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PROSPECTS FOR THE USE OF 3D PRINTING IN THE CREATION OF SMALL ARCHITECTURAL FORMS FOR THE URBAN ENVIRONMENT OF UZBEKISTAN

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Abstract. This article analyzes the prospects for using 3D printing technologies in the creation of small architectural forms for the urban environment of Uzbekistan. The study examines the potential application of 3D printing in the production of benches, urban furniture elements, decorative compositions, landscape modules, information stands, shading structures, and small pavilions. Traditional production methods and 3D printing technologies are compared according to such criteria as design flexibility, production efficiency, material optimization, environmental sustainability, and adaptability to local urban conditions. The findings indicate that 3D printing technology can become an effective tool for improving the functional, aesthetic, and environmental quality of public spaces in Uzbekistan. At the same time, the study substantiates the need to consider climatic conditions, material properties, the level of technical equipment, specialist training, and the regulatory framework when implementing this technology.

Keywords: 3D printing, small architectural forms, urban environment, additive manufacturing, digital design, public spaces, Uzbekistan, sustainable architecture.

Annotatsiya. Mazkur maqolada O‘zbekiston shahar muhiti uchun kichik arxitektura shakllarini yaratishda 3D bosib chiqarish texnologiyalaridan foydalanish istiqbollari tahlil qilingan. Tadqiqotda 3D bosib chiqarishning skameykalar, shahar muhitiga mo‘ljallangan mebel elementlari, dekorativ kompozitsiyalar, landshaft modullari, axborot stendlari, soyalovchi konstruksiyalar va kichik pavilyonlar kabi obyektlarni ishlab chiqarishdagi imkoniyatlari ko‘rib chiqilgan. Maqolada an’anaviy ishlab chiqarish usullari va 3D bosib chiqarish texnologiyalari dizayn moslashuvchanligi, ishlab chiqarish samaradorligi, material sarfini optimallashtirish, ekologik barqarorlik hamda mahalliy shahar sharoitlariga moslashuvchanlik mezonlari asosida taqqoslangan. Natijalar 3D bosib chiqarish texnologiyasi O‘zbekistonda jamoat makonlarining funksional, estetik va ekologik sifatini oshirishda samarali vosita bo‘lishi

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mumkinligini ko‘rsatadi. Shu bilan birga, ushbu texnologiyani amaliyotga joriy etishda iqlim sharoitlari, material xususiyatlari, texnik jihozlanish darajasi, mutaxassislar tayyorlash va normativ-huquqiy asoslarni hisobga olish zarurligi asoslangan.

Kalit so‘zlar: 3D bosib chiqarish, kichik arxitektura shakllari, shahar muhiti, additiv ishlab chiqarish, raqamli dizayn, jamoat makonlari, O‘zbekiston, barqaror arxitektura.

Аннотация. В статье анализируются перспективы использования технологий 3D-печати при создании малых архитектурных форм для городской среды Узбекистана. Рассмотрены возможности применения 3D-печати при изготовлении скамеек, элементов городской мебели, декоративных композиций, ландшафтных модулей, информационных стендов, затеняющих конструкций и малых павильонов. В исследовании традиционные методы производства и технологии 3D-печати сопоставляются по таким критериям, как гибкость проектирования, производственная эффективность, оптимизация расхода материалов, экологическая устойчивость и адаптация к местным городским условиям. Результаты показывают, что технология 3D-печати может стать эффективным инструментом повышения функционального, эстетического и экологического качества общественных пространств в Узбекистане. Вместе с тем обоснована необходимость учёта климатических условий, свойств материалов, уровня технического оснащения, подготовки специалистов и нормативно-правовой базы при внедрении данной технологии.

Ключевые слова: 3D-печать, малые архитектурные формы, городская среда, аддитивное производство, цифровой дизайн, общественные пространства, Узбекистан, устойчивая архитектура.

INTRODUCTION.

The rapid development of digital fabrication technologies is significantly transforming contemporary architectural design, construction methods, and approaches to urban improvement. Among these technologies, construction 3D printing has become one of the most discussed directions due to its ability to combine digital design, automated production, material efficiency, and architectural flexibility. Recent studies emphasize that 3D printing in construction can contribute to reducing material waste, improving production speed, and expanding the possibilities of complex architectural form-making. According to recent research, construction 3D printing is increasingly considered a sustainable alternative to conventional construction practices because it supports material optimization, design flexibility, and more efficient use of resources [1].

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In architectural and urban design practice, this technology is especially relevant for the production of small architectural forms. Unlike large-scale buildings, small architectural forms such as benches, urban furniture, decorative elements, landscape modules, information structures, shading elements, and small pavilions require lower structural complexity and can be implemented more gradually in real urban environments. Recent research on customizable urban furniture also shows that 3D printing has the potential to transform public spaces by enabling functional, aesthetic, and customized design solutions.

The relevance of this issue is particularly important for Uzbekistan, where urban modernization, public space improvement, and the expansion of green and recreational areas are becoming priority directions of urban development. According to the World Bank data source on Uzbekistan, the country's urban population indicator is tracked for the period from 1960 to 2024, reflecting the long-term importance of urbanization processes for national development [2]. In addition, recent government materials emphasize the need to improve the urban environment and expand green areas, especially in Tashkent, where the permanent population has exceeded 3.1 million and is projected to more than double by 2045 [3]. The same source identifies the expansion of green areas and the improvement of quality of life as priority tasks.

