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TRENDS AND THE FUTURE OF COMPUTERIZED PRINTING SYSTEMS: A FORECAST OF TECHNOLOGY DEVELOPMENT AND ITS APPLICATION IN PRINTING PRODUCTION

The object of research is computerized polygraphic systems, their technologies, current development trends and prospects for application in modern polygraphic production. The study solves the problem of determining current trends in the field of computerized printing systems, as well as developing forecasts for their future, taking into account modern technological innovations and the possibility of their application in printing. It was determined that the modern world is experiencing rapid technological changes. The integration of computer technologies in various branches of production not only optimizes processes, but also opens up new opportunities for development and innovation. The results were obtained: it was found that computerized polygraphic systems are becoming more and more widespread, providing the opportunity to improve product quality, reduce production costs and increase productivity. It has been proven that modern printing technologies demonstrate an impressive dynamic of progress, taking place in the context of intensive development of information and communication industries. The printing industry adapts quickly, assimilating modern technological advances and immediately implementing them into the production process. It has been confirmed that computer printing systems are actively developing, responding to the increase in market requirements and contributing to the improvement of print quality. Today's technologies, including 3D and 4D printing, digital stencil technology, laser engraving and central print management system (CPMS), are already integrated into the printing industry, providing automation, precision and efficiency. The obtained research results make it possible to ensure the industrial production of more individual, multifunctional and flexible products, expanding the horizons for printing companies. Forecasting the development of technologies and their application in printing production allows companies to always be one step ahead of competitors, rationally invest in innovation and effectively respond to changing market conditions. Given the globalization of the market and the growing demands for the quality of printing products, the ability to anticipate future trends and adapt to them is becoming a key success factor for manufacturers.

Keywords: *printing equipment, computerized printing systems, digital screen printer, 3D and 4D printing systems.*

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1. Introduction

Technological progress is important for various sectors of the national economy and at the enterprise level as well. Enterprises working in the printing industry today use various technological and software-computer solutions to increase the efficiency of production activities. Modern trends in the field of computer technologies and network solutions bring significant results to the work of printing industries. In recent years, the main task of printing publishing houses was to solve purely technical production problems. Now, the time limit and the complication of production conditions, increasing customer requirements and the development of Internet technologies make the rational organization of printing processes and operational control over all technological operations according to many criteria a key issue [1].

In today's world, technology is developing rapidly, which requires constant updating of equipment and approaches in various industries. The printing industry is no exception. Modern computerized polygraphic systems offer many new opportunities, but their effective implementation and application requires a detailed study of development trends and adequate forecasting of the future. To analyze the existing trends in the development of computerized printing systems, to make a forecast of their further development and to determine the possibilities of applying innovations in practical printing production.

The printing industry is of great benefit to the economy and plays an important role in the development of the country's technological level, social development, and the use of computer technology and software [2]. New technologies contribute to the rapid dissemination of information throughout the world [3]. Modern printing companies have to find and provide different printing techniques according to customer requirements. The printing industry requires an increase in production productivity, which requires the introduction of innovative printing systems of computer, technological and software support, the introduction of various new printing techniques [4]. Thus, the study of trends in the development of computerized printing systems is relevant, as it helps to understand the current and future directions of the industry, which, in turn, can be useful for making strategic decisions at the level of printing enterprises and industry associations.

The aim of the research is to study the current trends in the development of computerized printing systems, as well as to formulate forecasts regarding the future of these systems in the context of the latest technologies and their potential application in printing production. For this, it is necessary to perform the following tasks:

– analysis of the current state of computerized polygraphic systems and determination of the main trends in their development;
– research on the influence of new technologies on the quality and productivity of printing production;
– forecasting potential changes and innovations in computerized polygraphic systems in the medium and long term;
– assessment of the possibilities of using advanced technologies in printing production to improve the quality of products and optimize production processes.

2. Materials and Methods

The research methodology is based on the concept of optimizing technological flows in the field of computer technology and software, which are in the center of attention of those who work in the printing industry, the main reasons being the evolution of the structure of demand for printing. Methods are used that allow the use of new materials and technologies with modern, efficient equipment to obtain products with high technical qualities. A method of influence that determines efficiency in printing production from the introduction of digital printing technologies adapted to equipment of modular design. To this end, the analysis carried out to assess the consequences of measures to optimize production processes in the printing industry can provide relevant information without affecting the current production of the company or creating costs through the modification of production lines. The efficiency analysis was applied to the four most common structures of technological flows in companies in the field of polygraphic printing.

