling up” from a multitude of individual, largely disconnected micro organic enterprises with haphazard achievements, toward more integrated units, operating more systematically and allowing for replication of their achievements on a larger territorial and temporal scale. **Objectives:** The current states of activity, sectoral and inter-sectoral cooperation of Croatian associations of micro organic producers are assessed with a view to instigate and facilitate scaling up processes. **Methods/Approach:** The inquiry is based on thematic analysis of qualitative data collected through semi-structured interviews with representatives of Croatian associations of micro organic producers. **Results:** Lessening of tension between farmers’ strivings for autonomy and their need for mutual cooperation, trust in interpersonal relationships and organizational structures, and integration through value-based supply chains (VBSCs) are identified as important aspects of scaling-up. **Conclusions:** Scaling-up processes are distinctly path-dependent and, although examples of earlier working practices are welcome, they can seldom be carbon copied in different developmental contexts. Conceptualization of scaling up as intensification of relational interdependencies among various organizational units at several levels of aggregation underlines the need for strengthening the role of associations of micro producers as intermediaries between family farms and other, more complex, inter-sectoral organizational forms. **Keywords:** ecological food production; micro entrepreneurship; neoendogenous development; organic farming; rural development; scaling up

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Introduction

In this article we tackle the problem of scaling up micro organic agricultural enterprises. By “scaling up” we understand the process of advancement from the state of individual, largely disconnected micro organic entrepreneurs with haphazard achievements, toward more integrated units, operating more systematically and allowing for replication of their achievements on a larger territorial and temporal scale. The individual entrepreneurs would not have to sacrifice their autonomy during this process, meaning that, if willing, they would still be able to operate their micro farms as distinct enterprises, albeit with a larger social impact, manifested through their greater contribution to the local community or regional development.

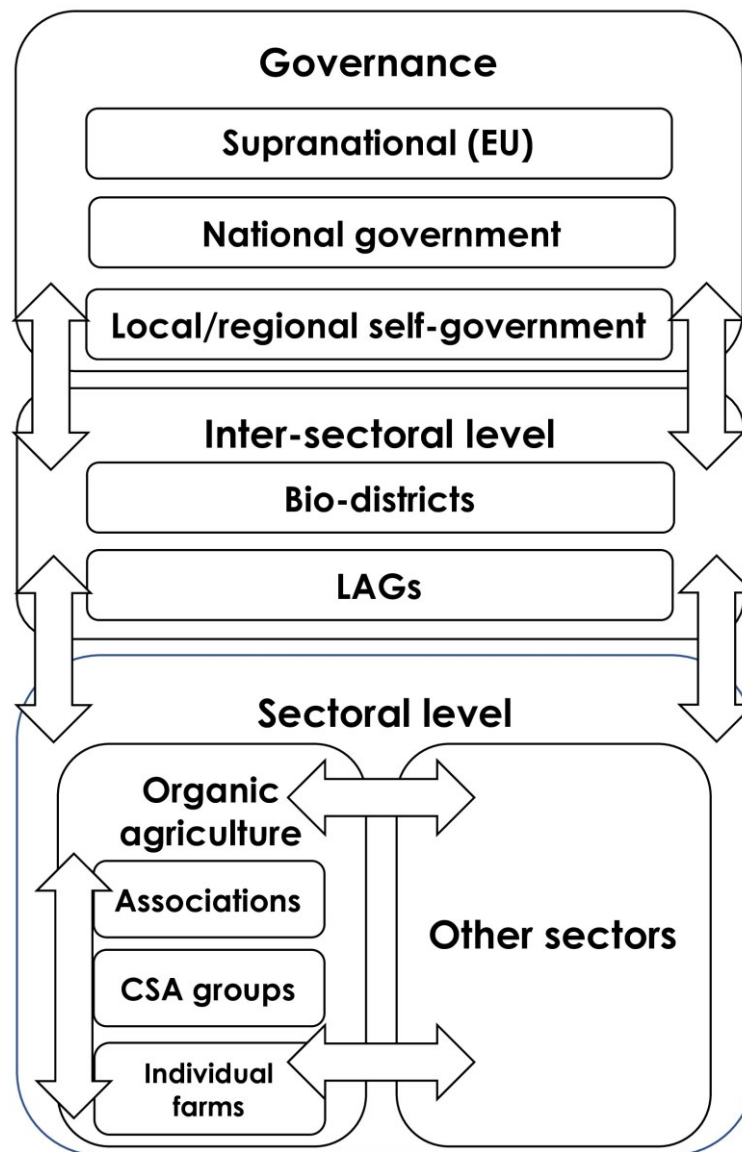
Our previous research (Božić & Srbljinović, 2021) has shown that Croatian micro organic entrepreneurs largely operate under a self-help regime. This means that their businesses are most often established to satisfy some needs of the founders, such as the need to put to use an inherited piece of arable land, to increase household income, to produce healthy food necessary for a healthy lifestyle, or to obtain official certificate for the food already produced largely in compliance with ecological standards. Apart from being important for entering organic farming, self-help also often remains dominant *modus operandi* in the later stages of business development, in the sense that farmers mostly rely on their own strengths and ingenuity to deal with the daily difficulties they encounter in their work. Any farmers face the problem of scaling up their self-help enterprises. State aid is usually not enough and it is too often tailored in ways that only help perpetuate the self-help regime, without enough attention given to the question of where the micro organic farms fit within a larger vision of community or regional development.

