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APPLICATION OF COMPUTER DESIGN SYSTEMS (CAD) IN THE DEVELOPMENT OF INNOVATIVE PRINTING EQUIPMENT: SYNTHESIS OF FUNCTIONALITY AND DESIGN

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ЗАСТОСУВАННЯ СИСТЕМ АВТОМАТИЧНОГО ПРОЄКТУВАННЯ (САПР) У РОЗРОБЦІ ІННОВАЦІЙНОГО ПОЛІГРАФІЧНОГО ОБЛАДНАННЯ: СИНТЕЗ ФУНКЦІОНАЛЬНОСТІ ТА ДИЗАЙНУ

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The article presents a comprehensive study and development of scientific and practical approaches to the integration of computer-aided design (CAD) systems into the processes of creating innovative types and series of printing equipment, considering the synthesis of functionality and aesthetic design, which contributes to the improvement of the constructive and aesthetic parameters of printing systems. It was found that modern concepts of industrial design, which underlie the design of printing equipment, provide for a detailed analysis of human-machine interaction aimed at optimising the form, functionality and visual design of devices. The role of CAD as a key tool that not only improves the technological characteristics of printing systems, but also significantly reduces development time due to the capabilities of digital modelling and optimisation of structures, is studied. The advantages of using digital technologies that replace traditional drawing and modelling methods, simplifying the creation of technical documentation and making changes to constructive parameters, are assessed. It is substantiated that the automated generation of three-dimensional visualisations in CAD provides the design of the structure of printing systems considering materials, mechanical properties and ergonomic characteristics, allowing to simulate real operating conditions and conduct preliminary tests without the need to create physical prototypes. Approaches to the integration of CAD into specialised areas, such as computer-aided industrial design (CAID), conceptual design (CACD) and process design (CAPP), have been developed, which contribute to the optimisation of modelling and the identification of design flaws at an early stage. Ways to modernise existing CAD systems have been proposed to increase their flexibility in the development of innovative designs, taking into account the needs of the printing industry. It has been found that, despite a significant reduction in time and financial costs due to CAD, technological barriers remain associated with the lack of adaptability of software to the creation of complex mechanical systems, which requires further research.

Keywords: *computer-aided design systems, printing equipment, digital modelling, innovative printing technologies, industrial design, design optimisation.*

Introduction. In the process of developing and improving innovative printing equipment, the use of prototypes plays a crucial role in training, testing, and optimising engineering and design solutions. Prototypes can be both physical and digital, allowing for the evaluation of technical characteristics, functionality, and ergonomics of the product at different stages of development. The definition of a prototype may vary depending on the research context; however, its core essence lies in creating models with different levels of detail, enabling researchers and engineers to analyse, modify, and improve design solutions during the iterative development process. The use of prototypes contributes to the effective study of not only the problem space that arises during development but also the identification of optimal solutions to technical and structural challenges. Modern prototyping methods include a wide range of technologies, from traditional manual modelling and sketching to digital prototyping using 3D printing and computer modelling.

Within the framework of this study, special attention is paid to the use of Computer-Aided Design (CAD) systems as a key tool for creating and visualising 3D models that act as digital prototypes of printing machines. The use of CAD in the design of printing equipment not only speeds up the development process but also reduces costs associated with the creation of physical mock-ups thanks to the ability to conduct detailed analysis of design solutions in a digital environment. An important aspect is that CAD systems make it possible to test future equipment already at the stage of virtual modelling, which allows for the detection of potential structural flaws and the implementation of necessary adjustments without significant material costs. CAD software suites also play a significant role in the implementation of the so-called "conceptual CAD", which involves the active use of digital modelling at the early stages of development, prior to detailed technical design [16]. Research confirms that the use of CAD as a method of prototyping in the early stages of design and engineering enhances the accuracy of predicted characteristics of future products and simplifies their further implementation in production.

The aim of this article is to conduct a comprehensive study and develop scientific and practical approaches to the use of CAD in the development processes of innovative types and series of printing equipment, taking into account the synthesis of functionality and design, which contributes to the improvement of aesthetic and structural parameters.

Presentation of the main research material. The modern process of designing innovative printing equipment is based on the concepts of industrial design, which involves a comprehensive study of printing devices in the context of human–machine interaction with the aim of identifying optimal solutions regarding their form, functionality, and aesthetic design. The integration of CAD in the defined process plays a crucial role, as it enables not only the improvement of the technological parameters of printing systems, but also significantly shortens the development time through digital modelling and structural optimisation.

