POSSIBILITIES OF IMPLEMENTING EDUCATIONAL PRACTICES IN THE FIELD OF AI AND 3D PRINTING AS AN ELEMENT OF THE DEVELOPMENT OF THE SMART CITY IDEA

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Summary: 1. Introduction; 2. Smart City as an Ecosystem Supporting Technological Education; 3. The role of artificial intelligence in shaping the education of the future; 4. 3D printing as a tool for practical education in smart cities; 5. AI-powered 3D printing education support system; 6. Conclusions.

Abstract: The main objective of the publication is to present the possibilities of using artificial intelligence technology and 3D printing in education as key elements of the development of the Smart City concept. It presents the factors and requirements that determine whether an effective Smart City ecosystem can emerge and be a driving force of social change based on modern technologies. The authors attempt to answer questions regarding the role of AI and 3D printing in the context of shaping the education of the future, the challenges related to implementing these technologies in curricula, and ways of integrating them with teaching processes. It was noted that in the context of 3D printing,

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there is a lack of educational applications that comprehensively and interactively teach about the essence of this technology, its processes, applications, and possibilities. Taking this into account, the chapter presents the assumptions and structure of the application that guides the user through the process of rapid prototyping based on 3D printing. An important element of this concept is the use of AI at various stages of preparation, implementation and control of 3D printing. Various AI methods and tools can increase the efficiency, as well as the available functionality of such a solution.

Keywords: *Artificial intelligence; 3D printing; Smart City; education.*

1. INTRODUCTION

Modern cities around the world, faced with the challenges of dynamic technological development and growing social expectations, are moving towards the idea of Smart City – intelligent spaces that use advanced technologies to improve the quality of life of their residents while taking into account the care of the natural environment (Freeda *et al.*, 2024). Within this concept, technological education becomes one of the key elements. It not only allows for the development of basic competencies for the future, but also prepares society for active participation in the digital revolution (Salaj *et al.*, 2024).

The development of modern technologies influences various areas of economic, social and cultural life. Therefore, technological changes and, consequently, industrial revolutions have a significant impact on all aspects of our lives. The key issue is the proper use of this potential. In order for this to happen, it is necessary to take care of the fundamental factors of future development. Therefore, properly initiated and implemented educational processes based on innovative technologies can initiate the processes of rapid development of society in an emergent way.

The breakthrough technologies in the digital revolution include artificial intelligence (AI) and additive technologies (also commonly known as 3D printing), which can play a central role in shaping modern educational methods (Zichar & Papp, 2024). Currently, artificial intelligence is changing the ways of teaching, learning and managing the educational process. AI allows for the personalization of learning, analysis of student needs, and implementation of innovative tools, the aim of which is not only to support the acquisition of knowledge, but also to motivate learning (Neuschafer, 2024). In turn, 3D printing allows for a practical approach to the educational process, developing creativity and technical skills. When combined with the learning of science subjects such as mathematics, physics, or robotics, 3D printing enriches the didactic process by facilitating the understanding of complex concepts through practical experiences. It is worth noting that the integration of artificial intelligence and additive technologies can have huge potential in technological education. Incorporating these technologies into educational programs, not only at the academic level but also in primary and secondary schools, creates opportunities to support the development of students whose competencies will be adapted to the requirements of the 21st century.

Considering the above, the main aim of this publication is to present the potential applications of artificial intelligence and 3D printing technologies in education as key elements in the development of the Smart City concept.

This chapter attempts to answer the following research questions:

1. What is the role of AI and 3D printing in shaping the education of the future?
2. What challenges do educational institutions face in introducing new technologies such as AI and 3D printing into the curriculum?
3. How can AI-based educational tools support the learning process of 3D printing in urban environments?

In the chapter, the authors present exemplary solutions and academic initiatives implemented in the city of Rzeszów, which can be an inspiration for other cities wishing to develop within the framework of the Smart City idea. Based on the research conducted, the publication presents the concept of an educational application, which, using elements of artificial intelligence, aims to support the teaching process on 3D printing, taking into account its complexity and technological requirements.

