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ETHICAL DIMENSIONS OF ARTIFICIAL INTELLIGENCE IN GRAPHIC DESIGN: CHALLENGES, OPPORTUNITIES AND THE FUTURE OF CREATIVE PRACTICE

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Abstract

Artificial Intelligence (AI) is rapidly reshaping societal dynamics and is expected to continue influencing various sectors. In the field of graphic design, its integration has generated both enthusiasm and concern. Today, AI is transforming how graphic designers work by introducing innovative tools and methods that enhance creativity, efficiency, and production capabilities. AI enables faster and higher quality realization of creative concepts by automating repetitive tasks, generating complex and realistic visuals, and improving design personalization. However, the rapid development and implementation of AI in design practices also bring forth a series of challenges that must be critically examined. Issues such as authenticity, originality, and authorship of AI-generated content are becoming increasingly relevant, and it is crucial that we address these challenges head-on. Additionally, the potential displacement of human workers by automated systems raises concerns about job loss and the redefinition of the designer's role in the creative process. The ethical use of AI in graphic design spans multiple dimensions: algorithmic bias, user privacy, transparency of sources and influence, and questions of ownership and intellectual property. This paper aims to comprehensively analyse the challenges, and key ethical considerations of using AI in graphic design through a systematic literature review. Special emphasis is placed on ethical challenges related to authorship, creativity, bias, transparency, and broader societal impact. The paper also considers the future trends considering graphic design, AI and creativity and explores how they may be adapted to meet the specific challenges posed by AI in graphic design. Ultimately, this research contributes to the academic discourse on the responsible and sustainable use of AI in the creative industries, laying the groundwork for future research in ethics and technology. Particular attention is devoted to the evolving role of human designers in an increasingly dynamic and complex AI-influenced environment, underscoring the urgent need for responsible use of AI.

Keywords: *Artificial Intelligence (AI), authorship, ethics, graphic design, intellectual property.*

Introduction to Artificial Intelligence and its ethical dimensions

Artificial Intelligence (AI) is increasingly permeating all facets of contemporary society, extending its influence from sectors such as healthcare and humanitarian assistance to more commonplace domains. Its applications span a growing range of fields, including autonomous vehicles, medical services, media, finance, etc., significantly enhancing operational efficiency and delivering measurable benefits (Wang, 2023). The rapid development of AI and machine learning technologies is already reshaping society and is expected to continue doing so in the decades to come. AI, including its embodied forms such as robotics and methodologies like machine learning, has introduced transformative changes across various sectors. Progress in machine learning, particularly neural networks, has been driven by the exponential growth of data availability, increased computational power, advancements in ML algorithms, and the expanding pool of skilled developers (Green, 2020). However, AI also presents notable risks and ethical challenges alongside its many benefits. Concerns regarding privacy breaches, algorithmic discrimination, job displacement, and security vulnerabilities underscore the complex impact of AI on the existing social order. As AI becomes increasingly embedded in high-risk and socially sensitive applications, there is growing pressure to ensure its design and deployment uphold accountability, fairness, and transparency principles. The discourse on AI ethics is diverse and evolving, related to AI-based systems' design, implementation, and societal impact. On one side are implications of who is accountable for AI-driven decisions. On the other side are the privacy challenges inherent in human-machine interactions and the implications of AI for business strategies and organizational practices (Cath, 2018; Giarmoleo et al., 2024). Several challenges and opportunities emerge at the intersection of AI development and ethical inquiry. These include ensuring technical safety and functionality; achieving transparency and safeguarding data privacy; promoting beneficial applications across sectors such as biomedical research, education, environmental protection, legal services, and transportation; preventing malicious use; addressing biases in data and training sets; mitigating potential job displacement and its psychological effects; confronting growing socio-economic disparities; acknowledging the environmental cost of energy-intensive ML models; navigating the automation of ethical decision making; guarding against moral deskilling; managing dependency on AI systems; and countering AI induced behavioural issues such as addiction, social isolation and loneliness (Green, 2020).

Ethical challenges in AI-enhanced graphic design and creativity

Bias, fairness, and diversity in design: One of the most pressing ethical concerns surrounding the use of Artificial Intelligence in graphic design and digital content creation is algorithmic bias. AI systems, particularly those used for image recognition and content generation, are trained on extensive datasets. If these datasets are not sufficiently diverse, the algorithms may inadvertently perpetuate existing biases, leading to visual representations that lack inclusivity and misrepresent or marginalize certain social and cultural groups (Crawford, 2024). For instance, AI-powered image recognition tools may struggle to accurately identify individuals with darker skin tones due to inadequate representation in training datasets. Similarly, AI models trained predominantly on Western visual styles may neglect non-Western artistic traditions, thus failing to capture the richness of global cultural diversity. This phenomenon raises concerns regarding the fairness and authenticity of AI-generated visual content and the potential reinforcement of stereotypes. Discriminatory or exclusionary design outcomes may harm underrepresented populations and undermine public trust in AI technologies (Eckert, 2023; Passas, 2023; Le-Nguyen, 2024; Minimalist Moon, 2024; Sashidharan, 2024). Designers, therefore, have an ethical responsibility to critically assess and address the potential for bias in their workflows, which includes curating diverse and representative datasets, auditing training inputs, and implementing fairness-oriented design protocols. Promoting inclusivity in AI-assisted design requires a multifaceted approach that emphasizes transparency, accountability, and diversity throughout the development and deployment processes (Eckert, 2023; Passas, 2023; Le-Nguyen, 2024; Minimalist Moon, 2024; Sashidharan, 2024). Human oversight remains essential to detect and correct biased outputs, ensuring that automated systems do not reinforce discriminatory patterns. Preventing the propagation of harmful stereotypes also necessitates ongoing data analysis and algorithmic refinement. There is an ongoing debate surrounding the capacity of AI to either perpetuate or mitigate bias in design. Proponents argue that with adequate oversight, AI systems can identify and correct human biases, serving as tools for fostering inclusivity and cultural sensitivity. Conversely, critics warn that when left unchecked, AI-generated content may reproduce and even amplify prejudices embedded in training data, particularly when designers lack awareness of these ethical challenges or fail to implement appropriate safeguards (Eckert, 2023; Passas, 2023; Le-Nguyen, 2024; Minimalist Moon, 2024; Sashidharan, 2024). Given the increasing use of AI tools in the graphic design industry, it is critical for designers and developers to engage actively with the ethical dimensions of their practice. Establishing clear guidelines and best

practices for identifying and addressing bias is essential for the responsible use of AI in visual communication. Although AI-generated outputs are often perceived as objective, they are ultimately shaped by the datasets on which they are trained and the decisions made by human designers. Recognizing this dynamic is key to creating fair, inclusive, and culturally sensitive visual content (Ok, 2025).

Intellectual property rights: As AI systems increasingly contribute to the creative process, critical questions arise regarding the rightful ownership of AI-generated works and the fair attribution of creative contributions. Ethical frameworks are necessary to navigate these complexities and to safeguard the rights of artists, AI developers, companies, and other stakeholders within the evolving digital ecosystem. The ability of AI to generate designs based on preexisting data introduces additional concerns related to intellectual property rights. If an AI tool produces a logo or artwork that closely resembles an existing piece, it may result in allegations of plagiarism or copyright infringement. Designers and organizations employing AI tools must exercise vigilance to ensure that the outputs are genuinely original and do not infringe upon the rights of other creators (Eckert, 2023; Le-Nguyen, 2024; Minimalist Moon, 2024; Sashidharan, 2024). The development of clear and enforceable guidelines governing the use of AI in design processes is essential to protect the intellectual property rights of all parties involved. Moreover, using copyrighted materials without authorization in training AI systems presents significant legal and ethical risks. Copyright infringement may occur if AI systems are trained using protected content without proper permissions, potentially leading to serious legal consequences. Human oversight remains critical in ensuring AI-generated outputs adhere to copyright laws and ethical standards. The broader implications of AI-generated content extend beyond questions of originality and ownership to concerns about misinformation, manipulation, and brand trust (Eckert, 2023; Le-Nguyen, 2024; Minimalist Moon, 2024; Sashidharan, 2024). In content marketing, for instance, marketers must be particularly mindful of the risks associated with AI-generated material. Proactive regulatory measures and ethical frameworks are crucial to mitigating these hazards, fostering responsible AI use, and establishing enduring trust with audiences (Eckert, 2023; Le-Nguyen, 2024; Minimalist Moon, 2024; Sashidharan, 2024). The debate surrounding copyright and ownership in AI-generated art has become one of the most contentious issues in the creative industry. As AI tools become increasingly capable of producing sophisticated designs, illustrations, and artistic works, the boundary between creator and tool becomes increasingly blurred. This raises fundamental questions about the nature of authorship

and whether AI systems should be recognized as creators in their own right. Addressing these questions is critical to ensuring that intellectual property frameworks remain robust, equitable, and capable of accommodating technological innovation (Ok, 2025).