The use of CAD in the process of developing innovative printing equipment is a modern achievement that has created technological opportunities to integrate advanced digital modelling technologies and structural optimisation solutions to improve the quality, functionality, and aesthetic aspect of printing machines. Modern software suites for automated design are characterised by high performance, powerful computational capabilities, and the ability to process complex graphic models, which significantly shortens the development cycle of new products. As noted in [12], the implementation of CAD in the printing industry is reflected in the use of digital tools that replace traditional methods of drawing, sketching, and modelling, significantly simplifying the process of creating technical documentation and introducing changes to the design parameters of products (Figure 1).

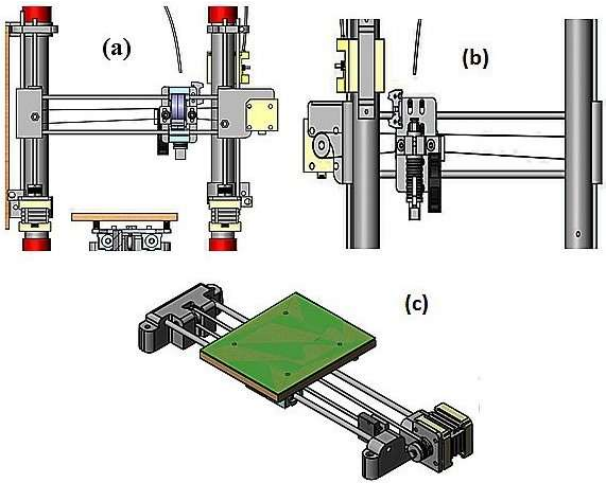

Fig. 1. Using CAD to model parts and components of a printing machine [14]

Thanks to this, digital technologies make it possible to carry out detailed design of printing system structures, determine optimal technical characteristics, and analyse the functional capabilities of future printing machines even at the modelling stage.

One of the key advantages of CAD in the development of printing equipment is the ability to automatically generate visualisations, which allows the creation of three-dimensional images of structures based on specified parameters, including materials, mechanical properties, and ergonomic characteristics. In this way, it is possible to simulate real operating conditions of printing equipment and conduct preliminary testing without expending resources on the production of physical samples [2]. These issues become important for further development of innovative solutions, where the combination of functionality and aesthetics plays a crucial role in creating competitive products. Modern information technologies, especially those related to automated design, have become an integral part of the process of creating new products, as they not only simplify the development stages but

also contribute to shortening the production cycle and improving engineering accuracy [1].

Today, CAD is widely used in all stages of engineering design, particularly in specialised areas such as CAID, CACD, and CAPP. The implementation of these systems creates opportunities for manufacturers of printing machines to optimise modelling processes, identify potential design flaws, and integrate innovative solutions already at the design planning stage (Figure 2).

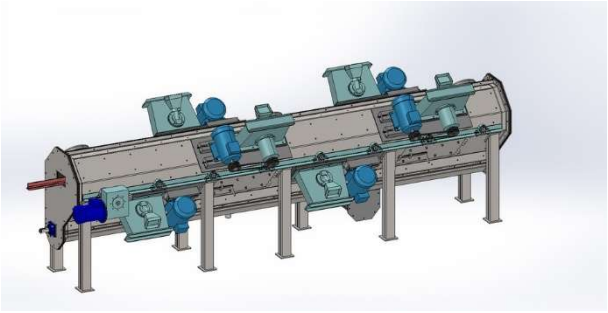

Fig. 2. Localisation and search for design flaws in the design of printing machines [15]

However, the main issue that remains relevant both in the industrial environment and in academic research is the need to adapt traditional CAD systems to ensure flexibility in the development of innovative designs for printing equipment. Therefore, the question of how to modernise existing software platforms in accordance with industry needs remains one of the key areas for further research.

Although the use of automated design has significantly reduced the time and financial costs involved in developing new printing devices, certain technological barriers still exist that limit the possibilities for a complete transition to digital design. One of the main problems lies in the fact that a considerable number of designers and engineers continue to work with highly specialised software products, which do not always provide the necessary flexibility for creating complex mechanical systems. This is particularly relevant during the stage of three-dimensional modelling, where it is necessary not only to build a geometrically accurate model of the printing mechanism but also to take into account all its operational characteristics, ergonomics, ease of maintenance, and visual appeal [9]. Although modern CAD packages for engineering modelling offer powerful tools for creating complex models, the development process remains rather labour-intensive and requires significant calculations and analytical work (Figure 3).