Whereas our previous research was focused on individual organic farms (Božić & Srbljinović, 2021; Božić et al., 2022), this article concentrates on the associations of organic producers. In line with the notion of scaling up as inextricably linked to the development of a wider community or a region, we see associations of organic producers as situated within a broader scheme of Figure 1, which is a simplified representation of the main stakeholders identified by our research as relevant for countries such as Croatia, where organic agriculture is largely based on micro entrepreneurship. The aims of our research were to assess the current state of activity, sectoral, and inter-sectoral cooperation of the Croatian associations of organic agricultural producers, and to use this assessment to formulate recommendations as to how the role of the associations in the processes of scaling up Croatian micro organic agricultural enterprises could be strengthened. We shall also underline several more general points by which we wish to contribute to the theoretical discussions of scaling up micro agricultural enterprises.

In what follows we shall first briefly review several approaches to scaling up agricultural enterprises. Then we shall describe the method of our research, including the interviews with the representatives of Croatian associations of organic agricultural producers, and the thematic analysis of their transcripts. After that, we shall present results concerning the current state of the Croatian associations of organic producers. In the course of discussion, we shall place the results within the context of earlier reviewed approaches to scaling up, and within the current efforts of the Croatian government exemplified by the recently adopted *National Action Plan for the Development of Ecological Agriculture 2023 – 2030*. Finally, we shall draw recommendations for policy-makers, and sketch the implications of our findings for theoretical accounts of scaling-up processes in agriculture.

Figure 1

Associations of Micro Organic Producers within a Broader Scheme of Interlinked Stakeholders at Several Levels according to Our Research Findings



Source: Author's illustration

Background

There have been a number of approaches to scaling up individual achievements in agriculture. As a general observation, which we shall illustrate shortly, theoretically richer approaches often miss the necessary extensions needed for their real-world applications, whereas more practically inclined case studies usually lack deeper theoretical underpinnings.

For example, Noe and Alrøe (2003, 2006) conceptualize farm as a self-organizing system, using Callon's (1986), Law's (1992) and Latour's (1996) actor-network theory and Luhmann's (1995) theory of social systems. Although such an elaborate theoretical approach has a potential to extend the notion of an individual farm to "farming systems" (Dixon et al., 2023), we have not been able to find any theoretically

grounded meso- or macro-level extension of Noe and Alrøe's work in the available literature. Hence the practical implications of that work for scaling up individual farming enterprises remain largely unclear.

On the other hand, recent body of research on bio-districts mostly consists of case studies (Dias et al.; 2021; Guareschi et al., 2020; Poponi et al., 2021; Stefanovic & Agbolosoo-Mensah, 2023; Truant et al., 2019), and with some exceptions (Stotten et al., 2018), lacks firmer theoretical grounding. A reader interested in the processes of emergence of bio-districts from constituent lower-level enterprises is therefore doomed to sifting through numerous cases in search of the bits and pieces related to those processes.

In this work we single out two approaches that combine both theoretical and practical considerations and therefore seem to be most useful as springboards for tackling the problems of scaling up organic agriculture in the service of wider rural development. These two approaches are: "peasant-driven rural development" – the concept originating from van der Ploeg's (2008) work on "new peasantries", and "organic regions" – a variant of bio-districts, conceptualized in the spirit of neo-endogenous development (Stotten et al., 2018; Stotten & Froning, 2023). Note that terminology varies: "bio-districts", "organic districts", "organic regions", and "bio-regions" are all very similar concepts that have often been used interchangeably. Generally, we join the call to "support terms that communities use to describe their own spatial identities" (Gkartzios et al., 2020, p.325).

Van der Ploeg (2008) contrasts "peasant-driven rural development", based on territorial cooperatives, with "entrepreneurial farming", based on competition and takeover of farms. While the scaling up under the entrepreneurial farming regime is characterized by larger farms gradually taking over smaller ones, the scaling up in the course of peasant-driven rural development involves formation of large territorial cooperatives that preserve the autonomy of individual farms, such as the North Frisian Woodlands cooperative, which joins some 900 members and covers the area of around 50.000 ha. Moreover, van der Ploeg (2008, pp.156-157) argues that peasant-driven rural development augments value added "both at the individual farm level and at the level of the sector as a whole", and that its multiplier effects are higher than those for entrepreneurial farming.

According to van der Ploeg (2008, pp.23-24), what enables peasant-driven rural development is a "peasant condition", comprising a *self-controlled resource base* and *co-production* in the sense of "ongoing interaction and mutual transformation of man and living nature", which involves both constant *struggle for autonomy* and *patterns of cooperation* "which regulate and strengthen these interrelations".

While van der Ploeg (2008) is concerned with scaling up agricultural enterprises in general, including both conventional and organic ways of production, Stotten et al. (2018) focus on scaling up organic agriculture by a specific way of territorial development known as "neoendogenous development" (Chatzichristos et al., 2021; De Rubertis, 2020; Eversole & Campbell, 2023; Gkartzios & Lowe, 2019; Gkartzios & Scott, 2014; Ray, 2001, 2006). Theoretical foundations of neoendogenous approach can be traced to general systems theory and Luhmann's (1995) theory of social systems (Ray, 2001, 2006).

The concept of neoendogenous development extends an earlier endogenous approach by realizing that a complete endogeny is unattainable in an increasingly connected contemporary world (Ward et al., 2005). Therefore, whenever needed, reliance on local, internal resources and strengths, should be aided by extralocal involvement "through the national up to the European level" (Ray, 2006, p.278). The extralocal agency is conceptualized as ideally "coordinating, managing, enabling"

(Shucksmith, 2009, p.4) or “facilitating” (Zeuli & Radel, 2005, p.48) the efforts of a local community, which still “has, or must acquire, the capacity to assume some responsibility for bringing about its own socio-economic development” (Ray, 2006, p.278). Neoendogenous approach is thus primarily concerned with setting up multi-level, inter-organizational and inter-sectoral linkages to bring about local development (Gkartzios & Lowe, 2019; Ray, 2006). We have tried to represent the key linkages with arrows in Figure 1. We did not want to encumber the figure with too many arrows but, in essence, the more “closely knit” the scheme in Figure 1 becomes, the closer the resulting organizational structure would reflect the ideals of the neoendogenous approach.