Change management method. In the context of globalization and intensive technological changes, the printing industry is undergoing a number of significant changes. From traditional printing methods to modern computerized printing systems, the transition was not only a reflection of technological progress, but also a response to the growing needs of the market. Each stage of the development of this industry is characterized by new opportunities, challenges and prospects that require deep understanding and analysis.

A method of comparison, within which the methods of solving technological problems in the printing industry are, determined due to the introduction of computerized control systems for printing preparation and printing itself. The largest manufacturers and installers of such systems in the world are the following companies: Agfa Apogee Prepress, Fujifilm XMF, Heidelberg Prinect, Kodak Prinergy, Screen TrueFlow. Many more computerized printing functions are offered by Dalim Twist and Esko ArtWork [5]. As a rule, computer printing and publishing systems are quite expensive. But their introduction into production gives many advantages to the enterprise [6]:

– standardization and unification of production processes;
– high speed of execution of basic routine operations of collection, systematization, transfer and processing of materials;
– flexibility of changing the production process and equalizing the terms of delivery of the finished material;
– building a system of parallel work on the publication;
– continuous operational monitoring of the execution progress;
– accumulation of statistical information for evaluating the work of employees and analyzing the use of materials.

3. Results and Discussion

Let's explore the leading and promising ones computerized printing systems and technological solutions.

3.1. 3D and 4D printing systems. 3D printing technology was invented in the late 1980s, which became popularly known as «additive manufacturing» or «rapid manufacturing». Three-dimensional printing quickly attracted attention and became a new production technology, including printing. From the point of view of computer software, 3D printing has a control software product, software characteristics, short time of the programming and output process, low cost, ease of driver and software configuration, and available printing material. 3D printing provides highly effective software support for platforms for designers, printing complex engineering, construction and molded structures [7].

Conventional 3D printing technology is used to print static structures from commercial single or large filaments that have no use in dynamic engineering structures. But 3D printing itself does not have soft grips, self-assembling spatial antennas; it does not use self-healing polygraphic polymers. To solve this problem, the term «4D printing» appeared. A similar name to 3D printing, 4D printing adds a fourth time coordinate in addition to traditional 3D printing.

4D computer printing, although it resembles standard 3D, where the object is created layer by layer, has its own peculiarity. The main difference is revealed after the printing is finished, when the object begins to transform. These changes are determined by the material, which can react to water, heat, light, mechanical influences or even be preconfigured for specific reactions [8]. Thus, 4D printing can be thought of as enabling the printed structure to change its shape or function over time under the influence of external stimuli such as temperature, ultraviolet (UV) rays, pressure or magnetic energy, etc.

Computer-aided 3D printing technology is known as additive manufacturing, which is used to produce products in successive layers. 3D printing is mainly classified into solid, liquid and energy based method based on the input material. There are now almost 100 different affordable 3D and 4D

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printers available on the market that are small and affordable, desktop 3D printers respectively (Fig. 1).

The polygraphic 4D printing system is designed for light-sensitive teeth that adjust their stiffness depending on environmental changes, for painless and easy-to-use functions (Fig. 2).

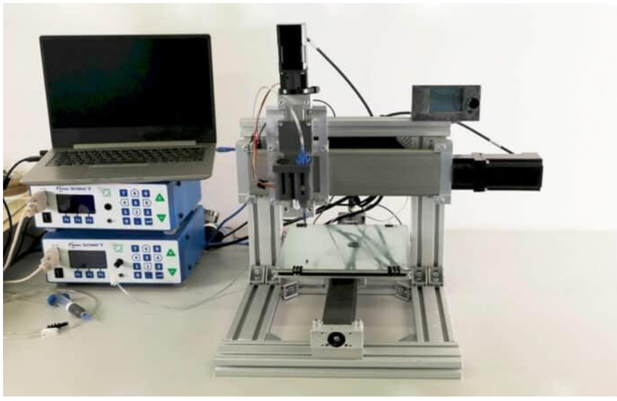


Fig. 1. Computerized 4D printing system [9]