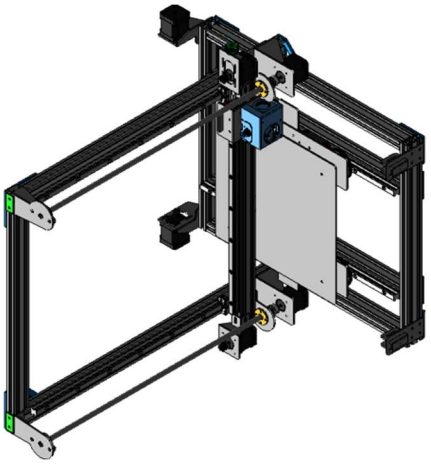

Fig. 3. CAD design of geometric correction of a separate printing mechanism [14]

However, in the case of printing equipment, there arises the need not only for high-quality visualisation but also for precise calculations of all structural features, which requires the integration of CAD with other technologies for graphic data processing. The use of specialised software may be useful for image correction and improving visual perception, but for engineering modelling, it is necessary to apply specialised tools that ensure full compliance between the digital prototype and its physical analogue.

In the process of developing innovative printing equipment, special attention is paid to analysing user needs, which allows a better understanding of the potential benefits that new technological solutions may provide in terms of functionality and design. As noted in [4], before starting industrial design development, it is necessary to conduct a comprehensive analysis of the positioning of the future product, which includes the use of modern digital tools, particularly big data processing technologies. The integration of big data management algorithms into the development process of printing equipment allows for systematising market information, analysing consumer feedback on the functional characteristics of printing devices, and, based on this, optimising engineering solutions to ensure their compliance with modern requirements (Figure 4).

Such an approach contributes to the effective generalisation of the obtained data, the formulation of strategies for further structural improvement, and the creation of innovative solutions that align with market trends. In the context of rapid technological development and increasing competition in the printing industry, the application of big data analytics is essential for forming competitive advantages that facilitate the development of new

high-tech products with improved characteristics [10].

Fig. 4. An example of innovative CAD design of printing equipment [13]

The intellectualisation of the printing equipment design process largely depends on the use of advanced methods of computer-aided design (CAD), which allow for increased personalisation and flexibility in the design and functional content of devices. As noted in [7], modern industrial design is gradually evolving from a traditional approach focused solely on functionality to an intelligent design model that considers user needs and integrates them into the development process. Thanks to digital technologies, there is a gradual transformation of industrial design in printing equipment, allowing companies to create products with improved technical characteristics that better meet customer expectations. An important factor influencing the development of this direction is the widespread adoption of internet technologies and digital platforms, which not only improve interaction between manufacturers and consumers but also contribute to the development of more effective project management systems in the field of automated design (Figure 5).

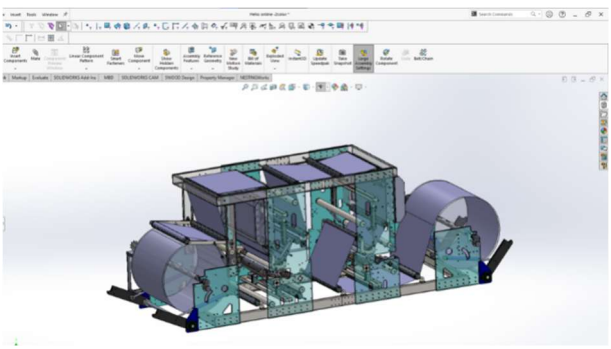

Fig. 5. Industrial design of a roll-to-roll printing machine [13]

Computer technologies play a crucial role in modernising the process of creating innovative printing equipment, as they significantly simplify operations related to graphic data processing, structural modelling, and testing of technical parameters. As noted in [8], the use of automated systems in design allows for the acceleration of structural variant analysis, the introduction of necessary adjustments to product parameters, and a comprehensive comparison of technical characteristics, which contributes to determining the optimal solution. One of the key advantages of CAD is the ability to store digital data on designs and graphic images in a unified system, ensuring quick access to necessary information and simplifying the decision-making process. Compared to traditional drawing methods, which required significant time and resources, the use of CAD allows for much faster and more efficient design processes, as well as simplifying the implementation of changes and the execution of operations such as copying, scaling, transformation, and mirroring of models (Figure 6).

Fig. 6. Design concept of a printing press (book printing) [13]

Modern automated design technologies are becoming the foundation for the implementation of innovative solutions in the production of printing equipment, combining data processing, digital modelling, numerical control, and rapid prototyping. As noted in [6], the development of automated industrial systems enables the integration of virtual design with manufacturing processes, contributing to the creation of more efficient and high-tech printing machines [11].