Environmental impact of AI-generated art: One of the most often overlooked ethical issues in Artificial Intelligence (AI) is its environmental impact. Training and running large AI models require a great deal of computing power and energy, advanced AI systems rely on powerful data processing, typically provided by large data centers that run around the clock. In design-related applications, these systems consume large amounts of electricity to perform the complex calculations needed to train AI models, resulting in a high carbon footprint (Ok, 2025). The environmental impact depends on factors such as the size and complexity of the model, the volume of training data, the efficiency of the hardware, and the energy source used (Ok, 2025). While such tools can increase access to design and boost productivity, their heavy energy use raises concerns about the long-term sustainability of their widespread adoption in creative industries. Thus, responsible and environmentally conscious innovation should be a priority to ensure that the benefits of AI do not come at an unsustainable cost to the planet (Le-Nguyen, 2024; Ok, 2025).

The risk of homogenization in design: Since many AI systems rely on the same datasets and algorithms, which can limit variation and originality in their results, and the more designers adopt AI tools to generate ideas and automate parts of their workflow, there is the concern that design outputs may begin to look increasingly similar. To address this issue, designers must maintain a balance between leveraging AI tools and preserving their own creative input (Clevertize, 2024). By combining AI-generated suggestions with personal creativity, designers can ensure their work stays distinctive and authentic.

Authenticity and plagiarism concerns: To uphold ethical standards in design, designers must use AI-generated assets with care, ensuring respect for copyright and intellectual property rights. Understanding the origin and ownership of AI-generated content is essential to maintain originality and credibility in creative work. Determining whether AI-generated outputs infringe on copyright can be challenging, particularly given the vast scope of training data used to develop these tools. AI systems do not copy specific artworks directly. Instead, they learn patterns, styles, and techniques from existing datasets and apply this knowledge to generate new content (Huang et al., 2023; Crawford, 2024; Ok, 2025). However, this process can lead to outputs that unintentionally resemble protected works too closely, rais-

ing concerns about potential copyright infringement. The use of copyrighted material in training datasets introduces further ethical and legal questions. If an AI tool generates content that closely mirrors a copyrighted work, it is unclear who bears responsibility, AI developers, the designers using the tool, or both. This ambiguity complicates questions of accountability and ownership in AI-assisted creation (Huang et al., 2023; Crawford, 2024; Ok, 2025). Traditional understandings of authorship emphasize the artist's unique vision and direct involvement. However, with AI-generated art, the boundaries of authorship have become less defined. As AI tools become more prevalent in the design industry, it is essential for designers to remain informed about copyright law and adhere to ethical guidelines. This ensures that their work is both legally compliant and ethically responsible, preserving the integrity of the creative process (Huang et al., 2023; Crawford, 2024; Ok, 2025).

Ensuring user privacy and data security: The practice of collecting and analyzing user data to provide personalized experiences and recommendations when integrating AI into design raises important ethical concerns related to user privacy and data protection. Designers and technology leaders share the responsibility of safeguarding personal information by implementing strong data security measures (Passas, 2023; Crawford, 2024). Striking a balance between personalization and privacy is essential. Designers must prioritize user consent, anonymize data wherever possible, and apply encryption techniques to prevent unauthorized access. By upholding high standards of data protection, designers can build trust with users and ensure that their tools respect individual privacy rights (Passas, 2023; Crawford, 2024). Another ethical issue tied to AI in design is the risk of privacy violations and data breaches. AI systems typically require large volumes of user data to create tailored content. Although this enhances user experience, it also raises concerns about how personal information is collected, stored, and used. Supporters of AI in design argue that, with transparent data practices and adherence to privacy regulations, it is possible to use AI effectively without compromising privacy. They stress the need for secure data management and regulatory compliance to protect users (Passas, 2023; Crawford, 2024). Conversely, critics warn that misuse of personal data is a serious risk. They advise caution in relying too heavily on AI and urge designers to remain aware of the ethical implications of working with sensitive information. Ultimately, balancing the advantages of AI with respect for user privacy and data security is crucial for ethical and responsible design practice (Passas, 2023; Crawford, 2024).

Accountability and transparency: AI systems can sometimes produce unexpected or problematic outcomes. When this happens, it can be difficult

to determine who is responsible, especially if the AI's decision-making process is not transparent. Transparency and human oversight are essential for addressing ethical and accountability issues in AI-assisted design. Building trust in AI systems requires clear explanations of how they work and regular reviews of their behavior. Transparency helps prevent harm and ensures that AI-generated content is used responsibly. To support accountability, companies should establish ethical guidelines, perform regular audits, and clearly communicate how AI decisions are made. By following these steps, designers and developers can reduce risks and ensure their AI tools are used in a fair and ethical way (Sashidharan, 2024).

Future trends in AI and graphic design

The growing collaboration between human creativity and intelligent systems marks the future of Artificial Intelligence in graphic design. AI continues to evolve as a powerful tool that enhances design workflows, offering efficiency, personalization, and innovation. As Artificial Intelligence continues to evolve, it is reshaping the future of graphic design by enabling more intelligent, more responsive, and ethically aware creative processes. Emerging trends such as intelligent design assistants, real-time feedback systems, and generative design tools enhance collaboration between humans and machines. AI integration with AR/VR is expanding the boundaries of visual storytelling. Additionally, ethical AI development and sustainability considerations are becoming central to responsible design practices.

Intelligent design assistants – enhancing human-AI collaboration: AI-powered design assistants are expected to become increasingly sophisticated, capable of interpreting project briefs, user preferences, and current design trends to provide tailored, data-driven suggestions. These systems can automate complex tasks such as layout optimization, font selection, and color palette generation, thereby allowing designers to focus on conceptual and creative aspects of their work. Those tools support tasks like image editing and layout suggestions while preserving human control and creative authorship (Sashidharan, 2024; Crawford, 2024).

Personalized and adaptive design: AI technologies enable the creation of personalized and adaptive design experiences based on user behavior and preferences. By analyzing user data, AI can generate custom templates, recommend color schemes, and suggest design elements tailored to individual needs. Specifically tailored applications utilize AI to enhance user engagement through adaptive interface elements, leading to more relevant and efficient design experiences (Sashidharan, 2024).

Integration with augmented and virtual reality (AR/VR): Integrating AI with AR and VR technologies opens new pathways for immersive, interactive design. AI facilitates the creation of realistic and adaptive virtual environments, enabling designers to visualize and refine their work in real-time. AI-based applications assist artists in translating sketches into interactive AR models. Furthermore, AI-driven virtual design spaces support real-time collaboration among distributed teams, revolutionizing traditional design workflows (Sashidharan, 2024; Crawford, 2024).

Real-time feedback and iteration: AI can provide immediate, context-aware feedback, accelerating the design iteration process. Real-time suggestions allow designers to adjust their work on the spot, improving workflow efficiency and design quality. This dynamic feedback loop encourages continuous refinement and higher-quality outcomes (Sashidharan, 2024).

Democratization of design: AI-powered platforms are expanding access to professional-grade design tools for non-experts. By automating complex processes, AI-based tools enable users without formal training to create visually compelling content. This democratization fosters creativity across a wider population, contributing to greater inclusivity in design practices (Sashidharan, 2024).

Conclusions

Integrating Artificial Intelligence into graphic design marks a pivotal transformation in the creative industry, reshaping how visual content is conceived, developed, and delivered. AI has introduced a new paradigm of design thinking, the one that blends computational efficiency with human creativity. By automating routine tasks, offering intelligent design suggestions, and facilitating personalized user experiences, AI has expanded the creative potential of designers while streamlining their workflows. These advancements have empowered professionals to focus on higher-level conceptual work, fostering innovation and enabling faster, more adaptive design processes. However, as AI tools become more embedded in the design ecosystem, it is essential to recognize and address the challenges they pose. Concerns such as the risk of design homogenization, reduced creative autonomy, job displacement, algorithmic bias, and threats to intellectual property highlight the need for critical reflection and ethical responsibility. Designers must ensure that AI complements rather than replaces the human element, preserving creative work's emotional depth, cultural nuance, and originality. This requires maintaining a careful balance between leveraging AI's capabilities and retaining the distinctly human qualities that give design its expressive power. Ethical considerations must be placed at the forefront of AI

integration. Transparent algorithms, fair data practices, inclusivity, privacy protection, and respect for intellectual property are vital for fostering trust in AI-driven design tools. Moreover, the development and use of AI should align with values such as accountability, accessibility, and sustainability. As AI evolves, next-generation systems will increasingly learn from and adapt to their users' individual styles and preferences, allowing for more authentic and expressive outputs. This evolution underscores the importance of keeping designers actively engaged in the creative process as both users and curators of AI-driven systems. The future of graphic design lies not in choosing between human and Artificial Intelligence but in harnessing the strengths of both. A collaborative approach, where human intuition, empathy, and storytelling intersect with AI's speed, scalability, and data analysis, will define the next era of visual communication. As the boundaries between technology and creativity continue to dissolve, designers must cultivate new skill sets, ethical awareness, and a readiness to experiment with emerging tools.

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APPLICATION OF AI DRIVEN SYSTEM FOR ESTIMATION OF ORDERS IN THE PRINTING INDUSTRY

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Abstract

Printing enterprises face growing competition, rapid tech progress, and higher demands for efficiency and quality. In this context, fast and accurate order evaluation is essential for resource optimization, cost reduction, and competitiveness. Traditional methods – manual input, expert judgment, and classic financial models – are labor-intensive, inflexible, and poorly suited to today's diverse technologies.