Stotten et al. (2018) use Ray's (1998, 2006) neoendogenous framework to analyze development of organic regions in Italy, France and Austria. Organic regions are conceptualized as “territories where farmers, citizens, public authorities and other local actors realize a formal agreement aimed at the sustainable management of local resources, based on the principles and model of organic farming and on the agroecological best practices, in order to boost the economic and sociocultural development of their community” (Basile et al., 2021, p.9).

Stotten et al. (2018) have been particularly interested in the contribution of value-based supply chains (VBSCs; Feenstra et al., 2011; Hardesty et al., 2014; Peterson et al., 2022) to the development of organic regions. VBSCs are the supply chains that “attempt to enhance small and midscale farmers' financial viability by capturing price premiums in the marketplace for the environmental and social benefits (values) embedded in the products” (Feenstra et al., 2011, p.71). Stotten et al. (2018, p.138) emphasize importance of not only vertical linkages along the VBSCs, but also “the horizontal integration and collaborations among groups of farmers or processors.” They underline “the value of trust” as central, “not only in personal relationships, but also in organizational structures” (Stotten et al., 2018, p.138).

Stotten et al. (2018) identify various actors as crucial for the development dynamics of bio-districts: processors of locally produced food in Austria, farmers' cooperatives in France, and the local branch of the national organic association in Italy. In all the three cases, however, the external impetus came in the form of facilitative regulatory frameworks: through the LEADER network in Austria, through regional policies with funding opportunities in France, and through a combination of legal acts on rural and quality districts, leading to the idea of bio-districts in Italy (Stotten et al., 2018).

Methodology

Data were collected in the beginning of 2022 by means of fourteen semi-structured interviews with the representatives of Croatian associations of organic producers. The interview protocol included groups of questions inquiring into: activities of the association; financing; organizational structure; sectoral and inter-sectoral cooperation; community impact; obstacles to work; plans for the future; and basic data about the association and the participant.

The sample encompassed representatives of 11 associations of organic producers, the Croatian Alliance of Associations of Organic Producers, 1 association of organic gardeners, and 1 association engaging in a spectrum of developmental activities including organic agriculture. Most of the associations were organized at the county level, with two associations covering the territory of more than one county. To our best knowledge, at the time when the research was carried out, these 14 associations comprised the entire population of associations of organic producers in Croatia, except for one association, the representatives of which declined invitation to participate.

With the exception of the association of organic gardeners, the majority of members of these associations were not individual persons, but entities engaged in organic agriculture, mostly family farms. The associations had 46.5 members on average. However, when the National Alliance and the association of gardeners, which both had numerous members, were excluded, the average dropped to 29. This figure shows that the associations under consideration were fairly small. The only two associations with employees were the association of organic gardeners, with 2 employees, and the association whose activities encompassed but were not confined to organic agriculture, with 6 employees.

According to the function in their respective associations, 11 participants were presidents, 2 were secretaries, and 1 was a member of the management committee (Table 1). This selection ensured that participants were knowledgeable about Croatian associations of organic agricultural producers.

Table 1
Summary of Participants' Data

Function	Age	Gender	Education	Experience in Agriculture	Experience in Organic Agriculture
Secretary	41	Female	University	20 years	20 years
Member of management committee	62	Male	High school	18 years	12 years
President	53	Male	University	13 years	13 years
Secretary	59	Male	College	From childhood	8 years
President	49	Female	University	10 years	10 years
President	45	Female	High school	13 years	13 years
President	45	Female	University	20 years	15 years
President	49	Male	High school	17 years	17 years
President	33	Male	University	9 years	9 years
President	62	Female	High school	13 years	13 years
President	40	Female	University	8 years	6 years
President	55	Female	High school	10 years	10 years
President	58	Female	University	10 years	10 years
President	41	Female	College	16 years	16 years

Source: Author's own

Nine participants were females and five were males. Their average age was 49 years. One participant reported involvement in agriculture "from childhood", and the rest of them had 14 years of experience in agriculture on average. Experience in organic agriculture was 12 years on average. Five participants completed high school education, two completed college education, and seven held a university degree. Of the latter seven, four held a degree in agriculture. A comprehensive summary of relevant data on the study participants is provided in Table 1.

The timing of interviews coincided with the peak of COVID-19 pandemic in Croatia. Inessential face-to-face contacts were discouraged by health authorities and many people were reluctant to meet others in person. To minimize possible non-response due to health concerns, we decided to conduct all interviews by telephone. Prior to interviewing, each participant was extensively informed about the research, and their informed consent was obtained. The research received ethical approval of the Department of Sociology Committee on Research Ethics, Faculty of Humanities and Social Sciences, University of Zagreb. The interviews lasted for 44 minutes on average.

Audio recordings of the interviews were transcribed and the transcripts were cleared of any data indicating participants' identities. Data were extracted by thematic analysis (Guest et al., 2011) with the help of MAXQDA 2022 Plus qualitative research software. Thematic analysis of text segments led the formulation of initial codes, which were subsequently further revised and fine-tuned on criteria of necessity, sufficiency and relevance. The analytical process resulted in themes and thematic clusters encompassing interconnected themes (Braun & Clarke, 2006, 2024), that presented the overall perception of organic producers' associations concerning their position and role in local and regional development processes.