Flexographic printing machines and automated design. Flexographic printing, or flexo for short, is one of the most dynamically developing and technologically flexible methods of printing production, widely used for the creation of packaging products in large print runs. Due to the ability to work with a wide range of materials, including paper, plastic, foil, and cardboard, this technology is indispensable for the production of

labels, packaging, and specialised printed products. The use of CAD in the design process of flexographic machines allows engineers to automate the development of structural elements, perform accurate calculations of printing parameters, and optimise equipment settings to achieve maximum production efficiency (Figure 7).

Fig. 7. Modern design of a flexographic printing press [5]

The use of CAD enables the creation of virtual prototypes of flexographic devices, testing their performance under different operating conditions, and adjusting design features before the stage of producing physical samples. Thanks to digital control and the integration of sensor technologies, modern flexographic printing machines are equipped with high-precision colour registration control systems, which help reduce errors and ensure high print quality even on complex substrates [4].

Gravure printing machines and their optimisation through digital technologies. Gravure printing, also known as rotogravure, is one of the oldest yet most precise printing methods, used for producing materials with detailed graphic elements and a high level of colour saturation. The use of modern algorithms in CAD significantly reduces the time required for the development of gravure printing cylinders, which were previously made manually or through complex mechanical processes (Figure 8).

Thanks to digital technologies, it is possible to automate the process of laser engraving of cylinders, which ensures more precise control over the shape and size of printing cells. The use of specialised software also allows simulation of the printing process, considering parameters such as ink viscosity, cylinder rotation speed, and the interaction between the substrate and the printing drum. The implementation of CAD in the design of gravure printing machines enables the creation of high-performance equipment with enhanced automation and quality control capabilities [2].

Fig. 8. Updated design of the gravure printing machine [5]

Digital printing has become one of the most promising technologies in the field of printing, as it allows for high-precision printing without the need for traditional printing plates. The use of digital printing machines enables quick adjustment of the production process, reduction of prepress costs, and the ability to produce personalised products even in small print runs. The use of CAD in the design of digital printing devices allows the creation of efficient ink supply control systems, colour reproduction regulation, and print parameter settings, ensuring consistent image quality regardless of the type of substrate (Figure 9) [16].

Fig. 9. 3D design model of a digital printing system [5]

However, traditional computer-aided design (CAD) systems still have certain limitations, including insufficient levels of intellectualisation, instability in theoretical foundations, and low flexibility in implementing innovative design concepts. Therefore, current research is focused on improving CAD through the integration of big data management algorithms, which significantly enhance design quality and the adaptability of products to market needs. Computerised design management systems in printing equipment not only improve development efficiency but also enhance communication between designers,

engineers, and clients, enabling quicker responses to changing product requirements and the development of optimal solutions [12].

The use of big data management technologies in combination with automated design opens new possibilities for the development of the printing industry, providing greater flexibility, accuracy, and personalisation in the creation of printing systems. Cooperation between CAD systems and big data processing technologies significantly reduces development times while ensuring product adaptation to modern demands. The use of integrated solutions such as CAID creates an effective feedback mechanism between manufacturers and the market, allowing rapid consideration of customer preferences and the modernisation of designs in response to changes in demand [4].

Software for automated design processes in the printing industry is a complex engineering tool that enables analysis, identification of potential weaknesses in technical solutions, and the implementation of innovative approaches to increase the efficiency of printing machines. The work process with automated design systems is divided into several stages, each requiring detailed analysis of previous results to identify design flaws and possible ways to eliminate them. After this analysis, modern technological solutions are integrated into the design, which provide high equipment productivity, improved print quality, and increased operational reliability of printing machines. The use of CAD in the design process not only accelerates development but also allows the creation of virtual prototypes, their verification, and evaluation, which significantly reduces the likelihood of errors even at the construction stage. Thanks to automated design methods, which are actively used in intelligent manufacturing environments, new printing device designs are being developed that take into account current requirements for design and technological parameters [11].

As demonstrated in Figure 10, various design drawings are created during the use of CAD, including those for arbitrary surfaces and complex composite structures. These technological capabilities allow engineers to develop high-precision models of future printing machines that comply with strict quality standards.

The complexity of geometric drawings created using CAD highlights the effectiveness of these digital tools and their ability to generate detailed visualisations that reflect all the structural features of future devices. Furthermore, the analysis of the production environment under conditions of automated design indicates the need to implement collaborative technologies, which allow designers, engineers, and end-users to be integrated into a unified development process [3]. The introduction of intelligent algorithms in combination with automation systems enables the creation of high-tech printing machines that meet modern market demands. Trends in the development of CAD in the printing industry demonstrate that the future of printing production depends on innovative approaches to synthesising functionality and design, which will allow companies to adapt to changing consumer needs and expand printing capabilities in the digital era.