Intelligent information systems offer significant value by automating data analysis, revealing hidden patterns, and supporting informed decision-making. Their use streamlines production, lowers costs, and boosts financial performance.

Although many printing stages (prepress, color management, quality control) are automated, smart order estimation remains underdeveloped – creating bottlenecks, especially for small and medium print runs.

This article presents the adaptation of the Flex Estimate AI system for the printing industry. Initially designed for IT project evaluation, the system was enhanced with machine learning and data mining to deliver automated, transparent, and accurate order assessment. Its adoption improves planning, optimizes workflows, and strengthens business resilience during digital transformation.

Keywords: *artificial intelligence, optimization, printing, estimates, order management*

Relevance of the problem

Modern printing enterprises operate in a highly competitive environment characterized by rapid technological change and increasing demand for speed, accuracy, and quality. Traditional methods of order evaluation − based on manual input, expert assessments, and static financial indicators − are insufficiently responsive, often resulting in delays and inefficiencies. While automation has advanced in areas such as prepress and ERP systems, the domain of project estimation remains underdeveloped, particularly for small and medium print runs where prompt responses are essential.

This study proposes a scientific framework and system architecture for intelligent order evaluation in the printing industry, integrating machine learning, natural language processing (NLP), and multi-criteria optimization. The developed system − Flex Estimate AI − automates data acquisition, preprocessing, classification, cost prediction, and lead time forecasting, enabling dynamic and scalable estimation workflows.

The research objectives include the critical analysis of existing evaluation methods, investigation of AI algorithms applicable to cost and timing predictions, and the design and implementation of a modular prototype incorporating forecasting, optimization, and dynamic pricing. Empirical validation was conducted using real production data, assessing predictive accuracy and economic efficiency.

Scientific novelty lies in the application of self-learning models and AI-driven analytics to dynamically adapt estimation processes to varying production contexts. The system utilizes regression models for forecasting, classification for order profiling, clustering for production optimization, and NLP for automated analysis of textual specifications.

The proposed solution significantly improves estimation speed and precision, enhancing planning agility and operational efficiency. Flex Estimate AI thus contributes to the broader digital transformation of the printing sector and demonstrates potential for scalability in adjacent domains such as packaging and customized production workflows.

Purpose of the system

Flex Estimate AI is an intelligent information system developed to enhance the speed and accuracy of project estimation through advanced artificial intelligence techniques. Initially designed for IT applications, the system has been adapted for the printing industry, where prompt and precise estimation is essential for maintaining competitiveness. Its modular architecture enables customization to industry-specific operational requirements.

The system automates the acquisition, processing, and evaluation of project data with minimal human intervention. By leveraging AI-driven data analysis, it improves estimation accuracy, minimizes human error, accelerates response times, and supports resource optimization. Key functionalities include:

- Automated extraction and processing of technical and order-specific parameters.
- Predictive modeling (e.g., regression analysis) for lead time and cost estimation.
- Project classification and clustering for effective planning.

- Natural language processing (NLP) to interpret textual specifications.
- Generation of client-ready commercial proposals in real time.

In printing enterprises, the application of Flex Estimate AI enables:
- Significant reduction in quotation preparation time.
- Enhanced estimation accuracy via adaptive AI models.
- Efficient utilization of production resources and reduction of downtime.
- Improved order conversion rates and cost-effective production planning.

The system integrates real-time data on machine availability, material stocks, and current workloads to deliver context-aware estimations. It evaluates technological capabilities − press types, finishing options, inventory levels − to generate feasible, optimized production plans.

Furthermore, the system identifies optimal production slots by analyzing existing and scheduled runs, offering fulfillment strategies based on either cost minimization or lead-time reduction. This supports dynamic capacity allocation and responsive order management.

By transitioning from manual calculation to AI-based estimation, Flex Estimate AI promotes proactive decision-making grounded in data analytics and predictive modeling. It enhances the adaptability and operational efficiency of printing enterprises within rapidly evolving market conditions.

Requirements for system functions

Flex Estimate AI is architected to fulfill stringent computational, functional, and integration requirements for real-time, high-precision order estimation in print manufacturing environments. The system integrates machine learning, optimization theory, and natural language processing (NLP) into a modular, scalable architecture optimized for enterprise interoperability and adaptive performance.

Order data is ingested through standardized APIs connected to CRM, ERP, and WMS systems. Unstructured text inputs are processed using NLP techniques − specifically Named Entity Recognition and semantic parsing– to extract and normalize key production parameters. This preprocessing enables downstream computational modeling without operator input.

The system employs regression models trained on historical operational data to predict lead times and production costs, incorporating variables such as equipment load, task complexity, and process type. Graph-based scheduling algorithms are used to model the production environment as a resource-

constrained network, enabling optimized task sequencing while minimizing idle time and changeover overhead.

Inventory forecasting is handled through time-series analysis, enabling predictive material management and reduction of stock-related delays. Cost estimation combines deterministic calculations for direct inputs and stochastic models for variable overheads, yielding comprehensive order-level financial projections.

Multi-scenario evaluation is performed using Pareto-based multi-objective optimization, supporting cost-time-resource trade-offs. A dynamic pricing engine utilizes supervised learning to generate adaptive quotations based on market factors and operational constraints.

The system supports business logic reconfiguration through a rules engine, ensuring adaptability across print formats without altering the core architecture. Modular services communicate through standardized data formats (JSON, XML, CSV), ensuring seamless integration and deployment across heterogeneous IT infrastructures.

Flex Estimate AI thus formalizes and automates the order evaluation workflow using robust AI-driven methods, achieving higher accuracy, reduced turnaround times, and improved resource utilization in digitally transformed print enterprises.

Overview of analogs

The global market for printing industry information systems includes numerous platforms for automating production, management, and commercial workflows (Kovtunenko, 2019). Leading solutions include Heidelberg Prinect, EFI Pace, Optimus MIS, PrintVis, PressWise, and Accura MIS, each catering to different scales of operations.

Heidelberg Prinect offers deep integration across prepress, press, and postpress with modules for planning, costing, and quality control. Despite high automation, its order evaluation relies on fixed scenarios and rate tables, limiting flexibility for urgent or non-standard jobs (2).

EFI Pace is scalable and suitable for larger operations, supporting comprehensive order and warehouse management. However, it lacks machine learning-based estimation and depends on static tariffs.

Optimus MIS features modularity and flexible production routing, appealing to small and mid-sized print shops. Still, its order estimation often requires manual input and lacks predictive analytics.

PrintVis, built on Microsoft Dynamics 365, excels in enterprise-level financial integration and process control. Yet, it relies on manual flowchart selection for costing without dynamic optimization or forecasting.

PressWise, a cloud MIS/ERP for SMEs, provides essential automation but limited support for adaptive, AI-driven evaluation models.

Accura MIS is designed for entry-level digitalization, offering basic order, CRM, and planning features. However, it lacks intelligent estimation tools, relying on static templates with minimal real-time adaptability.

Thus, the analysis of existing solutions allows us to draw the following conclusions;

- all major MIS/ERP systems are primarily focused on managing production and accounting processes rather than intelligent pre-qualification of new orders;
- assessment processes in existing systems are based mainly on static reference books of norms and tariffs, without the use of predictive analytics, machine learning and intelligent forecasting technologies;
- there is practically no adaptability of order calculation to the current production load and real-time material balances;
- integration with external data sources (online ordering platforms, electronic document management systems) is often limited or requires the development of additional modules;

Against this background, the Flex Estimate AI system offers a fundamentally different approach;

- Using machine learning to build models for predicting the timing and cost of projects based on accumulated data;
- application of clustering and classification of orders for optimal selection of technological routes of production;
- Integration of Natural Language Processing (NLP) technologies for automatic analysis of textual specifications;
- seamless integration via API with existing CRM, ERP and Prepress enterprise systems;
- construction of multi-scenario evaluations (cost minimization, time minimization, resource optimization) in automatic mode.

Flex Estimate AI does not replace full-featured ERP/MIS-systems, but becomes their powerful complement, which closes the most critical task of modern business – rapid, accurate and intelligent assessment of orders in the printing industry.

Review of methods and criteria for assessing the effectiveness of orders

Effective order valuation is a key element of successful planning, resourcing and management decision making in the printing industry. Traditional methods of financial evaluation were developed mainly in the middle

of the 20th century and have since become firmly embedded in the practice of economic analysis.

Let us consider the main methods, their theoretical basis, advantages and limitations in the context of today's dynamic market (Nagorny, P., Baziuk O., 2023).

One of the basic tools is the Net Present Value (NPV) method. It is based on the calculation of the present value of all expected cash flows from an order, taking into account the discount rate. The calculation formula is as follows (1):

$$\sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} - C_0, \quad (1)$$

where CF_t is the cash flow at time t, r is the discount rate, C_0 is the initial investment. A positive NPV value indicates the feasibility of order fulfillment.

The scientific basis of the NPV method includes the time value of money theory, according to which the cost of capital decreases over time due to inflation, risks and opportunity costs. The method is the most accurate among traditional methods, as it takes into account the dynamics of cash flows throughout the life cycle of an order.