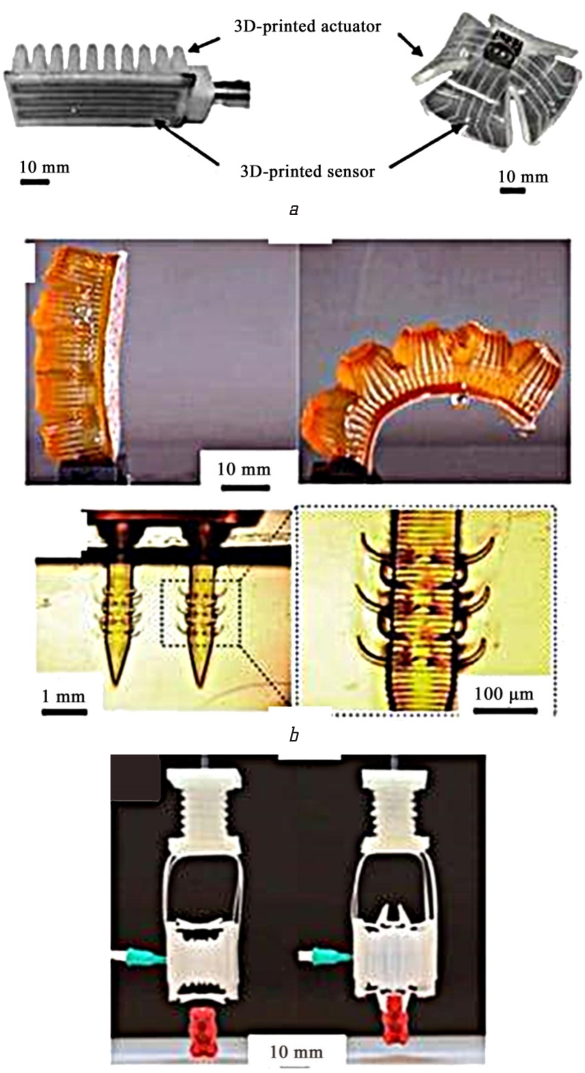


Fig. 2. Controlled 4D polygraphic systems: *a* – combined sensor and 3D printed pneumatic muscle (license «Creative Commons CC-BY»); *b* – piezoelectric sensor embedded in hydrogel actuator («SPIE» license); *c* – 4D-printed sweating system with thermoregulatory pores (American Association for the Advancement of Science) [10]

Computer and software support for 4D printing systems is based on the software package «4D-Additive Manufacturing Software Suite», which is the latest and sets standards in the printing industry. Thus, 3D models from all common CAD formats can be read and prepared for additive manufacturing processes directly as accurate, intelligent and lightweight «B-Rep» geometry. «4D-Additive» reads CAD data from 24 different formats such as: «CATIA», «NX», «SOLIDWORKS», «Creo», «Inventor», «STEP» and «JT» as accurate geometry «B-Rep», including all product manufacturing information (PMI), attributes, and design history. In addition, triangulated formats such as: stl, obj and 3mf can be read and handled perfectly [11].

CAD models optimized for 3D printing and placed on work plates can be saved in all common formats such as: amf, 3mf and STL, as well as common slicing formats: cli, sli, abf, svg, sls, usf and g-code. The intelligent capabilities of 3D and 4D nesting with multiprocessor computation provide fast automatic filling with optimal use of the assembly volume for all machine types available in the database, as well as for customized machine types [7]. The extremely fast nesting function «4D-Additive» uses ultra-fast multiprocessor processing and provides maximum automation.

In the future, the most real and promising areas of use of 4D printing will be:

1. *Cars of the future*. According to the engineers, the body of the car will be made of moving triangular sections printed on a 4D printer. Such parts will have integrated functionality, which is currently achieved by producing different parts and assembling them into a single mechanism. Thanks to the use of special materials similar in characteristics to carbon fiber, each section will have programmed functions from the moment of production. For example, a large part of the coating will serve the wheel niches created for better aerodynamics. When turning, the triangular sections stretch and the tires do not rub against the arches.

