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USE OF GENERATIVE AI IN THE CROATIAN MANUFACTURING INDUSTRY

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Abstract: As global manufacturing shifts toward the principles of Industry 5.0, emphasizing human-centricity, sustainability, and resilience, Generative Artificial Intelligence (GenAI) has emerged as a key enabler of next-generation industrial systems. While international research highlights the potential of GenAI tools to optimize workflows, enhance decision-making, and foster collaboration between humans and machines, the practical application of these technologies in the Croatian manufacturing industry remains underexplored. This study seeks to address that gap by examining the current state, usage patterns, and future potential of GenAI adoption among professionals in Croatian manufacturing companies.

A structured online survey was distributed to 682 manufacturing professionals across Croatia, yielding 33 complete responses. The questionnaire gathered data on demographics, company characteristics, and the use of GenAI in general applications (e.g., ChatGPT, DALL·E), office productivity tools (e.g., Microsoft Copilot, Google Gemini), and automation systems. The results reveal that while awareness of GenAI is relatively high, actual usage is still low. Text-based tools are the most widely used, primarily for content generation and operational support. Use of AI-enhanced office tools and automation platforms is less common, and the intensity of usage varies significantly across respondents. Despite the modest adoption levels, the study finds strong interest in expanding the use of GenAI technologies: 85% of respondents indicated they plan to increase usage in the near future. However, challenges such as limited infrastructure, lack of training, and inconsistent integration across workflows remain prevalent. The findings underscore the need for targeted policy support, investment in digital infrastructure, and cross-sector collaboration to unlock the full potential of GENAI in the Croatian manufacturing sector. This research provides a valuable empirical foundation for future studies and strategic initiatives aimed at fostering sustainable, intelligent, and human-centered manufacturing systems in Croatia, in line with the broader goals of Industry 5.0.

Keywords: Industry 5.0, Generative AI, artificial intelligence, manufacturing

1. INTRODUCTION

The rapid development of artificial intelligence (AI), and particularly Generative AI (GenAI), is redefining the future of manufacturing worldwide [1]. As industries move from the automation-driven paradigm of Industry 4.0 toward the human-centric and sustainable vision of Industry 5.0, the role of AI technologies is expanding beyond process optimization into the realms of creativity, personalization, collaboration, and resilience [2]. Among these technologies, GenAI stands out for its capacity to generate new content, simulate scenarios, support decision-making, and facilitate intuitive human-machine interaction, making it a key enabler of next-generation manufacturing systems.

Globally, recent studies have explored how GenAI can contribute to the sustainability goals of Industry 5.0, including energy efficiency, predictive maintenance, digital twin enhancement, and user-focused design [3]. Research has demonstrated that GenAI-powered systems can optimize resource use, support ethical governance, and enable proactive problem-solving by generating synthetic data, guiding adaptive planning, and improving the interaction between humans and machines. Integrations such as GenAI-based chatbots, explainable AI in fault diagnostics, and hybrid models for additive manufacturing are reshaping industrial ecosystems across sectors—from large-scale production to small, experimental factories. Despite the growing global momentum, the use of generative AI in the Croatian manufacturing industry remains underexplored, both in terms of academic research and practical application. Croatian manufacturing firms, many of which are small or medium-sized enterprises (SMEs), face unique challenges and opportunities in digital transformation [4]. These include limited resources for AI experimentation, fragmented data infrastructures, and a need to balance productivity with the well-being of workers

and environmental responsibility. Understanding how GenAI can be meaningfully implemented in this context is essential for aligning Croatia's industrial development with European Union strategic goals and broader Industry 5.0 ambitions. This paper aims to address this gap by investigating the current state, challenges, and potentials of generative AI adoption in Croatian manufacturing.

2. RELATED WORK

The emergence of Industry 5.0 has redefined the role of technology in manufacturing by shifting the focus from efficiency alone to a balanced emphasis on human-centricity, sustainability, and resilience. Within this evolving framework, Generative Artificial Intelligence (GenAI) has emerged as a transformative enabler, offering substantial potential to reshape the manufacturing landscape, including in Croatia. This literature review synthesizes key insights from recent academic contributions that explore GenAI's integration across various industrial functions and its alignment with Industry 5.0 principles.

A growing body of work positions GenAI as central to achieving sustainability goals in Industry 5.0. One foundational study develops a strategic roadmap that identifies ten key GenAI functions contributing to data-driven decision-making, operational resilience, and sustainable innovation. Crucially, the authors emphasize that while these functions are individually impactful, their synergistic application provides enhanced benefits when deployed in a structured sequence [3].