The initial round of coding resulted with descriptive codes (Gibbs, 2007, ch. 4), roughly corresponding to the earlier mentioned thematic groups of questions that were posed in accordance with the interview protocol. *Activities of associations* and their *sectoral and inter-sectoral cooperation* proved to be the most important themes related to our discussion of possibilities for scaling up.

As we iteratively reviewed and refined our initial codes, we moved toward analytic coding (Gibbs, 2007, ch. 4). These later coding cycles were theoretically informed in the sense that we concentrated on participants' utterances that could be related to the main issues raised in the earlier reviewed theoretical accounts of scaling-up processes in agriculture. Themes that emerged through such analytic coding included *the tension between farmers' strivings for autonomy and the need for mutual cooperation, trust in interpersonal relationships and organizational structures, and integration through VBSCs*.

In the next section, we describe results corresponding to each of the five identified main themes. When describing results, we use verbatim quotations from the study participants to bolster key analytical points (Rose et al., 2015). Translations from Croatian to English are our own. Whenever a research participant is cited, the number in parentheses at the end of quotation denotes the participant's ID.

Results

Activities of associations

Croatian associations of organic agricultural producers are currently fairly weak and small. They are largely underfunded. Most of the measures within the Croatian Rural Development Program have been tailored to the needs of individual farms. However, associations often do not apply even for grants for which they are eligible due to lack of personnel, time, administrative capacities, and experience in writing project proposals.

Moreover, associations of organic agricultural producers are officially categorized as professional associations. As such, they are not eligible for various lines of funding under the broad rubric of institutional support to civil society offered by various public and private funding bodies. Thus, unlike associations in other segments of civil society, associations of organic agricultural producers find it difficult to develop and stabilize their organizational capacities relying on assistance from funds for civil society development.

Not surprisingly, the activity level of associations of organic agricultural producers is not very high. Their activities are mostly limited to small-scale projects, such as educational workshops for members, participation in organic food fairs, seed saving and exchange, establishment of organic gardens in local schools, dissemination of information for members, and the like:

"Well, our most important activity is the organization of the local fair, plus we participate where we can, in various events, and promote ecology, organic

agriculture, gifts of nature. We have an event at the local library every spring called Seed Exchange. Then all those who are interested come, listen a bit, exchange experiences and so on. Occasionally, we also have some lecturers who come and talk about organic farming and so on." (3)

Pooling and sharing activities are exceptionally rare. Even moderately demanding activities, such as establishment of local green markets for organic food, are largely out of scope for those associations. Members of some associations considered establishment of online markets for organic products, but were mostly not able to put those ideas into practice.

Sectoral and inter-sectoral cooperation of associations

Cooperation between associations mostly takes place through the Croatian Alliance of Associations of Organic Producers. The Alliance, being itself legally registered as an association, shares many of the problems of its member organizations, such as lack of financial support, personnel, and other resources. As such, the Alliance is currently not able to assume the key role in scaling up processes.

Cooperation between associations of organic producers and community-supported agriculture (CSA) groups is another form of cooperation within the sector. CSA groups are informal groups of producers and consumers of organic food, whose gatherings are related to organic agriculture, whether in the form of sale or exchange of organic products, visits to organic farms, various events promoting healthy lifestyle, and the like (Orlić, 2014; Orlić et al., 2019; Sarjanović, 2014; Slavuj Borčić, 2020). Similar to the activities of associations, cooperation between associations and CSA groups is largely limited to small-scale projects such as seed exchange and co-organization of various promotional events that serve the common purpose of advancing organic agriculture. CSA groups are more directed at developing cooperation with producers themselves, than with their associations.

At the inter-sectoral level, the European Union encourages Community-Led Local Development (CLLD) through Local Action Groups (LAGs), territorially organized forms of "partnership between representatives of the public, economic and civil sectors in rural areas" (Baturina et al., 2023, p.166). LAGs have been envisioned as "motors of community development" through inter-sectoral collaboration among a wide spectrum of stakeholders.

The level of cooperation between Croatian associations of organic producers and LAGs is generally low. Only two associations reported membership in LAGs, but one of these two could not cite any example of mutual cooperation. One other association reported intense cooperation with several LAGs on drafting local plans of development, involvement in joint projects and educational activities. One association donated to LAG's funds. Three associations reported lower intensity of cooperation with LAGs, mostly by individual members, in the areas of education, promotion of organic agriculture, organization of gatherings and meetings. Eight associations could not cite any example of cooperation with LAGs.

Several Croatian associations of organic producers, particularly those from tourism-intensive coastal regions such as Istria and Dalmatia, have regular contacts with regional and local tourist boards, which help interested family farms organize tourist visits, participate at local food exhibitions and similar events. Some associations help their members to establish contacts and start delivering their products to hotels and restaurants. However, almost one third of the associations could not cite any example of cooperation with the sector of tourism.

There is some cooperation between Croatian associations of organic producers and educational and scientific institutions, and the interviewed representatives of the

associations expressed their openness, as well as the wish to improve that cooperation. The forms of cooperation include lectures of university professors to members of associations, as well as lectures of organic agriculture practitioners to university students, on select topics related to organic agriculture; study visits from high schools and universities to family farms; providing assistance to local schools in eco-gardening and environmental education in general; and participation of organic producers as informants in scientific research such as the one reported in this article.

As Croatian associations of organic producers are largely organized at the county level, and counties are units of regional self-government in Croatia, cooperation with counties is the main form of cooperation between associations and regional self-government. The most frequent form of such cooperation is small financial support, usually on an annual basis, from a county to that county's association.