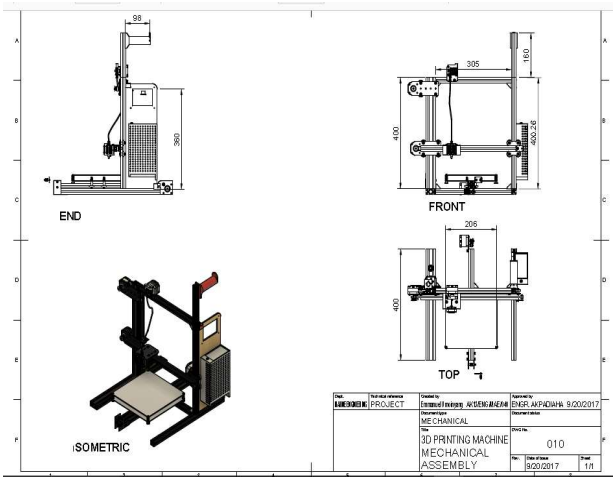

Fig. 10. Geometric visualisation of the appearance of a printing press CD [3]

Conclusion. The possibility of implementing digital technologies in the development of printing equipment has been studied, in particular through the use of computer modelling, analysis of the mechanical properties of structures, automated visualisation of technical solutions, and optimisation of printing mechanisms. The feasibility of using integrated software solutions for automated design of printing equipment has been substantiated, which enables improvement of modelling, visualisation, and simulation processes of printing mechanisms. It has been noted that the integration of algorithms for working with big data into the design process facilitates the analysis of market trends, forecasting changes in technological processes, and prompt adjustment of design parameters in accordance with consumer needs.

A conceptual model for the integration of CAD systems into the development processes of flexographic, gravure, and digital printing equipment has been developed. The model

envisages the use of virtual modelling, automated analysis of the mechanical properties of structures, intelligent control of technological processes, and an increased level of production automation.

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Зенкін М.А., Іванко А.І., Мялковський В.Ю. Застосування систем автоматичного проєктування (САПР) у розробці інноваційного поліграфічного обладнання: синтез функціональності та дизайну

У статті проведено комплексне дослідження та обґрунтування науково-практичних підходів до інтеграції систем автоматизованого проєктування (САПР) у процеси створення інноваційних видів і серій поліграфічного обладнання, враховуючи синтез функціональності та естетичного дизайну, що сприяє вдосконаленню конструктивних і естетичних параметрів друкарських систем. Виявлено, що сучасні концепції промислового дизайну, які лежать в основі проєктування поліграфічного обладнання, передбачають детальний аналіз взаємодії людини з машиною, спрямований на оптимізацію форми, функціональності та візуального оформлення пристроїв. Досліджено роль САПР як ключового інструменту, який не лише підвищує технологічні характеристики друкарських систем, але й суттєво скорочує час розробки завдяки можливостям цифрового моделювання та оптимізації конструкцій. Оцінено переваги використання цифрових технологій, які замінюють традиційні методи креслення та моделювання, спрощуючи створення технічної документації та внесення змін до конструктивних параметрів. Обґрунтовано, що автоматизована генерація тривимірних візуалізацій у САПР забезпечує проєктування структури поліграфічних систем із врахуванням матеріалів, механічних властивостей та ергономічних характеристик, дозволяючи імітувати реальні умови експлуатації та проводити попередні тести без необхідності створення фізичних прототипів. Розроблено підходи до інтеграції САПР у спеціалізовані сфери, такі як автоматизоване промислове проєктування (CAID), концептуальне проєктування (CACD) та проєктування процесів (CAPP), що сприяють оптимізації моделювання та виявленню конструктивних недоліків на ранніх етапах. Запропоновано шляхи модернізації існуючих САПР-систем для підвищення їхньої гнучкості у розробці інноваційних конструкцій, враховуючи потреби поліграфічної галузі. Виявлено, що, попри значне зменшення часових і фінансових витрат завдяки САПР, залишаються технологічні бар'єри, пов'язані з недостатньою адаптивністю програмного забезпечення до створення складних механічних систем, що потребує подальших досліджень.

Ключові слова: *системи автоматизованого проєктування, поліграфічне обладнання, цифрове моделювання, інноваційні технології друку, промисловий дизайн, оптимізація конструкцій.*

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