2. Smart City as an Ecosystem Supporting Technological Education

A Smart City that supports technological education becomes a key element in building modern, sustainable communities that are better prepared for future challenges. Awareness and consistent development of an ecosystem based on advanced technologies, social and economic needs within the context of a city or region do not contradict the approach rooted in globalization. On the contrary, it serves as a proper complement and, more importantly, a solid foundation for development (Dimitrova, *et. al.*, 2024).

A well-functioning Smart City ecosystem attracts investors, contributes to the development of innovative products and services, and fosters the growth of startups. Smart City serves as a universal platform enabling the use of technology to address real-world problems, implement innovations, and test services in a lively and dynamic environment. As a result, it facilitates, on the one hand, the emergence of ideas, concepts, and solutions that can have both local and global impact, and on the other, it ensures an environment for the global transfer of knowledge and technology (Gracias *et. al.,* 2023). Such synergy builds an informed, advanced, and well-educated society. Access to advanced technologies creates opportunities for the development of the passions and talents of young people. Combining this access with solid knowledge fosters creativity, collaboration, innovation, and critical thinking. On such well-prepared foundations, it becomes possible to create new technological leaders who are conscious of societal needs and prepared to tackle the challenges of Industry 4.0 and 5.0.

However, for such an ecosystem to emerge and function effectively, certain conditions must be met:

- **Investments** – extensive investments are essential in technological infrastructure, transport and mobility, urban infrastructure, data collection and processing systems, education and digital skills development, telemedicine systems, public monitoring, and safety, as well as innovation hubs.
- **Collaboration and Engagement** – public-private partnerships, along with cooperation with universities and non-governmental organizations, enable the effective identification of societal needs and development opportunities, as well as the implementation of concepts, programs, and projects aimed at fostering growth and improving the standard of living.
- **Openness** – this factor has many aspects that determine the development of a smart city. First of all, the openness of society and authorities to new technologies is manifested through dialogue, understanding, and involvement, both on a local and global scale. However, openness also has another aspect, namely the so-called open data, made available to society and other social and economic entities. Another important area concerns openness to the introduction of new, higher standards, often requiring formal and legal regulations, as well as rapid adaptation to changing conditions.
- **Awareness –** a society that is conscious of technology, social and economic processes, ecology, culture, and economics as well as needs and challenges is essential for the realization of the smart city concept. Well-established social awareness enables the effective implementation of innovations, fosters widespread public acceptance of change and investment, and enables the long-term benefits of development to be seen.

- **Education** – in the Smart City, it is the foundation for the successful implementation of technology through the development of technical competence, increasing social mobilization, building confidence in technology, creating a society open to knowledge, reducing digital exclusion, creating future engineers and managers, increasing standard of life through the ability to use intelligent services.

It should be noted that the lack of an adequate level of education can contribute to the creation of social, economic, and technological barriers that will limit the possibilities to fully exploit the potential of the Smart City.

3. The role of artificial intelligence in shaping the education of the future

Artificial intelligence is influencing all areas of our lives. It is no different with education. Today, we can already see how quickly tools supporting the teaching process are evolving thanks to AI, and new forms based on AI are emerging, such as conversations with a 'virtual assistant'. When analyzing the impact of AI on shaping education, the following aspects should be considered:

- **Personalization of teaching –** AI allows for the creation and ongoing adjustment of educational content and the level of teaching to current learning needs, it also enables ongoing tracking of progress in learning while dynamically modifying the paths and forms of teaching, taking into account the student's engagement and the goals to be achieved. It should be noted that the unprecedented personalization of teaching can also be directed to people with disabilities or those undergoing a complex treatment and rehabilitation process. AI can select various forms of learning, striving to obtain the optimal form for a given student, especially in the case of students who have difficulties in learning. As part of the personalization of learning, AI can also track the level of concentration and fatigue of students. Thanks to this, it can automatically select the intensity and scope of exercises, as well as introduce breaks, forms of relaxation, and entertainment, also taking into account forms of education based on geography.
- **Development of remote and hybrid education** – AI-based teaching tools can be implemented locally, completely in a remote location, as well as at various levels of the ICT infrastructure (Akila, 2024). This enables global access to the latest solutions, current content, and innovative forms of education. One of the forms of education that can be widely used in the future is the use of Virtual and Augmented Reality. A

properly designed "theater of action" can connect territorially distributed students, teachers, experts, and instructors within a virtual environment. Creating immersive educational experiences in VR will allow for simulating real scenarios and teaching practical skills. Additionally, AI enables ensuring a high level of education in remote areas or with limited resources.