The Zagreb County is by far the most active in supporting its organic producers and it was the first Croatian county which adopted a very ambitious *Program for the Development of Organic Agriculture until 2030*. The *Program's* goals by 2030 include, among others, 100% of agricultural land under organic farming; 100% organic food in kindergartens, schools and hospitals; and an organic menu in all restaurants and rural tourism facilities in the county (Karoglan Todorović & Znaor, 2020). The county's association of organic producers participated in the *Program's* creation by providing suggestions and feedback on drafts, and it has been involved in the *Program's* implementation.

Some associations, particularly the Croatian Alliance of Associations of Organic Producers, have their voice heard at the national level of government through their representatives in several committees of the Ministry of Agriculture.

Of all the associations participating in our research, only the Croatian Alliance of Associations of Organic Producers tries to develop international cooperation, e.g. with the ARCHE NOAH Seed Bank, but even for the National Alliance, membership fees in some international organizations proved to be too high.

Sectoral and inter-sectoral cooperation of Croatian associations of organic producers have been summarized in Table 2.

Table 2

Cooperation Profiles of the 14 Associations of Organic Agricultural Producers

Association ID	CSA groups	LAGs	Tourism and HoReCa	Science and education	Local/regional self-government
01	✓		✓	✓	
02	✓		✓	✓	✓
03		✓		✓	✓
04					✓
05	✓		✓	✓	✓
06		✓	✓	✓	✓
07			✓	✓	✓
08	✓		✓	✓	✓
09	✓	✓	✓	✓	✓
10		✓	✓	✓	✓
11				✓	✓
12				✓	
13	✓	✓	✓	✓	✓
14	✓	✓	✓	✓	✓

Note: HoReCa denotes Hotels/Restaurants/Cafés, i.e. hospitality industry

Source: Author's own

Both forms of cooperation are largely dependent on the networking and coordination abilities of the few enthusiastic individuals within each association. This is not surprising as the earlier described structural weaknesses of the associations significantly limit both the scope and intensity of their cooperative efforts.

Autonomy vs. cooperation

Croatian associations of organic agricultural producers are currently fairly weak and small. They are largely underfunded. Most of the measures within the Croatian Rural Development Program have been tailored to the needs of individual farms. However, associations often do not apply even for grants for which they are eligible due to lack of personnel, time, administrative capacities, and experience in writing project proposals.

Considering van der Ploeg's (2008) constituent elements of the "peasant condition" as a foundation for scaling up through peasant-driven rural development, our results indicate that the tension between farmers' "struggle for autonomy" and their need for cooperation may be problematic. Our previous research among individual farmers has shown that Croatian organic producers are somewhat ambiguous in regard to cooperation (Božić & Srbljinović, 2021). They tend to provide considerable rhetorical support to cooperation; yet, when it comes to putting cooperative principles into practice and reporting about their cooperative efforts, there is less evidence of enthusiasm. This study lends further support to these findings. Croatian associations of organic agricultural producers are not only small, but also have few active members:

"Frankly speaking, as in other associations, one, two, or three [active members] is the maximum. Everything is more or less on my back and I'm towing things the most in this association of ours, and in the county. One of my colleagues jumps in every now and then as much as she can. (...) Colleagues are active at the meetings, I can see that they are interested and make suggestions, but the actual operational duties are more or less up to me." (4)

Other authors studying Croatian organic producers report similar findings. While Croatian organic farmers have largely positive attitudes toward cooperation with other producers, their actual associational life is more modest (Zrakić et al., 2017). When farmers cooperate, "their cooperation is based only on the exchange of experience in production" (Bokan et al., 2019, p.407).

In our earlier research among individual organic farmers (Božić & Srbljinović, 2021), we had come across a participant whose motto had been: "Stand on your own two feet only!" A participant in the research reported in this article provided a similar example of extreme individualism from her experience:

"A brother and a sister took over the business from their parents. It works great and they have grown to a stage when they can sell all their products: 'Why should they team up, why should they work with anyone else when they are doing well?' Well, there will come a moment when they won't be well anymore, they don't really realize how little it takes for them to be unwell, and they didn't want to team up with anyone. So, there are those who are doing well, who found a market for themselves, and who reason: 'I did it myself, why should I team up with others when there was no one who helped me?'" (13)

While participants in this study, who all assumed the leading roles in their respective associations, did not express such extremely individualistic attitudes, a tension between strivings for self-sufficiency and wider social concerns was nevertheless echoed in the words of participants:

"I'm an old fellow, my goal is to produce for my grandchildren and my customers, while some social goals, well I won't say that I'm not interested, but I'm discouraged by an overall approach to organic agriculture (...) starting from legislation (...)" (2) This quotation is particularly interesting as it also hints at the problem of trust to which we turn next.

Trust

Results of an earlier study indicate that Croatian organic farmers "show a low level of trust in key agricultural services and institutions as well as towards people in general" (Bokan et al., 2019, p.407). Our results are very much in line with these findings. We have already cited the participant who feels "discouraged by an overall approach to organic agriculture," indicating a lack of trust in social institutions, legislation in particular. Another participant went to a great length searching for causes of the current lack of trust in recent war in Croatia, but even more in rapid, predatory privatization that ensued:

"I think [as an obstacle] of a mindset that does not understand that community and wider concerns are our future, instead of everyone looking for themselves only. Such mistrust is in large part the result of the war, but I think even more of the privatization that instilled in people extreme cautiousness: 'Don't trust anyone because anyone who wants to connect with you must have some hidden interest!' The same thing happened with cooperatives, as money was given especially to veterans' cooperatives, and that again proved to be unsuccessful because it was done by force, only to give some money to someone. Again, people have seen: 'Aha, another attempt failed, again someone messed something up!' Do you understand? Without trust, there is no development of a society. I keep saying that, as that is the key to the whole story." (13)