However, in the printing industry environment, the NPV method has a number of limitations:

- requires accurate cash flow forecasts, which is difficult with high fluctuations in demand and volatile material prices;
- is of little use for small and short-term orders, where the speed of capital turnover rather than long-term profitability is of primary importance;
- Does not consider multi-criteria factors such as production utilization, lead time or level of technology risk.

Another important indicator is the Internal Rate of Return (IRR) − the discount rate at which the NPV of the order is zero. IRR allows to quickly assess the attractiveness of the order in comparison with alternative investments.

Formally, IRR is solved from equation (2):

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} - C_0 \quad (2)$$

The scientific validity of IRR is based on the concept of maximizing return on capital with minimal risks. However, for real printing orders IRR can give false guidance in case of uneven flows or in orders with several changes of sign of cash flows, which reduces the accuracy of its application.

The third widely used indicator is Profitability Index (PI), calculated as the ratio of the present value of future income to the initial investment (3):

$$PI = \frac{NPR + C_0}{C_0}. \quad (3)$$

PI allows comparing the efficiency of several orders with limited investment resources, but just like NPV, it depends on the quality of forecasts.

Payback Period (PP) is another traditional criterion that determines the time it takes for an order to recover its initial investment. Although simple to calculate, the method ignores cash flows after the payback period and does not take into account the time value of money, which limits its application in strategic planning.

Limitations of traditional methods in a real printing environment

In today's printing industry, each order represents not just a financial transaction, but a complex production task influenced by equipment load, material availability, lead times, and urgency. As demonstrated in recent case studies (Kostaryev D. B., Tevyashev A. D., Sizova N. D., & Tkachenko, 2024), effective production optimization requires far more than calculating direct profitability − it demands real-time insight into machine (Bagan, T. G. 2021) center utilization, available time slots, changeover requirements, and multi-stage technological workflows.

Traditional evaluation methods fall short in handling such complexity. Intelligent systems like Flex Estimate AI address these gaps by applying advanced methods:

- Machine learning models predict lead times and costs using historical data;
- Clustering algorithms group orders by complexity and urgency to enhance planning;
- Integration with ERP, CRM, and prepress systems ensures up-to-date data on materials, capacities, and schedules;
- Natural Language Processing (NLP) extracts key parameters from unstructured specifications automatically.

Flex Estimate AI simulates the production environment as a serial-parallel process, with different operations executed in sequence or simultaneously. Accurate order estimation thus requires analysis of equipment availability, changeover times, process synchronization, and load balancing.

Key efficiency metrics − total order lead time, number of changeovers, and machine downtime − are all driven by the accuracy of the initial evaluation. Consequently, intelligent estimation evolves into a strategic instrument for improving production throughput and profitability.

From a production planning perspective, print orders consist of constrained, interdependent operations. Effective optimization involves:

- Constructing optimal production routes (job-shop scheduling.
- Minimizing setup times and idle intervals.
- Maximizing equipment utilization while meeting deadline requirements.

Given the combination of sequential and parallel processes (e.g., printing, folding, gluing, lamination), techniques like the Critical Path Method (CPM) and graph-based optimization are essential for determining efficient timelines and resource allocation.

Research (Makatiora, 2024) shows that misaligned scheduling increases costs, extends lead times, lowers equipment productivity, and raises the risk of missed deadlines. Since fixed costs accumulate even during downtime, precise initial estimates are critical for operational and financial performance.

Flex Estimate AI incorporates:

- Regression-based time prediction;
- Equipment performance coefficients;
- Shift schedule impact analysis;
- Route optimization for minimal lead time;
- Dynamic reallocation based on real-time conditions.

By integrating machine learning, graph optimization, and NLP, Flex Estimate AI enables intelligent order evaluation that serves as a control point for the entire order lifecycle − from request to fulfillment − transforming it into a core element of strategic production management.

Definition of system functions

In response to the increasing complexity and competitiveness of the printing industry, Flex Estimate AI is proposed as an intelligent information system designed to automate and optimize order evaluation, production planning, and cost management. Its architecture is grounded in advanced methods of artificial intelligence, machine learning, and systems integration.

At the core of the system is the automated collection and interpretation of order data from diverse sources − including CRM, ERP, and prepress platforms − as well as unstructured text, using natural language processing (NLP). This enables efficient extraction of key parameters such as quantity, format, and technological requirements.

Orders are then automatically classified by type, complexity, and volume using machine learning models trained on historical data. This classification informs downstream planning and routing decisions.

The system conducts a comprehensive analysis of production capacity, evaluating equipment specifications, load schedules, and technical constraints through integration with ERP/MIS systems. It applies regression models to forecast lead times based on current workload, equipment availability, and production history.

To optimize execution, graph-based algorithms are employed to minimize setup times, balance machine center utilization, and reduce downtime. Simultaneously, integration with warehouse systems allows for real-time inventory assessment, enabling the system to suggest alternative materials or adjust delivery timelines if shortages are detected.

Cost estimation is handled through adaptive models that factor in direct and indirect costs – materials, energy, labor, depreciation – and adjust to changing internal and market conditions. The system also supports multi-scenario generation, presenting options for minimum cost, minimum lead time, or a balanced strategy to support managerial decision-making.

Dynamic pricing mechanisms further refine quotations by incorporating historical customer data, seasonal pricing strategies, and market trends, ensuring both flexibility and competitiveness.

Flex Estimate AI is designed for seamless integration with existing IT infrastructure via standardized APIs and supports formats such as XML, JSON, and CSV. It includes self-learning capabilities, continually improving estimation accuracy and operational recommendations based on feedback from completed jobs.

Additionally, the system generates all necessary project documentation – from customer proposals to internal production plans – and supports multi-user environments with differentiated access rights.

Finally, a suite of analytical and reporting tools provides insights into forecast accuracy, production efficiency, and cost trends, making Flex Estimate AI not only a tool for operational automation, but also a strategic platform for data-driven decision support in modern printing enterprises.

Selection and justification of toolkits

The development of Flex Estimate AI aimed to deliver a high-accuracy, adaptive, and scalable system for intelligent order estimation and production planning in the printing industry. The architecture integrates machine learning, natural language processing (NLP), and multi-objective optimization within a modular, interoperable framework.

Implemented in Python, the system employs supervised learning models (XGBoost, LightGBM) to predict order costs and lead times using historical production data. Clustering algorithms (e.g., KMeans) support unsupervised grouping of orders by complexity. NLP components, built with spaCy, enable syntactic and semantic extraction from unstructured text inputs.

Production routing is optimized using graph-based algorithms, minimizing changeovers and idle time. Multi-objective optimization resolves trade-offs between cost, time, and resource utilization, generating execution scenarios for managerial decision-making. The system interfaces with CRM, ERP, and prepress environments through RESTful APIs and supports data exchange via standard formats (JSON, XML). PostgreSQL provides robust data storage and transactional processing.

Unlike static rule-based tools, Flex Estimate AI incorporates continuous learning, adjusting predictions based on operational feedback and system changes. This transforms estimation from a manual process into an adaptive, AI-driven decision-support system, enhancing production responsiveness and strategic planning efficiency.

Designing the functional structure of the system

The architecture of Flex Estimate AI is founded on modularity, scalability, and scientific precision in data processing. It is designed as an intelligent system capable of adapting to variable production conditions in the printing industry while maintaining high accuracy in cost and lead time estimation.

The system comprises specialized modules connected in a sequential pipeline. Data from CRM, ERP, and prepress platforms, along with unstructured specifications, is processed by a dedicated acquisition and preprocessing module using NLP and feature extraction for standardization.

Processed inputs are classified via machine learning models to determine order type, complexity, and volume − key factors in scenario selection. Forecasting and costing modules apply regression models trained on historical data, incorporating both direct and indirect production costs, including changeovers and energy consumption.

Execution scenarios are generated through multi-objective optimization, balancing cost, time, and capacity constraints. The dynamic pricing module

integrates operational costs with strategic pricing factors to produce final quotations, while the documentation module compiles internal and client-facing outputs.

Enterprise integration is managed through a unified interface layer, and access control is maintained by a role-based user management system. This architecture ensures coherent, stage-wise data processing and end-to-end analytical consistency.

In sum, Flex Estimate AI applies AI-driven modeling and optimization within a flexible, modular framework, offering a scientifically validated solution for efficient, adaptive order evaluation in print manufacturing.

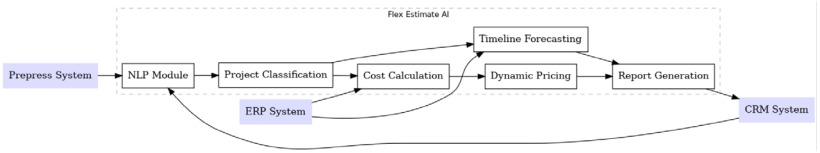


Fig. 1. Modular structure of FlexEstimate system for order evaluation in industry

Development of the technological process of system creation

The development of Flex Estimate AI was grounded in the integration of contemporary methods from machine learning, data engineering, and production optimization. The process adhered to modular design principles, incremental deployment, and systematic validation of intermediate outputs (Kostaryev D. B. Pearson V., Dovgiy, D. V. Tkachenko V. F., & Tevyashev A. D. (2024).