The integration of GenAI with digital twin (DT) technology has also been recognized as a critical area of innovation, particularly in predictive maintenance and fault diagnostics. GenAI enhances DTs by generating synthetic data, enabling real-time simulations, and improving anomaly detection, thus addressing key limitations such as data

scarcity. These contributions align strongly with Industry 5.0 by incorporating explainable AI (XAI) and edge computing for enhanced transparency and real-time responsiveness [5].

In the domain of adaptive social manufacturing, researchers have proposed frameworks that link GenAI functions to specific sustainability dimensions. Through a combination of content analysis and system dynamics modeling, these studies show that GenAI can promote inclusivity, ethical governance, and efficient resource use—core tenets of human-centric industrial design. Importantly, this work recognizes the need for balanced implementation that honors both technological and societal objectives [6].

Further exploring specific tools, several publications examine the impact of well-known GenAI models such as ChatGPT and DALL-E on production optimization, supply chain management, and customer engagement. These tools demonstrate tangible benefits in operational efficiency and responsiveness but also bring challenges related to data privacy, bias, and interoperability, suggesting a need for thoughtful integration strategies [7].

Other studies focus on GAI's accelerative role in bridging Industry 4.0 and Industry 5.0, particularly through four key dimensions: smart manufacturing, smart working, smart products/services, and smart supply chains. These works underline GAI's capacity to enhance mass customization, human-machine collaboration, and real-time logistics, though they also call for further domain-specific research on organizational impacts and system integration [2].

From a user interface perspective, the application of customized GenAI chatbots has proven valuable in human-machine interaction (HMI). By facilitating real-time data access and predictive troubleshooting via natural language interfaces, these tools exemplify the user-friendly, intuitive interaction environments envisioned in Industry 5.0. Such systems also support

enhanced machine learning model training and autonomous decision-making, reinforcing the shift toward operator empowerment [8].

The concept of parallel manufacturing, introduced through the DeFACT framework, extends GenAI's application to decentralized collaborative production. Incorporating digital, robotic, and human workers, the model relies on blockchain, scenario engineering, and GAI to support trust, adaptability, and customization, even in low-trust environments [9].

In the area of additive manufacturing (AM), Hybrid Additive Manufacturing (HAM) envisions a cyber-physical-social system where GenAI contributes to the digital training and behavioral modeling of intelligent products. This new paradigm expands AM's scope beyond material creation to include socially responsive and adaptive entities, underscoring GenAI's potential in future-ready design systems [10].

On a broader scale, frameworks such as AIDAF (Adaptive Integrated Digital Architecture Framework) demonstrate how GenAI can be integrated into enterprise architecture, particularly in healthcare and manufacturing. These systems aim to support cost reduction, strategic decision-making, and open, collaborative platforms, such as the proposed DSA&OHP2030 initiative, that align with Society 5.0 and Industry 5.0 visions [11].

Concrete implementations of GAI-enhanced systems in manufacturing environments further validate the technology's real-world potential. For instance, one study documents the deployment of a robotic cell and voice assistant, resulting in significant cycle time reduction and improved worker well-being, demonstrating that GenAI-driven solutions can effectively support safer and more satisfying work environments [12].

Moreover, the design of GPT-powered industrial bots for small factories illustrates how generative AI can monitor worker well-being and optimize operations in a personalized and context-sensitive manner. These tools not only assist in fault detection

and root cause analysis but also offer environment-specific recommendations to operators, reinforcing I5.0's human-centered philosophy [13].

The integration of AIGC (AI-Generated Content) within Product Lifecycle Management (PLM) is also gaining traction. One reviewed study introduces a human-in-the-loop framework that embeds AIGC across the manufacturing lifecycle while addressing current technological and ethical challenges, laying a foundation for more collaborative and resilient production systems [14].

AI-DT integration continues to be a focus area, with frameworks that leverage predictive analytics and scenario simulations to support autonomous decision-making and system adaptability. These models are essential for establishing global standards and ensuring scalability in future industrial ecosystems [15]. The importance of human-centric equipment health monitoring (EHM) is emphasized in studies that incorporate user needs into advanced model architectures, such as EDA-CGANs and knowledge distillation techniques. By incorporating XAI for interpretability, these approaches align technical innovation with operator expectations and safety, a defining characteristic of Industry 5.0 [16].

Finally, a comprehensive vision for human-robot collaboration (HRC) stresses the development of cobots that are context-aware, socially intelligent, and capable of balancing safety with performance. This interdisciplinary perspective underscores the role of GAI as a catalyst for enabling dynamic and personalized interaction between humans and machines [17].