Excessive administration and paperwork, as part of monitoring and control procedures in agriculture and rural development, only deepen the rift in trust between farmers and state institutions. The "zero-risk approach" adopted by European policy-makers, assumes "distrust as the default position" and "leads to excessive control and interference, with an emphasis on box-ticking and procedure" (Cloos, 2024, p.2). This is particularly pronounced in organic agriculture, where controls of compliance with standards of organic production are frequent and rigorous. While most participants understand the necessity of controls for upholding standards of organic farming, they also complain that the actual procedures are often too complicated and time-consuming, that too much administrative burden is placed on the farmers' backs, and that the extent of regulatory micromanagement sometimes borders with absurdity:

"I want to say at the end [of the interview] that bureaucratization has taken off in organic agriculture. What I fear is that many people will give up certification precisely because of bureaucracy. I don't mean that people will give up organic farming practices, but I think that the environment has simply become too demanding in terms of paperwork. (...) This is the biggest obstacle to any further development, and at the end of the day, all these laws and conditions under which you work are developed by bureaucrats who do not know [organic agriculture]. We had a meeting last year in the Ministry where it was discussed why some kind of rulebook was passed where it was expressly stated that a hoe must not be used in orchards." (12)

Another participant mentioned a similarly absurd case when bureaucratic procedures required wild mushrooms, as ingredients of an organic product, to be ecologically certified.

Value-based supply chains (VBSCs)

VBSCs are important for discussions of scaling up as they “can enable groups of farmers to aggregate their products for distribution at a larger scale while maintaining their unique business identity” (Peterson et al., 2022, p.386). In particular, VBSCs have been regarded as backbones around which bio-districts may be formed (Stotten et al., 2018).

We know from our previous research (Božić & Srbljinović, 2021) that individual organic farms in Croatia have been involved in incipient VBSCs. Some farmers, for example, supply organic products to the restaurants that value organic food. Other producers supply their products to public sector entities, such as local kindergartens and schools. At the time of writing, 31 elementary schools in the City of Zagreb have been involved in a pilot project of green public procurement of organic food from suppliers such as family farms (The City of Zagreb, 2024). Furthermore, on the input side, some Croatian organic producers acquire manure from local organic livestock farms.

However, this research has shown that associations of organic producers have neither been able to aggregate products of their members for distribution at a larger scale, nor have they used the opportunity to pool resources of their members to process larger quantities of their products, or acquire larger quantities of agricultural inputs at better price. Seed exchange is one of the seldom reported activities of associations that can be related to VBSCs. In other words, although associations of organic producers have been suited for “horizontal integration” (Stotten et al., 2018) along the VBSCs, this opportunity has largely been missed by the Croatian associations so far.

Discussion

Analysis of the results indicates that scaling up Croatian micro organic agricultural enterprises is not an easy task. Currently in Croatia there are neither cooperatives of organic producers nor organic regions or bio-districts. Struggle for survival often pushes farmers more in a direction of autonomy than toward mutual cooperation. Developmental trajectory of Croatian micro organic agricultural enterprises was heavily path-dependent. It was influenced by the recent war, followed by rapid, predatory privatization (Kotarski & Petak, 2019). The results of those destructive influences are felt in low levels of both inter-personal trust and trust in public institutions (Henjak, 2017; Linstead & Strabac, 2007). Overly bureaucratic financial allocation, monitoring and control procedures exacerbate the problem of trust in institutions in the agricultural sector (Cloos, 2024). Low trust impedes collective action necessary for cooperative accomplishments (Latusek & Olejniczak, 2016).

Overcoming barriers to trust is indispensable for any cooperative effort. Indeed, results of a previous study among Croatian organic farmers show “that the desire for mutual cooperation of organic farmers is related to (...) a higher level of trust in local government and other organic farmers” (Bokan et al., 2019, p.407).

However, national policy-makers do not seem to be enough aware of the barriers to trust and the need to overcome them. Although Croatia recently adopted the National Action Plan for the Development of Ecological Agriculture 2023 – 2030, none of the 40 measures envisioned by the *National Action Plan* foresees any of the Croatian association of organic producers, the National Alliance including, as either a leader or at least as a co-leader of the implementation process for any of the measures (Ministry of Agriculture, 2023). Hence, this opportunity to send a signal of trust from the national decision-making level to the associations of organic producers was missed.

Furthermore, although the *National Action Plan* notes that “in Croatia, it is not common for organic producers to form cooperatives” (Ministry of Agriculture, 2023, p.97), no action is foreseen to deal with the observed problem.

Trust can also be built bottom-up. Due to limited available resources, this research could not include interviews with representatives of CSA groups. However, it is well-known from earlier studies that trust and shared values are integral parts of consumer-producer interactions within CSA groups (Opitz et al., 2019). Trust plays an important role in Groups of Solidarity Exchange (GSEs), a particular form of CSA groups in Croatia, the members of which do not require official certificates from organic producers, but rely instead on interpersonal trust (Orlić et al., 2019). The relations of trust are established and strengthened during community events such as common gatherings and visits to organic farms, where visitors can witness first-hand agricultural practices used in food production processes. GSEs can be regarded as a Croatian version of the “local food movement,” which gives precedence to “trust and confidence in the social and ecological integrity of (...) food” over excessive standardization, certification, and control (Ikerd, 2017, pp.5-6).

CSA groups are important for raising grassroots awareness and coordination of ideas about desirability of organic production (Orlić, 2014). Common ideas, interpersonal trust and shared values are undoubtedly good starting points for scaling up micro organic agricultural enterprises. CSA groups have also been instrumental in establishment and strengthening of VBSCs (Sarjanović, 2014; Slavuj Borčić, 2020).