Initial system requirements were defined through a detailed analysis of printing workflows, identifying the limitations of manual estimation and static models. A formal domain model was constructed to represent key entities, process flows, and dependencies in the order evaluation lifecycle. A scalable, modular architecture was established, enabling parallel development of core components. The initial focus was on automated data acquisition and normalization, employing natural language processing (NLP) for structured extraction of parameters from unformatted textual inputs. Data quality assurance was incorporated through rule-based validation.

Classification models – using decision trees and logistic regression – were implemented for order type and complexity detection. Predictive models for lead time and cost estimation employed linear regression, gradient boosting, and ensemble techniques, optimized via cross-validation and parameter

tuning. In parallel, a multi-objective optimization engine was developed to generate production scenarios minimizing cost and time under resource constraints. The system was expanded with dynamic pricing algorithms and automated generation of commercial and internal documentation.

All modules were subjected to unit and integration testing to validate pipeline consistency and analytical coherence. At its current maturity level, Flex Estimate AI provides automated order evaluation with capabilities in data extraction, forecasting, optimization, and pricing. Further work aims at full integration with ERP, CRM, WMS, and prepress systems to support holistic production planning.

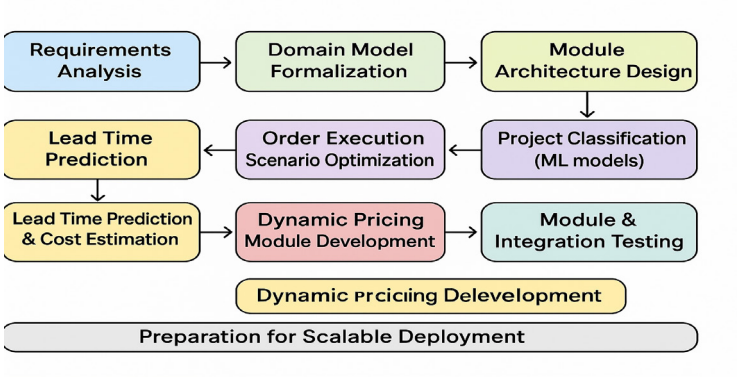
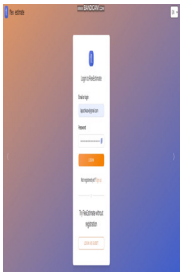
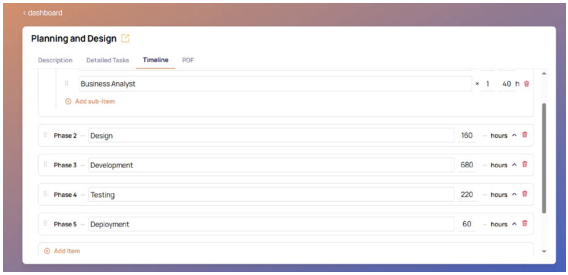


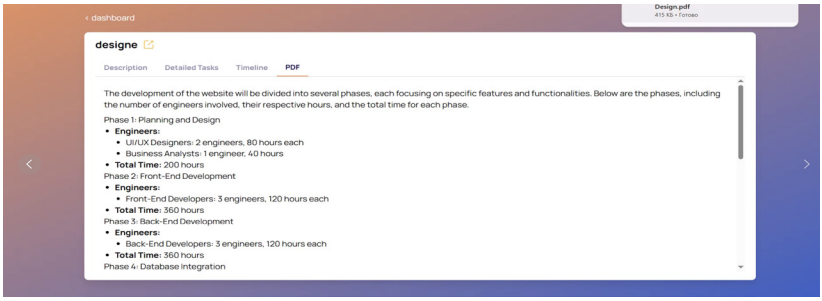
Fig. 2. Schematic of the technological process of creating an intellectual system FlexEstimate

The Flex Estimate AI information system has a specialized user interface (Fig. 3) aimed at automating the processes of data collection, processing and analysis related to the evaluation of printing orders. The interface supports integration with external corporate systems (CRM, ERP), provides automatic extraction of order parameters and predictive modeling of their fulfillment dates based on machine learning algorithms. The system generates alternative scenarios of order fulfillment with the calculation of cost and resource costs, presented in a structured and visually interpretable format. The implemented interface architecture is focused on improving the accuracy of management decisions, reducing the time of order preparation and optimizing production capacity with the possibility of further scaling of functionality.





(a) System login *(b) Evaluation*



(c) Preparation of quotation

Fig. 3. FlexEstimate system interface

System implementation and testing

The implementation of Flex Estimate AI followed an iterative, modular development approach, emphasizing component-level integration and continuous validation to ensure architectural stability and adaptability to real production environments in the printing industry. The initial phase included the development of core modules for data acquisition, text normalization using NLP, and order parameter extraction. These were followed by classification and regression models trained on historical data to predict order type, technological complexity, lead time, and cost. Model robustness was achieved via cross-validation and hyperparameter optimization.

The costing subsystem combined direct and indirect cost modeling using stochastic approaches to reflect variability in materials, labor, and machine operations. A multi-objective optimization engine, based on graph algorithms, was introduced to generate execution scenarios balancing lead time, cost, and resource load. Dynamic pricing algorithms and automated docu-

mentation generation were added alongside API-based integration with ERP and CRM platforms.

System validation involved unit and integration testing. Predictive accuracy was assessed using MAE, RMSE, Accuracy, and F1-score. Results on a test dataset of 2,000 real orders showed high performance: 6.2% MAE in lead time estimation, 8.5% RMSE in cost prediction, 91.7% classification accuracy, and an F1-score of 0.89.

Field implementation demonstrated significant operational gains. In medium-sized offset booklet orders (10,000 units), quote preparation time was reduced by 70%, cost estimate deviation dropped from 10% to 3%, and manager throughput tripled. In a large digital packaging run (50,000 units), preparation time decreased by two-thirds, cost deviation reduced from 15% to 5%, and planning accuracy improved from 75% to 90%, yielding savings of over $1,200 due to improved route optimization and reduced waste.

Overall, Flex Estimate AI outperformed manual estimation across all tested metrics, enhancing speed, accuracy, and resource efficiency. Its intelligent order evaluation and planning capabilities offer substantial economic benefits and scalable impact in production environments.

Conclusions

This study presents the development and validation of Flex Estimate AI, an intelligent information system designed to enhance the speed and precision of order evaluation in the printing industry. The system serves as a foundational component for the digital transformation of production planning and cost estimation processes, addressing the growing demand for operational efficiency, accuracy, and resource optimization in modern print enterprises.

The research confirms the inadequacy of traditional estimation methods based on expert judgment and static models in today's competitive, high-variability production context. In contrast, Flex Estimate AI integrates machine learning, predictive analytics, multi-criteria optimization, and natural language processing to enable automated data acquisition, forecasting of lead times, cost breakdowns, scenario generation, and dynamic pricing responsive to both operational and market conditions.

Experimental evaluation demonstrated the system's effectiveness: average prediction error was under 7%, classification accuracy exceeded 91%, and real-world implementation led to a 62% reduction in quotation preparation time and a 47% increase in managerial throughput.

The scientific contribution lies in the creation of a modular system architecture combining intelligent data processing with predictive and optimization capabilities tailored to the printing domain. Its practical significance is

reflected in measurable improvements in cost accuracy, planning efficiency, and enterprise competitiveness.

Future research directions include real-time production route optimization, dynamic queue control, incorporation of deep learning for improved forecasting accuracy, and extension of the system's application to related sectors such as packaging, promotional printing, and customized product workflows.

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INTEGRATION OF ARTIFICIAL INTELLIGENCE INTO GRAPHIC DESIGN PROCESSES

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Abstract:
Recent years were highlighted by the development of artificial intelligence (AI) technology that has already become part of our everyday lives, although it has brought many debates in society about its usage.
Quite a few resources on the Internet have built-in neural networks that were trained to work on particular types of tasks. It can be used in different areas of our lives for different purposes. Working well on tasks related to calculation, processing, and managing large amounts of data, it can be seen how AI is advancing. Not just in fields that require logical thinking but also in the area that was thought to be a human prerogative—creativity. A visible impact of this technology can currently be seen in graphic design, which future is already hard to imagine without AI integration. Along with rising capabilities in handling creativity-related tasks, it raises questions about its future influence on the design.
AI tools are able to automate the design process, assist with many routine tasks, generate high-resolution illustrations from the text prompt, and design brand identity elements. They are also able to do a lot of other things that change workflow by taking part of work that previously required much time and attention. Being integrated into applications and web resources with intuitive and user-friendly interfaces, the popularity of AI-based tools such as MidJourney, DALL·E, Ideogram, Recraft etc. is rising more and more. These tools are available for everyone, without skill-level limitations, that allow designers, from students to professionals, create high-quality designs with minimal efforts.
In this conference paper were analyzed the main ways and tendencies of using AI in the design process. It examined how designers can benefit from using it while working on their routine tasks and how it helps to enhance workflow, automating processes and increasing efficiency, despite the problem with possible originality limitations.
Keywords: *Artificial Intelligence, design process, design tools, graphic design.*

Introduction

The active development of artificial intelligence technology in recent years has become one of the most discussed topics. Now, the number of fields where this technology can be used is increasing, including the creative sphere. A visible impact is seen in graphic design. The possibility of using AI in creating visual content raises discussions about the role of designers and the future of the sphere, it makes the topic relevant and important to analyse

Along with the growing popularity of AI in design, the question of how it influences the work process and creativity still does not have a clear answer. However, understanding the potential of AI becomes necessary.