2. *Changes in the shape of products*. Engineers of the laboratory «Self-Assembly Lab» (MTI) have developed a 2D template that folds into a cube when immersed in water. To print «Self-Assembly Lab» use the Stratasys Objet260 Connex1 4D printer, which allows working with various materials (including rubber and polypropylene). In this way, many different products can be created that can independently acquire the desired shape or self-assemble. Today there are experimental models: shoelaces that tie themselves and pieces of furniture that unfold on their own [12].

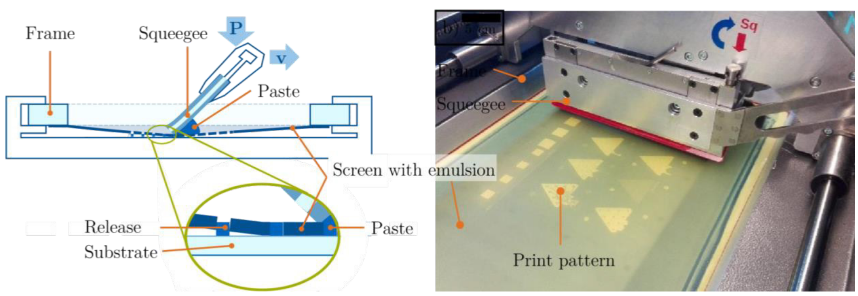
3. *Space protection*. 4D printing can be used to create metallic fabric to protect satellites from damage and radiation, as well as to produce flexible antennas. The fabric is a kind of «mail» made of pieces of silver and other metals. The material can be repeatedly bent, expanded, stretched and compressed. Each side of the fabric has its own properties, reflecting or absorbing light and heat. Despite its flexibility, the fabric is very difficult to tear. It is planned that satellites will be packed in the protective material before they are launched into space, or space suits and modules will be shielded with it.

4. *4D printing for military needs*. 4D printing is expected to enable the creation of new chemical and biological sensors, structures and materials for microchips. The four-dimensional printer will become the basis of a new generation of tools for the development of architectures in which materials forming functional components of electronics can be combined with biological objects [13].

5. *Form memory*. 4D printing techniques can be applied by incorporating shape memory polymer fibers into composite materials used in traditional 3D printing. Examples of applications of the technology include solar cells that can be folded up and unfolded for transportation, automotive coatings that adapt to the environment, and military uniforms that change the type of camouflage or more effectively protect against gas or debris.

6. *Printing in medicine*. 4D bioprinting has revealed a new way to make stents from stimuli-responsive materials in a relatively compact size. Several 4D bioprinting methods and materials for stents have been developed. After transplantation, irritants and stents are applied self-deform to the desired size and shape. Manufactured structures can be customized according to the anatomy of each patient, corresponding to anthropometric dimensions and location in the body. Over time, they decompose in the human body.

3.2. Digital screen printing. It is digital screen printing is one of the new printing methods that has been introduced in printing in recent years. It is used for both graphic printing, such as labels, and functional printing, such as conductive or insulating patterns. In Fig. 3 shows a diagram of the printing process with the components marked.



a *b*

Fig. 3. Screen printing: *a* – printing scheme with marked components, pressure *P* and speed *v*; *b* – a photo of a commercial screen printer with an installed squeegee and screen [14]

The main component is a screen with a grid on which the print pattern is reproduced by covering all non-printed areas with emulsion. The print pattern can be seen in yellow, while the rest of the screen is covered in green emulsion. The basis of each screen printer is a table, on which the substrate is fixed by vacuum, glue or simply by gravity (Fig. 4).

Fig. 4. High-precision digital screen printer [15]

Computer control system. The high-precision digital screen printer is controlled by a computer and provides considerable flexibility with all functions of the MS Windows operating system and has programmable printing parameters (print stroke, pressure, print gap and bottom stop). It is recommended to install the «DinoCapture» software on the PC. A successful connection with the cameras is established if their light turns on and a live image appears on the screen. Magnification and other settings can be changed using software components. For screen printing, a computer control system based on the «EtherCAT» distributed architecture is used. Various motors and sensors are connected via «EtherCAT» and accurate location information is received via «EtherCAT I/O» which returns accurate control output signals (Fig. 5).