3. METHODOLOGY

The research was conducted to gain insights into how generative artificial intelligence (GenAI) tools and AI-powered office solutions are being utilized within the Croatian manufacturing sector. A structured, multi-phase methodology was employed, with the primary data collection instrument

being a detailed questionnaire developed specifically for professionals working in manufacturing environments.

The survey instrument consisted of 19 questions, divided into four thematic sections. The first section collected demographic and professional background information, such as respondents' gender, job role, industry segment, years of experience, and the size of their company. The second section explored the use of general-purpose GAI tools—such as ChatGPT and DALL·E—in work-related contexts. The third part addressed the adoption of generative AI features integrated into commonly used office software, including tools like Microsoft Copilot and Google Gemini. The final section captured broader trends in automation and digital technology adoption at the organizational level.

Prior to broad distribution, the questionnaire was piloted with a small number of manufacturing professionals to test the clarity and relevance of the questions. Based on the pilot feedback, minor adjustments were made to ensure the survey would be both accessible and meaningful. To accommodate the target group, the final version was translated into Croatian.

The finalized survey was distributed via email to 682 professionals employed in Croatian manufacturing companies. From this outreach, 33 completed responses were received, resulting in a response rate of roughly 4.8%. Despite the relatively limited sample size, the data gathered offers an important first look at how GenAI technologies are entering the manufacturing workspace in Croatia—highlighting early use cases, benefits, and practical limitations encountered during adoption.

4. RESULTS

The study gathered responses from a total of 33 professionals working in the Croatian manufacturing industry. The majority of respondents were male (91%), with only 9% identifying as female. Respondents

represented a diverse range of industry sectors, including metal processing, food and beverage, printing, tourism-related manufacturing, and service industries. Companies of all sizes were represented: 35,3% of participants worked in small enterprises (1–50 employees), 23,5% in medium-sized firms (51–250), and another 29,4% in large companies (251–1000).

Most participants had significant industry experience, with 58,8% reporting more than 10 years in the field. Job roles varied and included operations managers, production directors, procurement officers, and mid-level management positions, offering insights from different decision-making and operational layers within manufacturing firms.

When asked about the purpose of using general generative AI tools (e.g., ChatGPT, DALL-E), a strong preference for text-based tools was observed. Approximately two-thirds of respondents used tools like ChatGPT for content generation and query-based support. A small number indicated using image-based tools, while others reported no use of general GenAI tools.

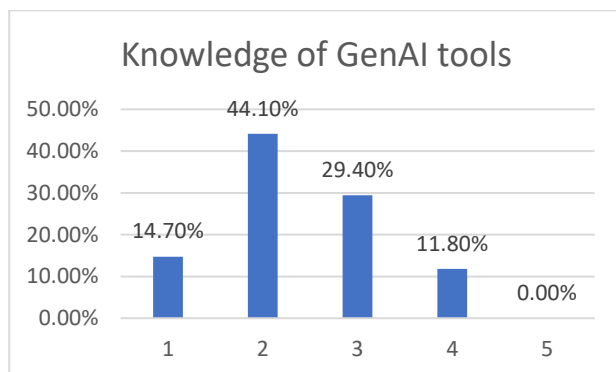


Figure 1. Assessment of knowledge about working with general generative AI tools

In terms of intensity of use, responses were widely distributed. About 20,6% respondents rated their usage as moderate (level 3 on a 5-point scale), while 70,6% reported low to minimal use (levels 1–2). Only a few respondents reported high or very high intensity of use (8,8%).

Satisfaction with GenAI tools also showed variation. While 44,1% respondents

expressed moderate satisfaction, 14,7% reported very high satisfaction, and 17,6% expressed low satisfaction.

Notably, 85,3% stated that they plan to increase their use of generative AI tools in the future, indicating strong perceived value and interest in broader adoption.

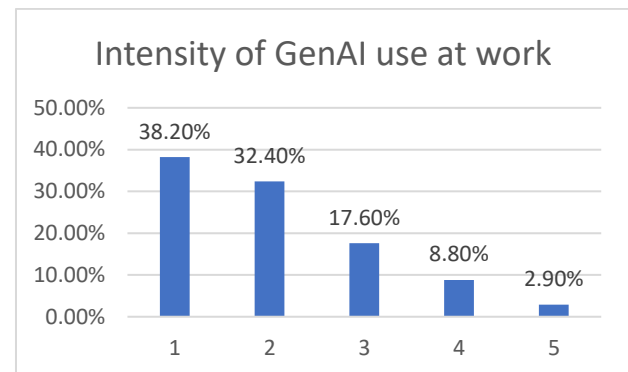


Figure 2. Intensity of use of special office generative artificial intelligence at work

Regarding AI-enhanced office tools such as Microsoft Copilot or Google Gemini, the most common uses were for document summarization (50%) and email writing (38,2%). However, usage was less widespread than general-purpose GenAI tools. Many respondents either did not use these tools or used them at a low intensity.