- **Teacher support** – AI can support teachers by proposing various forms of conducting classes, automating selected activities, e.g. verifying the level of knowledge, creating tests, quizzes, and varied exercises, taking over repetitive activities from the teacher (e.g. administrative), increasing the inclusiveness of teaching, effective processing of big data to identify patterns and trends in educational processes.

As you can see, the AI-supported education process increases the possibilities of cooperation, problem-solving, and decision-making in realistic situations. However, it should be remembered that the widespread implementation of AI in the education system requires:

- Adjustment of legal regulations and regulations at the level of the Ministry of Education, introducing the possibility of common use of modern forms and IT tools in the educational process while maintaining key educational goals.
- Ensuring the possibility of dynamic changes in the form and content of education - currently, in many cases, core curricula, educational programs, and subject cards are static in nature, and their evolution is slow and often requires multi-level institutional acceptance.
- Ensuring access to broadband Internet and efficient end devices (including personal computers).
- Introduction of a system/tools enabling monitoring and control over the content and course of the educational process.

It is therefore important to note that while artificial intelligence has the potential to revolutionize educational processes, its implementation must be well thought out and appropriately managed. It is essential to develop regulations both at the international and local levels to ensure the ethical use of technology, minimize social inequalities, and guarantee data security. Furthermore, it is crucial to maintain a balance between technology and direct human interactions, which should remain a priority in any education system.

4. 3D printing as a tool for practical education in smart cities

3D printing in education has opened up completely new possibilities. In many countries, these technologies are used in primary schools, secondary schools, and universities, where they help students better understand individual issues (Ford & Minshall, 2019). In Poland, there are also significant initiatives in the field of including 3D printing in educational processes. An example is the government program "Laboratories of the Future", initiated in 2021, the main goal of which was to equip primary schools with modern technologies, including 3D printers, and thus build future competencies among students, from the so-called STEAM (Science, Technology, Engineering, Arts, Mathematics) fields.

In Poland, local authorities are also creating their own initiatives that are closely aligned with the idea of the Smart City concept. In Rzeszów, thanks to the cooperation of the local government and the initiative of URBAN LAB, the Minecraft and 3D Printing Center was established, which conducts classes for children from primary school. Such activities contribute to the early interest of young people in modern technologies and the development of their engineering skills.

It is also worth highlighting the role of higher education institutions. For instance, Rzeszów University of Technology, through the involvement of its academic staff and collaboration with industry and local government authorities, contributes to the integration of various sectors in the field of modern technologies and 3D printing. This was particularly visible during the COVID-19 pandemic, when many solutions and forms of assistance in the fight against coronavirus were created in cooperation with the medical community. An important element of development is also the activity of students - in 2016, on their initiative, the Student Scientific Club of Rapid Prototyping and Industrial Design of Rzeszów University of Technology was established. Thanks to access to professional 3D printers, 3D scanners, tools, equipment, and software for CAD modeling, members of the club have the opportunity to implement their own projects and expand their knowledge in the field of 3D printing (Budzik *et al.*, 2022).

By utilizing 3D printing, the younger generation has the opportunity to develop spatial imagination and apply knowledge practically, not only in the fields of science and technology but also in the humanities, such as art and history (Pearson *et al.*, 2022). Thanks to the use of 3D printing, the younger generation has the opportunity to develop spatial imagination and the practical application of knowledge, not only from exact and technical sciences, but also from humanities, such as art or history. Another advantage is the fact that pupils and students are more motivated to learn, and thanks to this, the teaching process becomes more engaging and effective. Learning in the form of teamwork is also important, which supports the development of social competencies, such as cooperation and communication in a group (Özeren *et al.*, 2023). In addition, this technology helps students define their interests and career paths, offering practical experience in working with advanced tools. All these aspects allow the young generation to prepare for the challenges of the modern labor market. Despite many potential benefits, initiatives to implement educational practices in the field of 3D printing are also associated with certain limitations and challenges. These include:

- **Printer purchase and maintenance costs** – the relatively high price of the devices has a negative impact on the use of 3D printing in the educational process. Sometimes, the materials used for the printing process and the devices and tools used in post-processing processes can also be very expensive. An additional cost may also be the organization of training and the purchase of teaching materials. For small schools that do not have a large budget, such investments can be a significant barrier to development. In addition, the school budget may not provide funds for repairs and regular purchase of printing materials. There is therefore a risk that despite the purchase of 3D printers, the equipment may not be fully utilized over time.
- **The need to organize an additional workstation** – due to their specificity, 3D printers should be located in a separate room, because they are not suitable for work in office conditions. Implementing 3D printing classes in schools requires the organization of additional space that will meet specific technical and safety requirements. It is important to ensure that the classroom has good ventilation, because during the printing process, e.g. using ABS materials, a smell characteristic of melted plastic is emitted, which in consequence causes the release of harmful fumes. In addition, the room should have stable and even surfaces for setting the printers. Another requirement is access to electrical sockets with an appropriate current load. It is also important to prepare a special place for filaments, tools for post-processing processes, as well as finished prints and technological waste.
- **Lack of qualified staff** – conducting 3D printing classes by teachers requires skills in, among others, designing 3D models, and operating 3D printers, as well as knowledge of software dedicated to the given devices. Operating a 3D printer, especially with more complicated models, requires appropriate skills and technical preparation. Otherwise, it can lead not only to wasting time during the lesson, but also material, and worse still, damage to the equipment. In addition, 3D printers are susceptible to various types of failures, such as material jams, nozzle clogging, or

calibration problems. A well-trained teacher should be able to deal with such failures and regularly service the equipment, which requires specialist knowledge.

- **Lack of teaching materials** – in order to fully use the potential of 3D printing, it is also necessary to develop teaching materials, such as textbooks, worksheets, and instructional videos, which both students and teaching staff will use (Ford & Minshall, 2019). Teachers should have access to well-developed lesson plans that will allow for the implementation of the core curriculum. Students, especially those without experience with this technology, need detailed instructions on how to proceed to feel confident in direct contact with a 3D printer and with the software (Pearson & Dubé, 2022).
- **User safety** – 3D printers can heat up to high temperatures, and their improper use can lead to burns. Another threat may also be improperly carried out post-processing. It is related to, for example, removing the 3D model from the printer's workspace or removing unnecessary support structures. In such a case, cuts or other injuries may occur. This fact requires teachers to supervise students properly and strictly adhere to safety rules, and school management to introduce detailed regulations for work in the laboratory.
- **Legal issues** – with the dynamic development of additive technologies, numerous legal and organizational challenges related to their use have emerged. These problems focus mainly on three key areas: protection of intellectual property, responsibility for the safety and quality of products, and data protection (Budzik *et al.,* 2022) The use of 3D printing in a school environment may involve certain threats, especially in the area of safety. In schools, there is a risk that students could unknowingly or consciously print potentially dangerous objects, such as knives or other sharp tools. It is worth noting that the huge number of 3D models available on the Internet means that even students with no experience in design can download and print potentially dangerous objects.

In conclusion, it can be stated that 3D printing technologies, with appropriate support and resources, have the potential to become an important tool in fostering student development and education. The benefits of incorporating 3D printing into educational processes can be particularly evident in technical fields, where it enables students to a gain practical understanding of theory, develop design skills, and enhance creative problem-solving abilities.

5. AI-powered 3D printing education support system

Each student's approach to the process of acquiring knowledge may be different and dependent on their own predispositions, interests, or needs signaled by the market. In connection with the above, it seems reasonable to develop teaching methods that will prepare students for the challenges that reality poses to them, taking into account their capabilities and preferences. Current trends in science and students' preferences indicate the growing popularity of interactive methods, digital technologies, and personalized approaches. Such solutions are offered by various types of learning applications that use artificial intelligence in their functions. An example is the "Duolingo" application, which has been assessed by a large research group as an effective tool supporting the learning of foreign languages, although it was noted that its effectiveness may depend on the individual preferences and involvement of the user (Essafi, *et.al.,* 2024; Akila, 2024).