Fig. 5. Scheme of computer control of screen printing based on the distributed architecture «EtherCAT» [16]

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To achieve high print accuracy, the built-in digital time stamp module can be used to determine the exact time of paper arrival and convert it into location data using the encoder reader module. This causes the squeegee blade to start at the same moment to start dispensing ink with the time stamp module. The precision time stamp module with 1 ns level is fast and accurate enough for precise machine control and high quality printing. The 10 MHz encoder reader also helps to speed up the process response time, ensuring maximum performance of the high-precision digital screen printer and giving maximum efficiency [17].

New advanced screen printing techniques are expected in the future, such as:

1. *An electronic display applied directly to everyday fabric for medical use.* This technology will allow patients to be monitored using a soft cloth that can be worn and not imposed. Screen printing could be a major player in the next movement of printed electronics.

2. *Computer to screen printing, or CTS, is relatively new to the screen printing industry.* This innovative screen printing process eliminates the need to work with films, reducing costs and labor time. The latest computer version of this system, «CTS digital light imaging», also eliminates the need for toner, using instead a digital mirror device to expose the image to ultraviolet light.

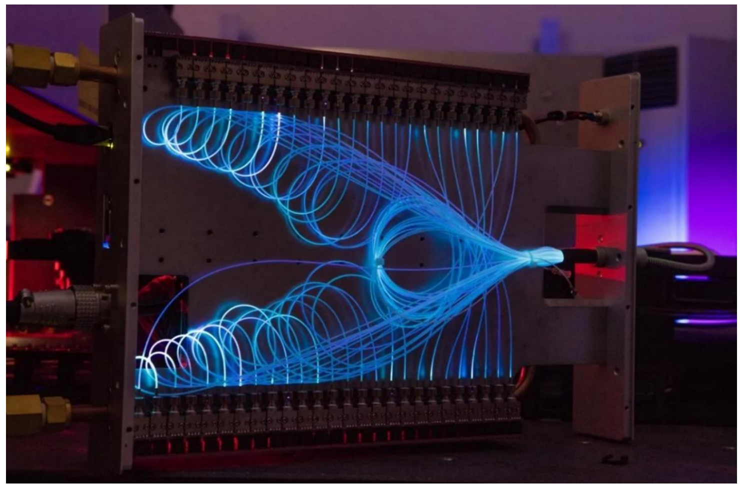

Fig. 6. Visualization of a laser line in polygraphy [18]

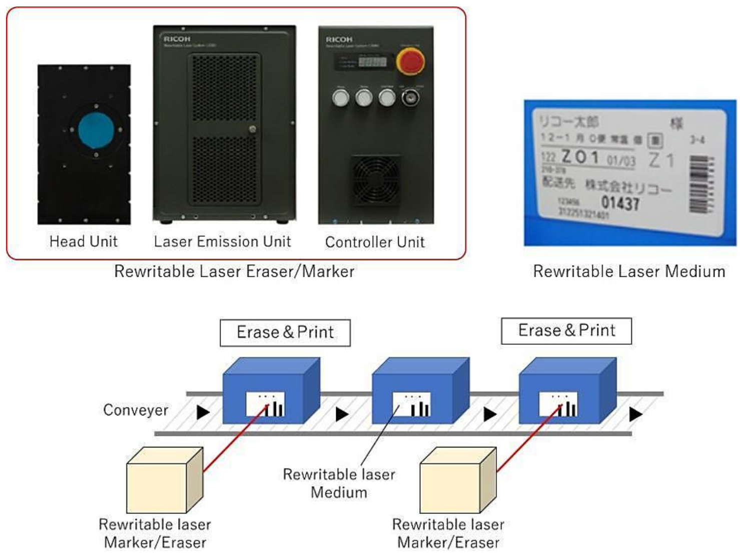

Fig. 7. «Ricoh» computerized laser system with the possibility of multiple printing, moving by a printing belt conveyor [13]

3.3. Laser direct printing. *Direct write (printing) (DW)* is a type of digital printing technology that involves a large number of flexible multi-scale functional material deposition procedures that can be used to create basic linear and complex conformal electronic structures on a substrate. Direct writing uses a number of processes and energy modalities, including laser, jet, and mechanical pressure, and tips to facilitate material transfer and create features ranging in size from nanometers to millimeters.