However, CSA groups do not develop trust in institutions, as their activities are mostly informal and they attempt to circumvent traditional social institutions. Furthermore, only more complex organizational forms, such as associations of organic producers, can provide access to organizational and financial resources necessary for, e.g., applying for tenders, larger-scale projects management, lobbying and policy influence, networking with foreign and international organizations of organic farmers, and other “more formal” activities, which are all necessary for a stronger development of the sector. While CSA groups are certainly important elements of organic agriculture, it is difficult to envision scaling up, in the sense developed in this article, solely by means of CSA groups.

Bio-districts have also been mentioned in the *National Action Plan*. However, except providing an example of a good practice from Italy, and two brief remarks on the potential of bio-districts for eco-tourism development, the *National Action Plan* remains silent on how exactly bio-districts could gain a foothold in Croatia.

The *National Action Plan* rightly recognizes potential for cooperation between the sector of organic agriculture and the sectors of tourism and hospitality, and the *Plan* envisions measures for strengthening that cooperation. However, the *Plan* falls short of developing a broader vision of bio-districts, or other forms of inter-sectoral cooperation, which could also include cooperation with cultural and creative industries in conjunction with heritage-based rural regeneration, or cooperation with IT sector in more vigorous development of online green markets for organic products, for example.

There are bottom-up initiatives in the tourism sector, such as the establishment of an association of small environmentally-friendly renters in the region of Istria, aimed at “strengthening the local economy, preservation and promotion of local values, customs and traditions, and preservation of the environment and local architecture” (*Glas Istre*, 2023, p.2). Such bottom-up initiatives have a potential to become “the main actors who lead the territorial development dynamics” (Stotten et al., 2018, p.150) in direction of “sustainable and circular tourism” (Avasiloaei (Muscal), 2021, p.436), and they should be encouraged to involve micro organic producers as well.

The *National Action Plan* envisions measures for both strengthening and shortening organic supply chains, and it mentions explicitly their value component. The *Plan* encourages public sector institutions, such as schools, to implement green public procurement measures. The *Plan* also includes educational activities for groups and associations of organic producers to facilitate their access to green public procurement tenders. What is lacking again is a vision of broader forms of inter-sectoral cooperation, such as bio-districts, which could grow out of incipient local VBSCs.

While budgeting for LAGs is secured from the European Agricultural Fund for Rural Development, there are no specifically allocated budgets for bio-districts at the EU level (Stefanovic & Agbolosoo-Mensah, 2023). We have mentioned already that various countries adopted various regulatory frameworks facilitating development of bio-districts (Stotten et al., 2018). Croatia is still to establish such a regulatory framework and this could be the reason for the observed vague treatment of bio-districts in the *National Action Plan*. However, a complete omission of LAGs from the *Plan* is more difficult to explain. The lack of guidance on possible involvement of micro producers in both bio-districts and LAGs indicates gaps at the inter-sectoral level of planning, which impede coordination of development of organic agriculture with development of other sectors. Without a proper inter-sectoral coordination, scaling up micro organic agricultural enterprises becomes even more difficult.

A word of caution is needed also as not every organic supply chain is necessarily value-based. Studies of Croatian organic producers' perceptions of the value component within supply chains have been rare and the results so far have been mixed (Gajdić et al., 2017). Our earlier research (Božić & Srbljinović, 2021) has shown that a considerable number of Croatian organic producers of fruits and vegetables distribute their products through large retail chains. However, producers were reluctant to speak about their contracts with retailers because the terms of those contracts were treated as confidential information. One participant declined to answer the question about whether his products were allowed to retain the label of his family farm, or they were lumped together with the same products of other organic contractors. Obviously, if the unique identities of small farms get lost along a supply chain, such chains cannot be regarded as value-based. Strengthening associations of organic producers, particularly their lobbying and policy influence abilities, could mitigate imbalances of power between micro producers and large retailers, and prevent imposition of unfair contract terms by the stronger parties. More generally, conflicts between economic, environmental and social sustainability within supply chains can be mitigated by giving voice to all the stakeholders, addressing their concerns, and trying to integrate their various perspectives early on in supply chains planning and development processes (Pejić Bach, Klinčar et al., 2023; Pejić Bach, Žmuk et al., 2023).

The role of social innovations has also been discussed in the literature on neoendogenous rural development (Bock, 2016). Although we have not come across examples of social innovation during interviews with representatives of Croatian associations of organic producers, our previous research (Božić et al. 2020; Božić & Srbljinović, 2021) informed us about social innovations, such as a mobile and computer application for eco-garden renting and management assistance, which was developed with the help of one of the leading members of an association of both conventional and organic vegetable producers. The *National Action Plan* recognizes the need to encourage innovations in organic agriculture, but the emphasis seems to be on agro-technological innovations. Social innovations have not been mentioned explicitly, although innovative ways of networking and cooperation among various

stakeholders, for example, would be very much helpful in our vision of scaling up micro organic agricultural enterprises.

The *National Action Plan* includes measures for enhancing cooperation between organic agricultural producers and educational and scientific institutions. This is particularly encouraging as participation of small farmers in scientific research has been widely regarded as insufficient so far (Nature Editorial, 2020; Verger & Le Bars, 2024). The emphasis in the *National Action Plan* is again on agro-technological research and education. As our results indicate, however, many of the problems besetting Croatian organic agriculture are socio-relational and organizational, so that dealing with them calls for social-scientific expertise as well.