Based on knowledge gained during industry meetings and literature analysis, it can be concluded that the 3D printing industry lacks educational applications that comprehensively teach the essence of this technology, its processes, applications, and possibilities in an interactive and user-friendly way. Moreover, there are no solutions that would support the process of learning, designing, and physically producing a project with the help of artificial intelligence. In Figure 1, the authors of the study present the concept of a system that incorporates the necessary stages and components for designing and manufacturing using 3D printing, supported by AI.

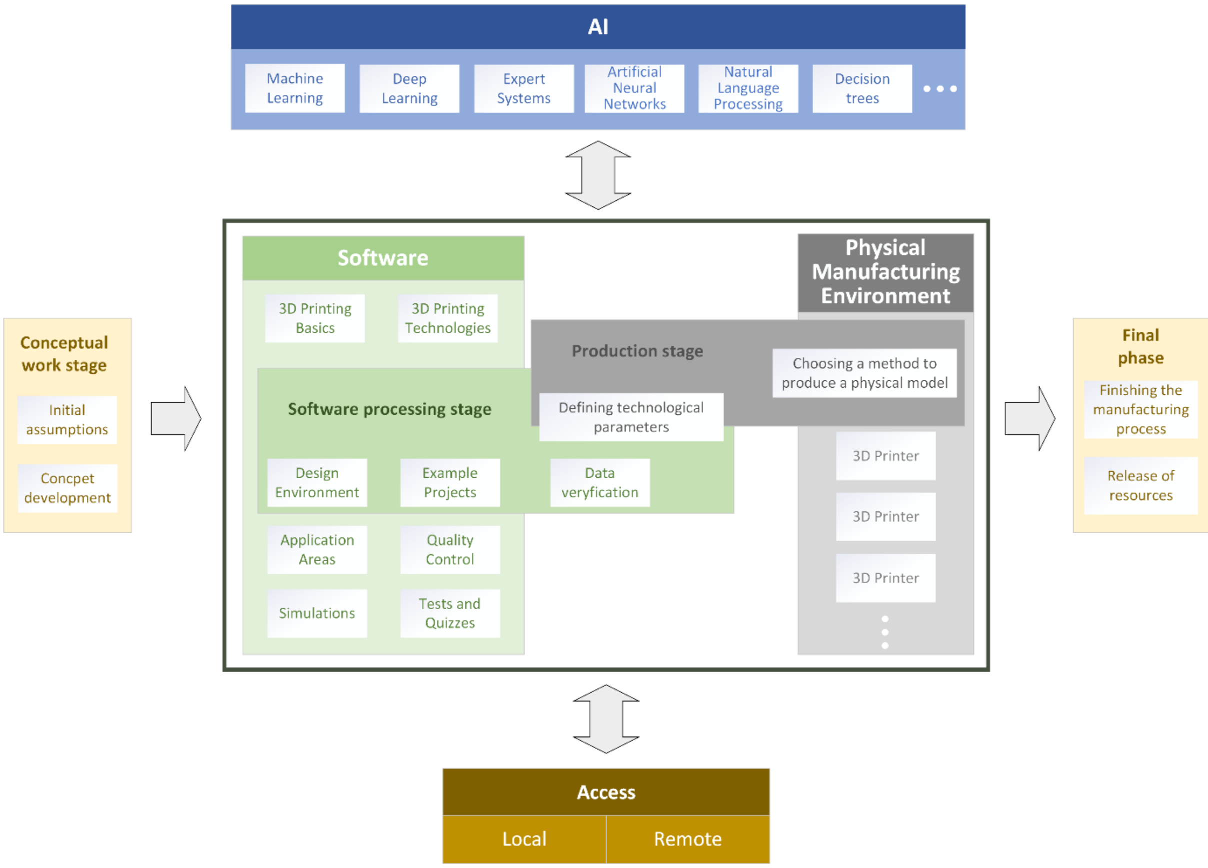

Figure 1. The architecture of a system supporting education in the field of 3D printing using AI methods.