With its conformal recording capabilities, this new group of on-demand additive methodologies complements existing conventional electronics manufacturing approaches, particularly in terms of product miniaturization and footprint reduction. There is a wide range of materials, ranging from various dielectrics, ceramics, metal, polymers and biomaterials [18]. For the microscopic world, two-photon *laser direct writing (LDW)* is a 3D printing technique. LDW can typically recognize smaller details from several microns to sub-microns, thus enabling 3D drawing of complex shapes with fine details (μm to several nm). The limitations of the optical setup and the photochemistry of the materials used determine the complexity of manufacturing the shapes that can be achieved with LDW (Fig. 6).

Basic configuration and functions of a computer system. «Rewritable Laser System» is a non-contact overwriting system using computerized lasers developed by Ricoh, which consists of a rewritable laser marker/eraser that improves reproducibility by making the optical distribution uniform and a rewritable laser medium with improved light resistance (Fig. 7).

Computer systems for laser direct printing are supported by a number of leading software products:

«LaserGRBL» is a free laser cutting software for Windows, and it is one of the few programs designed for beginners and hobbyists. With it, almost anyone can learn the basics of software management, file formats, and the ins and outs of laser cutting. Some of the valuable features of the LaserGRBL include a jogging function that allows the operator to manually position the laser head using two sliders, controlling the size and speed of the steps.

The bitmap import function allows to load any image, including photos, pictures, pencil drawings and icons, into LaserGRBL and convert it to g-code without additional software. Raster images provide a different type of graphics than vectors in most laser engraving programs.

«Inkscape». A versatile open source vector graphics software, Inkscape is more of a general purpose tool than a specialized laser cutting software. This free engraving software uses Scalable Vector Graphics (SVG) and can work with PDF, JPG, GIF and PNG. Unlike LaserGRBL, Inkscape is available on all major desktop platforms, including Mac, Windows, and Linux.

«*SolveSpace*», as opposed to «*Adobe Illustrator*», has a relatively simple user interface, but requires a quick learning curve due to minimal input. However, SolveSpace can meet your laser cutting design needs and has some advantages: SolveSpace is extremely resource-friendly, taking up less than 10 MB on your computer. It is possible to run it on a desktop or laptop without any problems, and the program is free. There is export directly to SVG.

«*LaserWeb4*» is a free laser cutting application with a community of users who help with tips, changes and additions to the code. The program has a variety of features, including some not found in most other programs. LaserWeb 4 includes material and price calculators that allow users to design a new part and estimate its cost.

Technology of laser direct polygraphy is attracting a lot of attention due to its convenience and reduced environmental impact. In the future, thermal rewritable recording media using heat will be applied to card display applications, such as displaying numbers and expiration dates on loyalty cards, IC cards, etc., using a thermal head recording method. In addition, research has been conducted on the application of rewritable recording technology for industrial applications such as production automation and logistics [19]. For example, in logistics where regular deliveries are made, barcodes and text information indicating the delivery address and contents are printed on labels using a printer and attached to return containers for each shipment to ensure delivery accuracy. When the container is returned, the labels are peeled off and discarded, and new thermal labels are applied.

If these discarded labels can be replaced with rewritable recording media, this will reduce the environmental impact by reducing waste and CO_2 emissions. In addition, the system significantly increases operational efficiency by reducing the labor costs associated with changing labels and the risk of problems with the logistics system caused by leftover labels.

3.4. Central Print Management System (CPMS). The Central Print Management System (CPMS) in the printing industry is an innovative technology specializing in the development of print and document management solutions. It is a service offered to optimize the use of the printing device, minimize the costs associated with printing and manage the printing to improve productivity. The components of a central print control system consist of hardware and software. Each of these components provides a set of related functions in the system. A multifunction printer is a hardware device used for printing [17]. This is hardware that creates printed copies of documents on paper or other media for printing (Fig. 8).

A print server is considered as a network device, software, or computer that connects a print device to clients over a network to administer a print request.

«*Hyper-V*» (virtualization environment). This is a Microsoft product that allows to create virtual machines. During this project, the author followed the company's separate server policy to avoid complications during troubleshooting. «*Hyper-V server*» was installed on «Windows» servers, that is, a virtualization environment was launched that allows to create virtual machines (considered as software computers on which the operating system runs). The author took into account the minimum system requirements for installing the «uniFLOW» server. «UniFLOW» is software for optimization, registration and accounting of printing tasks (Fig. 9).