As with general GenAI tools, satisfaction levels for office AI tools were mixed, with most respondents expressing moderate satisfaction, while a smaller portion were highly satisfied or dissatisfied.

Participants also reported on their use of automation technologies within their organizations. Common applications included order processing (26,5%), inventory management (26,5%), document handling (44,1%), and warehouse operations (26,5%). However, 38,2% respondents indicated no use of automation tools, highlighting a gap in broader digital transformation efforts among certain firms.

The intensity of automation tool use varied, with the largest share reporting minimal or low usage, suggesting that automation adoption is still in its early stages in parts of the Croatian manufacturing sector.

5. DISCUSSION

The results of this study offer an important early insight into the application of Generative AI (GenAI) technologies in the Croatian manufacturing industry, particularly within the broader transition toward Industry 5.0. While global literature increasingly recognizes the transformative role of GenAI—from enhancing digital twins and predictive maintenance to enabling human-machine collaboration—the findings from this survey show that Croatia is still in the early stages of practical adoption.

First, the survey responses reveal that a majority of manufacturing professionals are aware of and have experimented with GenAI tools, particularly text-based platforms like ChatGPT, which are used primarily for information retrieval and content generation. However, the intensity of use remains modest, with most respondents reporting low to moderate engagement. This suggests that while there is interest and awareness, full integration into daily workflows has not yet been achieved. Still, the high percentage of respondents who plan to increase their use of GenAI in the future (85%) reflects strong latent potential and openness to technological innovation.

Interestingly, the adoption of generative AI features embedded in office tools—such as Microsoft Copilot or Google Gemini—is less widespread, indicating that enterprise-level AI deployments may face barriers such as software availability, digital infrastructure limitations, or lack of internal training and support. Similar patterns were observed with automation tools, which remain underutilized across the surveyed companies. While some respondents reported the use of tools for document management, inventory control, and order processing, a significant number of professionals (over one-third) indicated no current use of automation technologies. These results echo concerns noted in the introduction, such as resource limitations,

fragmented IT ecosystems, and a cautious organizational culture—factors that may slow the pace of digital transformation in Croatian manufacturing SMEs.

Another important aspect is the human-centric dimension. Most respondents occupy middle or upper management positions with extensive professional experience, making them key actors in shaping technological strategies. Their moderate satisfaction levels suggest that existing GenAI tools are not yet fully aligned with local workflows or expectations, pointing to the need for more tailored, context-sensitive AI solutions. Furthermore, low reported use of GenAI for creative or collaborative tasks may indicate a lingering perception of AI as a support tool rather than a co-creative partner—an issue that resonates with broader debates in Industry 5.0 literature.

Finally, it is worth noting that although the survey had a limited sample size (33 respondents), the diversity in company sizes and industry segments adds depth to the findings. The trends identified in this research highlight the need for targeted policy support, cross-sector education, and structured investment in digital infrastructure to ensure the Croatian manufacturing sector can fully leverage the potential of generative AI technologies.

6. CONCLUSION

This study represents one of the first empirical investigations into the use of generative artificial intelligence within the Croatian manufacturing industry. While adoption levels remain in their early phases, the findings reveal a clear interest in and openness to expanding the use of GenAI tools among industry professionals. Text-based generative AI applications—such as ChatGPT—are the most commonly used, while more advanced or embedded tools,

including office AI features and automation systems, are still emerging.

The survey confirms several core challenges facing Croatian manufacturers: a lack of infrastructure, limited use of automation, and uneven digital maturity across enterprises. At the same time, it highlights substantial support this evolution, several recommendations emerge:

- Education and training initiatives should be introduced to improve GAI literacy and implementation skills at all organizational levels.
- Public policy and funding should prioritize small and medium-sized enterprises, helping them overcome financial and technological entry barriers.
- Collaborative projects involving universities, technology providers, and manufacturers can serve as innovation testbeds for Croatian-made GAI applications tailored to local industry needs.

Future research should extend this pilot study by including larger samples, qualitative interviews, and longitudinal tracking to evaluate the evolving role of generative AI in Croatian industry. Doing so will help ensure that the country not only follows global trends but also actively shapes the development of a sustainable, innovative, and human-centered industrial ecosystem.

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