The input element of the system is an interface whose task is to define the basic objectives of the activities undertaken in the 'teaching by example' model. Teaching by example is an educational method of showing patterns of behavior or solutions in practical contexts so that students can imitate them. It allows them not only to see "how it's done," but also to learn by observation and draw their own conclusions from the situations presented. For example, in this mode, a student may want to make an artifact related to his daily life - such as a dedicated bracket for mounting an air quality meter, or a housing for a circuit he designed. If the student has had no previous exposure to 3D printing systems then the threshold for entry into this technology can be very high, which will consequently discourage the student from finalizing the project. Therefore, in the proposed approach, the system creates an opportunity to use AI elements such as Natural Language Processing (NLP) at the first stage to verbally describe the problem (in our case, an artifact) that the student plans to create. Based on the information obtained, the system selects a set of tools from the Software module and creates a virtual working environment for the student - i.e., a unique set of software and tools that is fully adapted to the student's knowledge, skills, and needs and will allow to achieve the student's goal in the easiest way possible. At this point, it should be noted that the NLP model can be developed in-house, or designers can use third-party providers such as OpenAI or Google. The language models developed by these companies make it possible to connect to them using well-known programming interfaces (e.g. RestAPI). Various technologies, such as virtualization, resource containerization, or Virtual Desktop Infrastructure (VDI) systems can be used to create a virtual work environment. It should be noted that in such an approach, the student is not only provided with a dedicated set of tools for creating 3D artifacts, but also has access to supporting tools, such as tutorials and AI models, which support the artifact creation process and the learning process. The artifact creation process can use predefined 3D models which can then be customized by the user.

In principle, the application can be aimed at both beginners and students who already have some knowledge about 3D printing. When starting to use the proposed solution, important information that can help to perform the above-mentioned user profiling by AI includes information on: the type of school the user attends (primary grades 1-3, primary grades 4-8, secondary school, university) and experience with 3D printing (beginner, intermediate, advanced). The software part reconfigured by AI may consist of modules related to expanding knowledge in the field of 3D printing, support for 3D object modeling, and simulation of printing processes. AI mechanisms can flexibly select the scope, and content of individual sections. In the section '3D Printing Basics' the user can learn about the history and essence of 3D printing and the basic terms and definitions characteristic of this technology. The section '3D Printing Technologies' should include the classification of additive manufacturing methods in accordance with the ISO/ASTM DIS 52900 standard. Therefore, at least seven additive manufacturing processes should be described, which include: VPP (VAT Photopolymerization), MEX (Material Extrusion), PBF (Powder Bed Fusion), DED (Directed Energy Deposition), MJT (Material Jetting Additive), BJT (Binder Jetting) and also SHL (Sheet Lamination). In addition, the user should be able to understand the advantages and disadvantages of each technology in the context of their applications. The section called 'Application Areas' should contain information on industries in which 3D printing plays a significant role. Thanks to this, the users will be able to familiarize themselves with selected developed projects for each industry and see 3D models in three-dimensional space. 'Example Projects' may include methods for implementing sample projects. The user will become familiar with the individual stages of the production process, which include: 3D model development - CAD, checking the correctness of the designed model, preparing process data, manufacturing control, and post-processing. This section closely correlates with the 'Design environment', in which the user can create their own models, as well as develop those obtained from 'Example projects'. The 'Quality control' section will contain information on the methods of quality control of models and the guidelines that users of this technology should follow. In addition, the user should be able to familiarize themselves with the issues of identification, analysis and prevention of problems that may occur during the 3D printing process. In the next available module called 'Simulations', the user could virtually prepare the 3D printer for the printing process, selecting, for example, parameters such as the type of filament and temperature, and then conduct a simulation. Such tasks will allow the user to work in a safe environment, where they will be able to learn and make mistakes without negative consequences related to, for example, damage to the machine. In addition, an AI assistant would be available in real-time to provide tips, explain difficult issues and suggest the best ways to solve problems. The 'Tests and Quizzes' section will be about testing knowledge and competition. Questions will be adapted to the user's level and different topic categories. The format could include single and multiple-choice questions and logic tasks, such as questions about choosing a printing method. After completing each quiz, the application would analyze the results, indicate areas for improvement, explain the issues, and present additional educational materials. Gamification would be an important element. For each completed topic, the user would receive points that would help advance in the rankings and unlock subsequent sections in the application. The available leaderboard would encourage participants not only to maintain their current position, but also to achieve higher places in the ranking. By analyzing the user's answer history, AI could adjust the difficulty level of tasks to their skills. This would allow for greater focus on a given area and adjust the course and speed of learning to the needs of a given user. What's more, this section could also be data for models supporting the selection of components of the virtual work environment from the point of view of the knowledge and skills of a specific user.