The printing management software (UniFLOW) had to be installed on a dedicated server. In Fig. 10 shows the workflow of «uniFLOW», and also shows the complete network structure of the printing architecture of contact solutions after installing and configuring the «uniFLOW» server.

Fig. 8. Multifunctional printing device with computer network support [20]

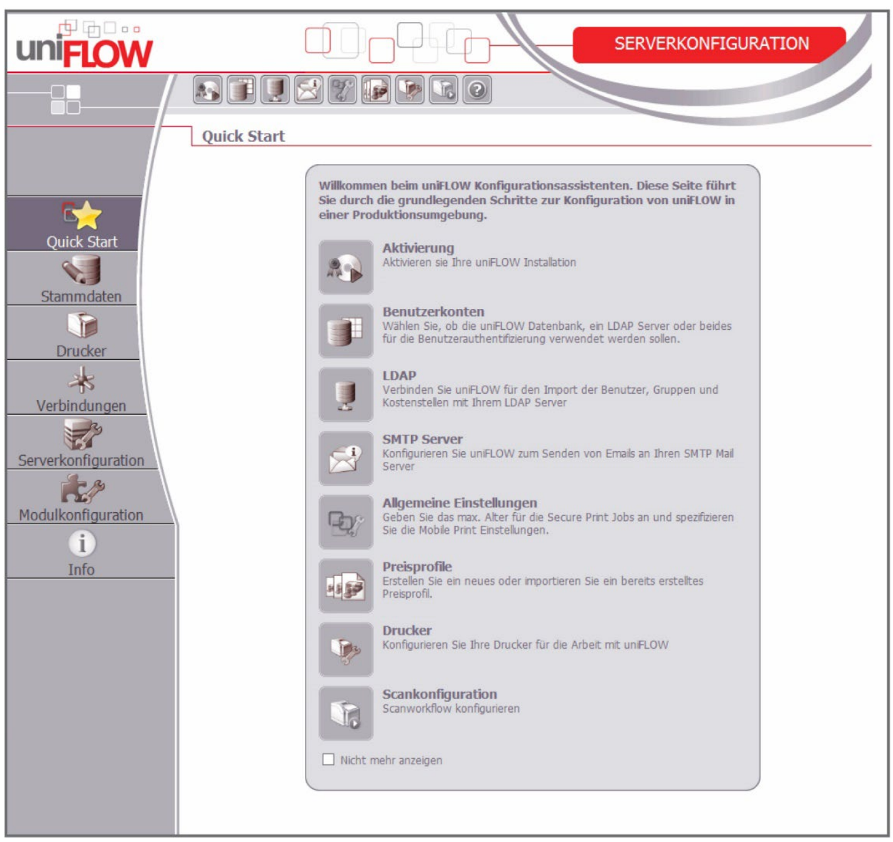

Fig. 9. Graphical user interface «uniFLOW» [20]