Conclusion

Prior to the concluding remarks, a brief reflection on limitations of the study should be in place. First of all, the sample comprising 14 civic associations is valid as it encompassed almost the whole population of Croatian organic agricultural entrepreneurs' associations. The Croatian Alliance of Associations of Organic Producers has 15 member organizations. As the sample covered roughly three fourths of the twenty Croatian counties, ensuring a fairly complete geographical coverage, we can be quite sure that the findings are relevant for Croatian organic agriculture. However, due to nation-specific differences in quantity and quality of state support to organic agriculture and other developmental path-dependent idiosyncrasies, our findings can be generalized only to those countries whose organic sectors follow similar developmental trajectories.

The majority of scholarly works on scaling up agricultural enterprises has been concerned with a *posteriori* description of scaling up processes. Discussion of peasant-driven rural development has been, for the most part, based on Dutch experience with territorially organized cooperatives (van der Ploeg, 2008). Accounts of organic regions and bio-districts development have most often shed light on examples of good practices in the service of sustainable regional development (Basile et al., 2021; Dias et al., 2021; Guareschi et al., 2020; Poponi et al., 2021; Stefanovic & Agbolosoo-Mensah, 2023; Stotten & Froning, 2023; Stotten et al., 2018; Truant et al., 2019;). There is, however, a lack of literature on how to instigate and facilitate scaling up processes that have been only beginning to display signs of their potential. In this article, we have attempted to tackle this "incitement problem", which is, in our view, one of the largest obstacles to further development of Croatian organic agriculture.

We have used the mentioned body of literature on successful past examples to address the problem of scaling up micro organic agricultural enterprises, which have, up to now, largely been operating under a self-help regime. As the previous studies already indicated (Stefanovic & Agbolosoo-Mensah, 2023; Stotten et al., 2018; van der Ploeg, 2008), scaling-up processes are markedly path-dependent and, although the examples of earlier working practices are useful, they can seldom be carbon copied in different developmental contexts.

For example, although much of the Croatian agriculture does satisfy the requirements of the "peasant condition" (van der Ploeg, 2008), developmental idiosyncrasies related to the recent war and excesses in privatization emphasized "the struggle for autonomy" to the detriment of "patterns of cooperation". Both interpersonal trust and trust in institutions were ruined. Within the sector of organic agriculture, interpersonal trust has been, in the meantime, renewed to a degree through bottom-up activities of CSA groups. Trust in public institutions remains more problematic, and its renewal requires more involvement on the part of all relevant stakeholders.

Our results and discussion imply that all the stakeholders in Figure 1 should try to develop a sense of a common vision – to become aware of the wider scheme of things and of their own place within it, as well as of their own potential contribution to developmental processes. Indeed, a sense of perspective regarding “my place in the grand scheme of things” has been emphasized in sustainability science as an aspect of human–nature relationships (Gould et al., 2023). Here we assume that the same sense of perspective can be transferred to inter-organizational relations with similarly beneficial effects. On the one hand, this means that micro farmers should become aware of not only their narrow business perspective, but also of their role in local community and regional development. On the other hand, this also assumes that national and supranational levels of governance pay more attention to the grassroots, encourage their participation in decision-making processes, and develop more trust-building measures.

Translated into more concrete policy requirements, these principles require that the *National Action Plan for the Development of Ecological Agriculture* encourage stronger participation of associations of organic producers in the implementation of the *Plan*, empowering the associations by giving them leadership or co-leadership roles in at least some of the envisioned measures. The *Plan* should attempt to transcend the narrowly sectoral perspective by providing at least some guidance to the local self-government units and the county-level associations of organic producers on the actual establishment of bio-districts, instead of only mentioning their desirability. If there are problems with financing establishment and development of bio-districts, innovative methods of financing, such as green bonds (Chahine & Liagre, 2020; Tran et al., 2024), may be considered. The *Plan* should also pay more attention to the CLLD initiatives, the LAGs in particular, and provide guidance with regard to involvement of organic producers, their associations and CSA groups in LAGs.

Local and regional self-government units, counties in particular, should be encouraged to develop their own action plans for development of organic agriculture, considering their regional specifics. Neither all counties can, nor should, set their ambitions as high as the Zagreb County did, but setting at least some kind of milestones, and monitoring their completion, would certainly help regional development of organic agriculture in conjunction with development of other sectors at the regional level.

In the view described above, scaling up means, above all, intensification of relational interdependencies among various units at various levels in Figure 1, rather than mere subordination of the lower-level units to the higher-level ones. In accordance with such a vision, scaled up micro organic farms would be allowed to retain their autonomy, while gradually being more and more strongly involved in sectoral and inter-sectoral cooperative networks.

Going back to the earlier mentioned Noe and Alrøe's (2003, 2006) theoretical framework of a farm as a self-organizing system, we can say that an extension of their approach, beyond the level of an individual farm, should start from the notion of scaling up as relational intensification, which would be in accordance with their view of “a farm enterprise as a heterogeneous network of interrelations” (Noe & Alrøe, 2006, p.47). Second, through the intensification of relational interdependencies, the farm should not only retain, but also strengthen the capacity to “reproduce its own boundaries, as a selection of possibilities (meanings) that are open for the system, selected from a surplus of possibilities offered by the environment” (Noe & Alrøe, 2006, p.44). The social environment of a farm can be roughly represented as the scheme in Figure 1. We believe that the notion of a farm as a self-organizing system can be meaningfully extended along the lines sketched here, but such an extension asks for

a detailed engagement with Noe and Alrøe's (2003, 2006) theoretical framework, which would require more space than available in a single article.

Finally, improving theoretical insights into multi-level, systemic functioning of individual farms and farming systems should benefit practitioners and decision makers at various levels, who "urgently need data, models, and knowledge products that provide user-friendly data collection and analysis capabilities" (Brečko & Žgajnar, 2022, p.24).

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