The aim of this paper is to analyze how artificial intelligence is used in the graphic design process and how it affects the work of designers. The object of the research is the integration of AI into the design process.

Methodology

Mainly, the research is based on analyzing existing AI design tools and their applications in branding, logo creation, image generation, etc. To investigate the view of the design community on AI-generated content, were analyzed professional platforms such as Medium, Behance, freelance platforms like UpWork and recent studies on the integration of AI in the design process. The analysis also included a comparison of popular AI tools in terms of usability, visual output, and relevance to real design tasks. Examples of practical use were studied through open cases and posts by designers. In addition, academic publications were reviewed to explore how new technologies, including AI, influence the formation of the design process and creative thinking (Bokarieva & Ippolitova, 2022). Special attention was paid to how AI tools are used not only for technical automation but also as a source of visual inspiration and stylistic experimentation. This helped to assess their role not just as instruments, but as co-creators in the modern design workflow (Muji, Svensson, & Faraon, 2023).

Presentation of Research Results

The biggest advantage AI has, is using it as a design tool that helps to handle routine work such as editing, sorting, working on repeated tasks, etc. It effectively saves time, allowing designers to focus on the creative part of projects (Recraft, n.d.). This tendency can be proved with the launch of Adobe Firefly (Autumn 2024), which provides new features to its software by adding built-in generative AI.

Moreover, recently, AI has shown much higher results than just functioning as a tool. Today's developments in generative AI allow creating images

by converting text prompts into mathematical elements, encoding them as random noise, and generating the image, adding details step by step until the image looks clear (Kolisnyk et al., 2023) (Fig.1). Nowadays, its popularity in creating pictures has increased significantly. Its usage can be very different, from brainstorming to generating high-resolution illustrations and brand elements.

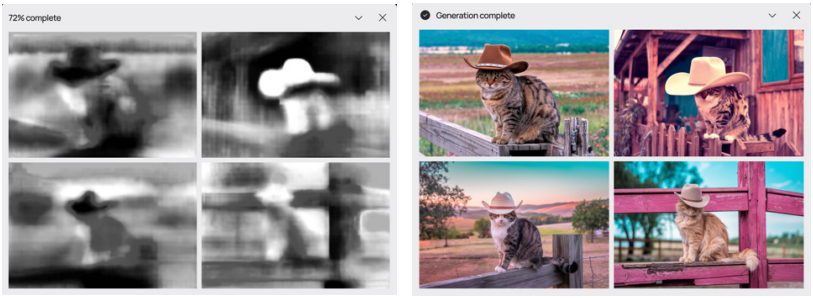

Fig. 1. Example of image generation on the Ideogram.ai web-site

Using its editing skills and ability to recreate human ideas from text can help designers make outstanding projects with fewer resources. For example, the limited-edition release of Nutella Unic in 2017 (Fig. 2), where seven million unique jar patterns were created by a single algorithm to show the uniqueness of Nutella customers (Sobolev, 2017).

Fig. 2. Limited edition Nutella Unic in 2017

Talking about AI usage in graphic design, cannot be skipped its influence on brand design. On resources such as Looka, Fiverr Logo-Maker, Recraft, etc., users can have a few logotypes in seconds after putting in a text prompt and choosing a suitable style (Muji, Svensson, & Faraon, 2023) (Fig. 3).

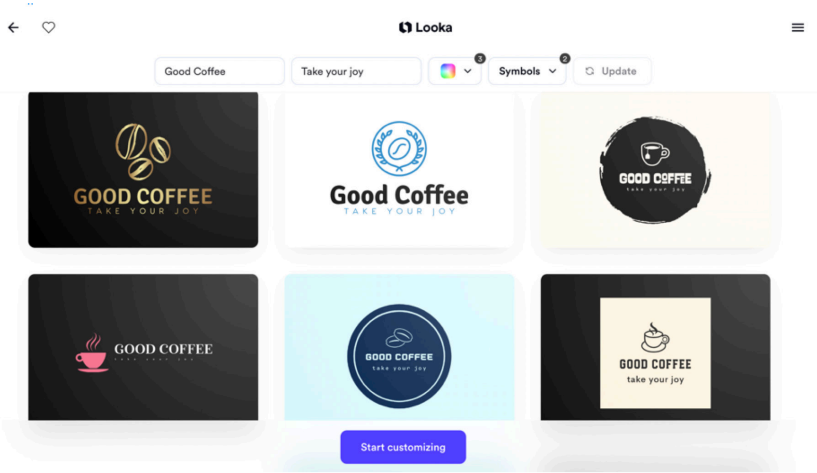

Fig. 3. Example of logo generation on the Looka platform.

It can be used as a good alternative to collaboration that provides an opportunity to look at projects from new angles. Its working speed also can be used for briefing to clarify a client's preferences by quickly adding their remarks (Designveloper, 2024). Furthermore, lately clients show not just examples from other designers that are tasted, but exact ideas that have already been generated on AI platforms and sometimes want designers just to add a few edits. Just a quick look through freelance platforms like UpWork leaves no doubts about it.

But here it appears the main disadvantage of giving AI a main role in the design process. As a mathematical model, AI has limited creativity—it can generate ideas only based on the data it was trained on, but cannot create original ones (Kolisnyk et al., 2023). As a consequence, it is not able to create emotional designs that apply storytelling and brand tone that continue having a value in branding and marketing strategies.

Despite having problems with generating unique ideas, AI algorithms can work with an amount of data that is unreal for humans to handle (Matthews, 2024). This capability helps it generate personalized designs that in-

clude all details and are based on logic, although a person can lose some details or be biased because of feelings, emotions, or previous experience that is not always suitable.

Conclusions

As a consequence, with its own advantages and disadvantages, AI is a very powerful tool that is spreading more and more across different areas, and this fact already can no longer be ignored. Because of this, the most valuable skills to stay relevant in the industry are technical literacy and tool proficiency. In the future, they will be as important in the design process as creativity and original thinking (Recraft, n.d.).

In addition to speed and automation, AI tools are becoming part of the creative process, influencing not only how designers work but also how they think (Bokarieva & Ippolitova, 2022). The question of coexistence between human-made and AI-generated content makes designers reconsider their views on authorship and originality.

Despite existing limitations, such as a lack of emotional expression or uniqueness, AI can still help build effective design strategies, especially in tasks where logic, structure, and speed are prioritized.

Further study is needed to understand how AI will shape visual culture and the professional identity of designers in the long term. However, now it is already clear that the ability to combine creative thinking with confident use of modern tools will be the key to staying competitive.

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KEY DRIVERS OF THE FUTURE EUROPEAN PRINTED PACKAGING MARKET

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Abstract

Europe's packaging sector is transforming—driven by innovation, regulation, and collaboration. The sector continues to grow while undergoing significant change, responding to increasingly complex expectations from regulators, brand owners, and consumers alike. Drawing on recent conference presentations, journal articles and market reports, the authors present detailed the key drivers of the packaging market: sustainability and regulation, the growth of e-commerce, changing consumer attitudes and lifestyles, digitalisation and innovation, advances of printing technology and packaging format innovation.

Keywords: *printed packaging, sustainability, digital printing, consumer attitudes in packaging, packaging innovation*

Introduction

Europe remains a key region for print products globally. Despite this only moderate growth is expected in the overall value of print in Europe to 2029. Packaging is expected to grow alongside more high-value printed products.

The printed packaging industry in Europe is broad and diverse, encompassing a wide range of materials and applications from corrugated boxes and cartons to flexible and rigid plastics, metals, and labels. With an estimated market value of €114.6 billion and a growth rate of 1.9% CAGR, the sector remains a critical component of the European economy, even as demographic trends – such as a projected population decline in Europe - begin to temper long-term regional growth. In 2024, printed corrugated and solid fibre packaging accounted the highest market share in total European printing output, both in terms of value and volume, and this segment is forecast to retain its top position in 2029. On a global scale corrugated and solid fibre packaging also accounts for the largest market share in value, with this trend continuing into 2029.

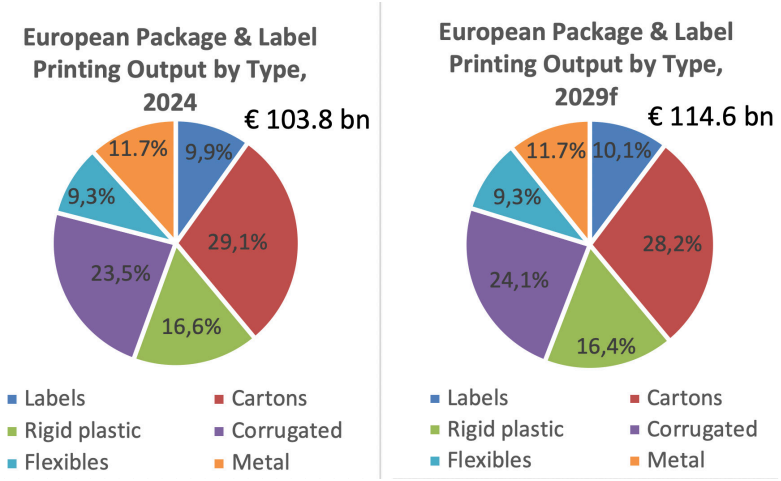
Printed packaging accounts for some 75% of all European packaging but significant differences exist between the packaging segments (Table 1).