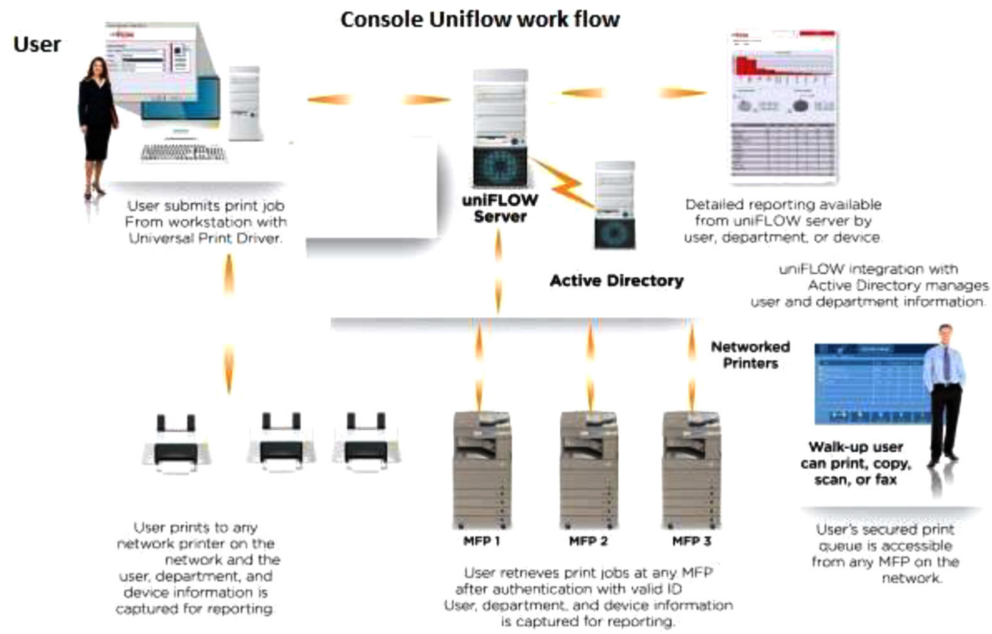

Fig. 10. Work process «uniFLOW» [20]

After the final testing of the integration of the Central Print Management System (CPMS) into the legacy system (direct printing), the printing devices must be turned on for full readiness. Additional functions of the printing devices, such as scanning, Internet faxing and copying, have also been configured and tested. A central print management system will ultimately ensure efficient support of print business processes at reduced costs. In addition, printing, faxing, and scanning are important day-to-day business process activities [8]. Therefore, it must be maintained properly to improve and maintain the quality of printing production.

3.5. Discussion of research results. *The practical significance* is that the integration of computer technology in the printing industry can improve product quality, reduce production costs and increase productivity. The study points to the potential of using the latest technologies, such as 3D and 4D printing, digital stencil technology and more, which expands the opportunities for printing companies. This study not only reveals the current state of the printing industry, but also highlights the importance of innovation and foresight to ensure competitive advantage in the marketplace.

Limitations of the study. Analysis of current trends and forecasts for the future process of computer technology in the printing industry has current limitations on the planning of printing production, the risks of investing in innovation in the field of printing technology and adaptation to changing market and technological conditions in the industry. In the conditions of market globalization, the ability to predict future trends and adapt to them in a timely manner is the key to success for manufacturers of printing products.

The influence of martial law conditions. Martial law, being an emergency situation, significantly affects many sectors of the country's economy. The printing industry is no exception. The reallocation of resources and prioritization of military needs can lead to shortages of basic materials for the printing industry, reduced investment and delays in the implementation of digital and new software solutions. An unstable economic situation and a possible drop in the purchasing power of the population and businesses may lead to a reduction in orders for printing products.

Prospects for further research consist in the further development of technical and software solutions for the complex integration of the latest technologies in printing and market requests for types of printing products. Digitization is increasingly taking over the world of print, adapting to changes in the way people consume content. As online content becomes increasingly accessible through various devices, including smartphones, converting this content into print requires advanced research for analysis, interaction, personalization and layout of the material.

4. Conclusions

It has been determined that the printing industry today solves the problems of using computer and printing technologies of digital origin, which changes the entire system and results of printing production. These changes are also dictated by customer demand, which has a real impact on changes in technological developments, followed by changes in quality standards and computer control of printing production. It has been determined that with the development of computer technologies, printing systems opened new horizons for the printing industry. This has allowed manufacturing to move from flat printed materials to three-dimensional structures and, in the case of 4D printing, to objects that can change their shape or properties depending on external stimuli.

It has been proven that computerized printing systems continue to evolve at a rapid pace, responding to the growing needs of the market and increasing the quality of printing products. The latest technologies, such as: 3D and 4D printing systems, digital screen printing, laser direct printing, central printing management system (CPMS), are already being implemented and used in printing production, making it more automated, accurate and efficient. These new technologies have made it possible to create more personalized, functional and adaptive products, opening up new markets and segments for printing companies. It is predicted that the integration of advanced technologies in printing production will continue, opening new horizons for innovation and development of the industry.

It is believe that for future success, printing companies must be ready for continuous learning, investing in the latest technologies and adapting to changing market conditions. Given the above, computerized printing systems definitely play a key role in the future of printing production. They have already revolutionized the industry and promise to bring even more innovations in the near future.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has associated data in a data repository.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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