Once the model is created, the next step is to select the manufacturing technology and materials from which the target object will be created. In this process, expert systems models are used in the proposed architecture. At the initial stage of system construction, the models are created by specialists in 3D manufacturing. In the subsequent stages of the system's work, the users themselves further train the model through the use of an information feedback loop, i.e. they visually evaluate the printed items and describe verbally the level of satisfaction with the fabrication of the item. This information is processed by the NLP model into a form that allows to retrain and improve the expert system model. With this approach, the proposed architecture can be viewed in terms of a self-learning and self-improving system for learning and manufacturing 3D parts.

User ranking is a separate issue. Authorization of access to resources will be a dynamic process that can be controlled by systems such as LDAP or Active Directory. Access rules (permissions) will be modified on an ongoing basis by the AI system based on the evaluation of the end-user's actions and/or the results of his screening tests. Based on this, users can gain access to more advanced application tools or better 3D printers. This approach is optimal from the point of view of equipment and consumables utilization and 3D printer availability time. The research also tested the ability to automatically evaluate artifacts using AI models that recognize images. The model was trained on the basis of images that showed damaged artifacts and artifacts printed correctly. Preliminary test results indicate that the model works correctly for well-known printing errors so it can be used successfully in particular for low-end users of the system.

It should be noted that the whole system should be prepared in microservice architecture. Individual components perform their tasks autonomously and their operation is synchronized by means of a central monitoring service. The exchange of messages is carried out by using classical software interfaces such as RestAPi or GRPC (Bolanowski *et al.*, 2022). Even hardware components can be treated in terms of autonomous systems. In ongoing research work, 3D printing was managed by using the printer's built-in software to enable remote printing, or by upgrading existing printers with hardware-software modules(RaspberryPi + OctoPrint) (Salach *et al.*, 2023). After printing, users have the option of using tools for the final processing of artifacts, i.e. tools for polishing, painting, removing supports, etc. Of course, this process can be outsourced or carried out internally, depending on the conditions and the implementation model of the system.

Access to the system can be implemented in different models, but it is generally assumed that the basic model will be remote access to resources (Bolanowski *et al.*, 2022). The user, via a website, describes his needs and, based on this, the system creates a virtual environment for him. In the ongoing PoC (Proof of Concept) work, the authors used virtual machines (Linux or Windows) that contained the components needed for the work. End users used a VPN (Virtual Private Network) to connect to the systems and RDP (Remote Desktop Protocol) to work with the created virtual machine in the VDI model. In the proposed model, there is no fundamental difference between remote and local work - because local users will use computers to connect to the virtual work environment anyway.

In addition, local users will not need assistance in removing the produced artifacts from the printer and will be able to do the final processing themselves.

6. Conclusions

Both artificial intelligence and 3D printing are of great importance for the development of smart cities, as they directly correlate with key aspects of smart cities, such as innovation, resource optimization, education of the future, sustainable development, and automation. These technologies require appropriate knowledge and skills as a barrier to understanding their importance and building the potential of their use in the real smart city environment. Therefore, to overcome this barrier, appropriate education focused on practical applications is necessary. The presented concept of an application for learning 3D printing integrated with various AI models and mechanisms could be a comprehensive tool that combines theoretical knowledge with practical exercises. By using elements of artificial intelligence, gamification, and interactive challenges, users will be able to develop their skills in a way that is attractive to them, while adapting to their needs and level of advancement.

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