Table 1. Europe: Printed vs Unprinted packaging output, 2024 (share by value)

	Packaging segments	Printed	Unprinted
1	Consumer flexible packaging	65.0 %	35,0 %
2	Corrugated packaging	87,5 %	12,5 %
3	Cartons	82,0 %	8.0 %
4	Industrial / Other flexible packaging	85,0 %	15,0 %

Estimates considered for all countries in Europe. (Source: Smithers)

Printed packaging (including labels) is expected to reach €114.6 billion in 2029, growing at a CAGR of 1.9% between 2024-2029 (Figure 1). During the same period, label printing output in Europe is forecast to increase at a CAGR of 2.6% reaching €11.6 billion in 2029. In this area, Western Europe growing at a slower pace than Eastern Europe.



Notes: Countries considered include the EU27 + UK, Norway, and Switzerland. Other packaging includes rigid plastic packaging and metal packaging; flexible packaging comprises plastic film, paper and aluminium foil substrates. Source: Smithers,2025

Fig. 1. European package printing output by type, 2024 &2029 (% share by value, constant 2023 price & € exchange rate basis)

The relative proportions of traditional key packaging printing technologies will not change significantly in the future. However, digital printing technology is developing rapidly and may play a decisive role in the production of smaller series (Table 2).

Table 2. European package printing output by key printing technology, 2024 & 2029f (€ billion, constant 2023 prices & exchange rates)

	Package printing technology	Printing output		Compound annual growth rate (CAGR)
		2024	2029f	
1	Offset lithography	€ 16.7 bn	€ 17.5 bn	0.9 %
2	Rotogravure	€ 8.0 bn	€ 8.5 bn	1.2 %
3	Flexography	€ 44.0 bn	€ 47.2 bn	1.4 %
4	Digital	€ 2.7 bn	€ 5.2 bn	13.9 %

Source: Smithers,2025

European printed packaging key trends and drivers

Based on recent market analyses and publications – when writing this paper – we consider the following six key factors and drivers to be decisive for the development of the European printed packaging market over the next five years.

- Retail changes driving supply chain (growth of e-commerce)
- Sustainability and regulation
- Economic uncertainty
- Consumers attitudes and lifestyles
- Digitalization and innovation
- Advances in print technology

1. Retail changes driving supply chain (growth of e-commerce)

The rise of e-commerce has had a major effect on the retail supply chain and is also a key driver for printed packaging. E-commerce saw major growth in popularity during the Covid-19 pandemic, and although there has been some later adjustment particularly in 2022 with growth rates falling to a more normal level, e-commerce remains a large and growing part of the overall retail business. Global growth is forecast to be 15.3% CAGR between 2017 and 2027, with Asia significantly above this and both North America and Europe a little way behind the global average. The largest e-commerce segments are fashion, electronics and furniture while health and

pharmaceuticals is showing strong growth above the global average. These trends are illustrated on the Figure 2.

The rise of e-commerce is having an ongoing and very positive effect on the volume of packaging materials needed including printed packaging. Transit packaging is widely used to protect goods during transport, and this has driven growth of corrugated and other paper-based packaging materials, much of which is printed. There is also significant growth in the use of void fill and shrink wrap although these materials are largely unprinted.

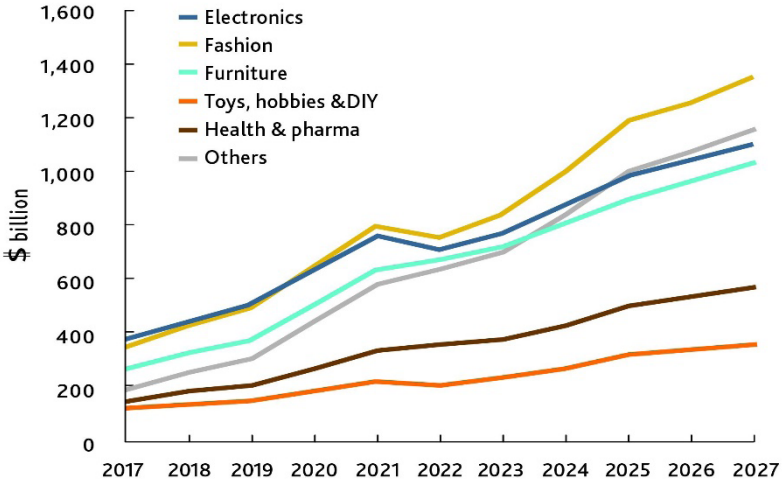


Fig. 2. Global B2C e-commerce growth 2017–2027

2. Sustainability and regulation

The issue of sustainability has been growing in recent years and is now one of the highest-priority concerns of many brands. All the leading consumer brands have well-publicised sustainability policies, and the reduction in packaging waste together with its safe and efficient recycling form a major part of their sustainability goals.

In addition to sustainability initiatives driven by many of the leading brands, government regulation is increasingly focused on improving sustainability, and several regions are introducing legislation that will further reinforce the drive to more sustainable packaging.

2.1. Circular Packaging

The main objective of the circular economy is to keep valuable resources in use and to use them over as many life cycles as possible. This implies a gradual decoupling of economic activity from the consumption of finite (fossil) resources and the diversion of waste out of the system. The transition to a circular economy is not just about adjusting reduce the negative impacts of a linear economy. Rather, it is a fundamental change that builds long-term resilience, creates business and economic opportunities, and delivers both environmental and social benefits (Munroe, 2023).

The Circular Economy Action Plan requires EU countries to ensure that packaging placed on the market complies with the essential requirements of Annex II of the Packaging and Packaging Waste Directive.

2.2. EU Legislations influencing the label & packaging markets

European strategy for plastics in the circular economy

The Plastics Strategy is part of the EU's transition to a more 'circular' economy. Its aim is to improve "the way plastics are currently produced, used and disposed of", as the status quo fails to reap the economic benefits of a more circular approach and is damaging the environment. The strategy calls for all plastic packaging on the EU market to be reusable or recyclable in a cost-effective way by 2030.

The Single-Use Plastics Directive (SUP Directive)

In February 2021, the European Parliament called on the Commission to consider further measures, such as amending the Single-Use Plastics Directive to ensure that single-use plastics are replaced by reusable products wherever possible. The Commission was also called on to develop standards for reusable packaging and the replacement of single-use packaging.

Labelling requirements

Labels and packaging are increasingly subject to legislation, requiring more information and, in some sectors, coding to reduce the possibility of counterfeiting. The legislation extends beyond the pharmaceutical industry to consumer goods. Unique codes and tracking and tracing using a simple phone camera app for authentication are being offered as a method of authentication and as a logistical tool for distribution. Many high-value products can be authenticated, although for high-volume, low-value products, some brands are concerned about potential litigation over counterfeit products.

3. Economic Uncertainly

The world has suffered from a series of global events that have led to major economic shocks, disrupting trade and creating significant inflation-

ary difficulties. The first of these was the Covid-19 pandemic in 2020, but the war in Ukraine that started with Russia's invasion in February 2022 and is still ongoing at the time of writing caused an additional series of problems for world economies. This has been followed by the difficulties in the Middle East that have further disrupted global supply routes and stifled economic recovery.

World events had a direct effect on the printed packaging business. Concern over supply chain fragility that increased during the early days of the Covid-19 pandemic led many brands, copackers and converters to hold higher stocks of raw materials as well as semi-finished and finished packaging, and this led to a significant stock build throughout the supply chain for most packaging types. However, the ongoing global uncertainty compounded by soft consumer demand in 2023 led to widescale de-stocking and a return to more normal inventory levels. This led to a short-term decline in printed packaging volumes with the global value falling by 8.2% and volume by 2.8% in 2023 relative to the previous year. This is a one-off effect, and volumes are forecast to return to more normal growth levels for the last five years of the review period.

Significant uncertainty remains about the economic impact of ongoing world events including the war in Ukraine, global inflation, energy transition and geopolitical tension, and the connected nature of these factors makes forecasting a challenge. The IMF is forecasting global GDP growth of 3.2% in 2024 followed by 3.3% in 2025, with Western economies a little behind this average and emerging markets somewhat ahead. The global economy is still adjusting to the aftershocks of the Covid-19 pandemic, and the war in Ukraine plus increasing tension in the Middle East have added layers of complexity.

The uncertain economic outlook has a clear influence on the market for printed packaging as volumes are closely linked to consumer confidence and economic well-being. However, the printed packaging market is very robust, with much of the volume linked to essential items such as food and beverages, and although packaging for more discretionary items is more exposed, any further economic shocks are unlikely to have a dramatic effect on this sector.

4. Consumers attitudes and lifestyles

Consumers have a negative perception of single-use plastic packaging, which has encouraged the development of alternative materials and packaging. A good example of this is the food sector, where brand owners and retail chains are constantly experimenting with substitutes for single-use plastic

packaging, such as compostable bags, paper bags and cellulose nets. It is expected that the recent trend of replacing single-use plastic packaging with reusable renewable materials will continue (Oliver et all, 2022).

4.1. Consumers are driving the demand for recyclable and compostable packaging

Partly as a response to the media's portrayal of the harmful effects of plastic on the environment, consumers are becoming more aware and passionate about the impact of packaging on the environment. Consumer advocacy is driving action by brand owners and national governments. Many European countries have banned single-use plastic products such as plastic straws, bags, coffee cups and other non-recyclable products. There is also a growing interest in reusable products and efforts are being made to increase recycling in waste collection. European consumers are looking for packaging made from renewable and recyclable materials with recovered or recycled content wherever possible. The need for education on the need and opportunities for sustainability has also been highlighted.

4.2. Consumers do not like oversized packaging

Consumers are becoming increasingly concerned about the use of oversized packaging for home delivery, forcing brand owners and retailers to respond to this demand with improvements.

Consumers expect printed packaging to take this into account. Sustainable printed packaging can go a long way to adding value to the unboxing experience for the consumer.

4.3. Consumers are changing, and they are driving the packaging agenda

Consumers have greater environmental knowledge, and packaging is now a key purchasing differentiator. Convenience is key- consumers are increasingly "Cash rich, time poor" – a trend that is having a huge impact on food packaging. Accelerating urbanization is also generating significant changes in the world of packaging products, supply and recycling systems (Figure 3). Urbanisation related to changes in lifestyles with larger numbers of smaller and single parent households. Urbanisation increases demand for printed packaging.

Growing middle class with higher disposable incomes will be a big driver for packaging over the coming decade.

More than 50% of the world's population now **live in urban areas** — increasingly in highly-dense cities.

Urban areas typically have **higher waste collection rates**, & better recycling infrastructure which drives opportunities for "recycle ready" packaging.

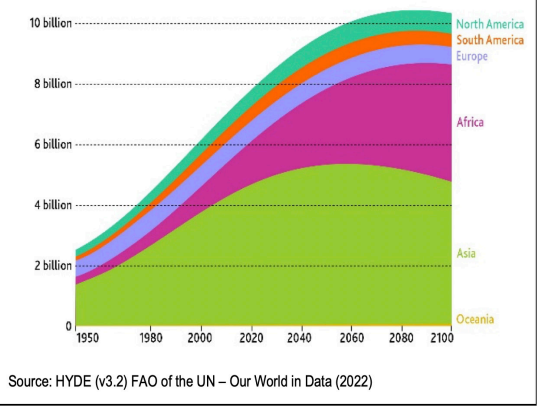


Fig. 3. Effects of accelerating urbanization

5. Digitalization and innovation

One of the most significant impacts of traceable packaging on the global market is blockchain technology, which is likely to continue to evolve in the future.

5.1. Leveraging blockchain technology for traceable packaging

Blockchain technology can be described as a distributed and immutable ledger that records transactions, tracks assets, and provides greater transparency across the supply chain. With blockchain technology, data is stored in time-stamped, tamper-proof, interconnected blocks. When combined with other technologies, such as near field communication (NFC) or internet-enabled devices, blockchain technology allows consumers to access the entire history of a product, which has significant benefits in areas such as anti-counterfeiting and record keeping (Gegeckienė at all, 2022).

Supporters of blockchain technology believe that it offers significant benefits to companies and organizations seeking traceability, anti-counterfeiting, and brand authentication solutions. This solution improves record keeping and, as a result, the efficiency of the supply chain and inventory management. As more and more people have internet-enabled mobile devices such as smartphones, consumers have become much better at quickly and conveniently checking the authenticity of goods or the traceability of the supply chain using QR codes and similar technologies. For consumer

goods such as food, blockchain technology can be a useful tool in combating contamination and threats to consumer safety, while also offering innovation and intellectual property (IP) benefits by making it clearer what information has been produced, when, and by whom.

5.2. Development of smart packaging

There are many recent examples of the use of smart packaging to enhance the value of products.

Accenture has recently partnered with a European luxury brand to create a virtual retail store that consumers can enter by scanning or activating a product's smart packaging. Within the metaverse, consumers can interact with the digital equivalent of the product – information generated during consumer interactions can be recorded and used, for example, in sales and manufacturing.

Pharmaceutical developments in smart packaging include new time-temperature technologies that increase safety and extend the shelf life of certain products, such as vaccines. In May 2022, Essentra Packaging and Advanced Material Development (AMD) announced that they would collaborate on the development of next-generation solutions to improve patient safety in the industry.

During 2021, US and Chinese authorities announced that they would develop advanced food traceability systems to improve food safety through the introduction of smart packaging solutions.

The introduction of smart packaging with tracking capabilities can often improve the competitiveness of companies operating in the logistics sector by providing them with information that helps reduce waste and costs and improve productivity.

Laava is a leading Australian company in the smart packaging market, specializing in product authentication technology. Its portfolio includes Smart Fingerprints, which uses patented optical technology to place unique, randomly generated images on labels and other packaging and is being promoted as an alternative to QR codes. Smart Fingerprints technology has been used on more than two million products and has been introduced in both the food and beverage industries in recent years (‘t Hart, 2023).

5.3. Innovation in packaging formats

There are many noteworthy examples, but the most significant developments at the beginning of the decade were as follows (Lippitsch, 2023)

- Paper postal packages for e-commerce
- Paper bottles in the beverage and household goods sector

- Dry molded cellulose for the food service and pharmaceutical industries

6. Advances in print technology

Print technology is advancing, with digitisation of workflows, increased automation of equipment and the introduction of artificial intelligence driving improvements and opening new opportunities for printed packaging.

6.1. Increased operational efficiency

AI influences the optimisation and efficiency of packaging processes, offering streamlined production throughout the supply chain from sourcing to delivery. In addition, AI is employed through learning algorithms to optimise inventory management, reviewing historical sales data to predict future demand and adjust production volumes accordingly. AI is being increasingly used to drive predictive maintenance requirements of printing, conversion and packaging equipment, optimising production schedules to take predicted downtime for maintenance into account. Computer vision and machine learning are being incorporated into machines with cameras and sensors learning to spot imperfections and defects within set quality assurance parameters.

6.2. AI in packaging design

AI is also widely used for packaging and print design. In design, generative AI is used to create a range of images based on a client's brief, doing so quickly and accurately. There are several image generators available to designers including Open AI Dal-e-2, Midjourney and Stable Diffusion. Software from these companies uses input text to create images, doing so rapidly and accurately. Generative AI is also a feature of professional design software such as Adobe Photoshop which now incorporates Firefly. This is a text-to-image tool and is designed to allow easy manipulation of photographic and other images based on text inputs rather than creating them from scratch.

6.3. Digital printing

Although printing is perceived to be going through difficult times, it is in fact a highly competitive and dynamic business, especially in the packaging sector. There are huge expectations for the development of digital printing, both inkjet and electrophotography. Digital printing is increasingly used to print labels, corrugated, cartons, flexible, rigid, plastic, metal and glass packaging. In 2020, as the global Covid pandemic disrupted all aspects of

human life, digital packaging volumes soared as suppliers were able to respond quickly to changing demands.

Digital printing allows for greater flexibility, helping packaging manufacturers and converters to meet the increasingly tight schedules of their customers. The ability to print variable content enables brands to create new, innovative solutions, delivering higher levels of engagement and new customer experiences that increase brand effectiveness and value (Heidelberger Druckmachinen AG, 2022).

6.4. Market drivers for adoption of digital print for packaging

Among the factors driving the growth of digital printing, the trend towards lower print runs (batch sizes) plays a major role. Differences in set-up costs when producing shorter runs can contribute significantly to variations in cost per print between printing processes. On the other hand, for large print runs, these set-up costs are significantly reduced and the costs of consumables used – ink, coating and other consumables – dominate.

The 'Amazon' effect – The need and expectation for same-day and next-day delivery is widespread, but not typical in the labelling and packaging sector. It is expected that by 2027, many converters will offer on-demand printing and finishing services (Figure 3). This technology will be exploited not only by craft brands, but also by large companies that will be able to move to smaller and more frequent orders with changes to meet consumer demand. Environmental benefits will come from less set-up waste, printing accurate quantities on demand and eliminating minimum order quantities (Guga - Strătilă, 2023).

Fig. 4. Personalized packaging (Hallam, 2023; Smith, 2025)

7. Staying ahead of the trends

The packaging market is changing rapidly. Its shareholders must be aware that their key tasks for successful operation are to monitor market changes and trends, keep up to date with the constantly changing regulatory environment, and assess the specific impacts on their own businesses. In our summary, we have highlighted the key processes that we consider important in the current period and for the coming years, based on our own experience and market information, drawing on the market reports and publications referred to in our article. Due to the limited length of our article, we were unable to cover all factors. Accordingly, our analysis should be interpreted as our own subjective assessment.

In compiling this paper, we considered the following market analyses: IMARC, 2023; Mordor Intelligence, 2023, Smithers Research 2023 and 2025.

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