From the perspective of architectural practice, small architectural forms can play an important role in improving the comfort, identity, and functional organization of public spaces. They are not only utilitarian elements of the urban environment, but also visual and spatial components that influence the perception of parks, pedestrian zones, university campuses, tourist routes, residential areas, and recreational spaces. International urban development projects in Uzbekistan also indicate the relevance of upgrading public spaces, pedestrian access, street networks, sidewalks, and associated urban infrastructure [4].

However, the practical application of 3D printing technologies in the creation of small architectural forms in Uzbekistan remains insufficiently studied. Existing research on construction 3D printing highlights both advantages and limitations, including material efficiency, waste reduction, production speed, high initial costs, scalability issues, and the lack of standardization. Therefore, the introduction of this technology into the urban environment of Uzbekistan requires a systematic analysis of architectural, technological, environmental, economic, and regulatory factors.

The aim of this study is to identify the prospects for the use of 3D printing technologies in the creation of small architectural forms for the urban environment of Uzbekistan. The study focuses on classifying suitable types of small architectural forms, comparing traditional and additive production methods, and

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assessing the strengths, weaknesses, opportunities, and threats associated with the implementation of 3D printing in local urban conditions.

LITERATURE REVIEW.

The scientific literature on construction 3D printing demonstrates that additive manufacturing technologies are increasingly considered as an important direction in the modernization of architectural design and construction practice. Researchers emphasize that 3D printing enables the production of complex geometric forms, reduces dependence on formwork, improves material efficiency, and provides opportunities for automated and customized fabrication. In comparison with conventional construction methods, 3D printing is often associated with reduced material waste, increased design flexibility, and the possibility of producing individualized architectural elements directly from digital models [5].

A number of studies focus on the sustainability potential of 3D printing in the construction sector. The main advantages identified in recent research include optimized material consumption, reduction of unnecessary construction waste, improvement of production accuracy, and the possibility of using alternative or locally adapted material mixtures. At the same time, scholars point out that the environmental benefits of 3D printing depend on several factors, including material composition, energy consumption, printing strategy, durability of printed elements, and the organization of the production process [6].

The use of 3D printing for urban furniture and small architectural elements has also attracted increasing research attention. Unlike large-scale printed buildings, small architectural forms are more suitable for experimental and gradual implementation because they require lower structural complexity and smaller material volumes. Studies on customizable urban furniture show that 3D printing can be effectively applied to benches, planters, modular landscape elements, information structures, decorative panels, and sculptural objects. These elements can be adapted to specific spatial, functional, and aesthetic requirements of public spaces [7].

Previous studies also demonstrate that 3D printing has significant potential for improving architectural expressiveness. Additive manufacturing allows designers to create curvilinear forms, complex textures, parametric patterns, and customized surfaces that are difficult or expensive to produce using traditional methods. This is especially relevant for small architectural forms, since they often perform not only utilitarian functions, but also contribute to the visual identity, comfort, and cultural character of urban spaces [8].

At the same time, the literature highlights several limitations that must be considered before the practical implementation of construction 3D printing. These

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include high initial equipment costs, the need for specialized software and trained personnel, limited local experience, material adaptation problems, durability issues, and the lack of clear regulatory standards for 3D-printed elements. In outdoor urban environments, additional attention should be paid to climatic resistance, surface protection, structural stability, maintenance, and safety requirements [9].

For the context of Uzbekistan, studies on urbanization and sustainable urban development emphasize the importance of ecological balance, social sustainability, public space improvement, and the modernization of urban infrastructure. These directions confirm the relevance of introducing innovative, resource-efficient, and context-sensitive design solutions into urban environments [10].

Thus, the review of existing studies shows that 3D printing has considerable potential for the production of small architectural forms, but its successful application requires a balanced assessment of technological, material, economic, environmental, and regulatory factors. This confirms the need to analyze the prospects for using 3D printing technologies in the urban environment of Uzbekistan, especially through pilot applications in small-scale architectural and public space elements.

MATERIALS AND METHODS.

The methodological basis of this study is formed by a comprehensive research approach aimed at assessing the prospects for the use of 3D printing technologies in the creation of small architectural forms for the urban environment of Uzbekistan. Since the topic combines architectural design, digital fabrication, urban improvement, sustainability, and local implementation conditions, the study applies several complementary research methods: literature review, comparative analysis, classification, and SWOT analysis.

The literature review method was used to examine current scientific approaches to construction 3D printing, additive manufacturing, digital design, and the production of architectural elements. Particular attention was paid to studies dealing with the technological potential of 3D concrete printing, material efficiency, design flexibility, environmental sustainability, and the limitations of additive technologies in construction. This stage made it possible to identify the theoretical basis of the research and determine the main directions in which 3D printing can be applied to the production of small architectural forms.

The comparative analysis method was applied to compare traditional methods of producing small architectural forms with 3D printing technologies. The comparison was carried out according to several criteria: design flexibility, production speed, material efficiency, customization potential, environmental

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impact, suitability for complex geometric forms, and adaptability to public spaces. This method allowed the study to reveal the main advantages and limitations of 3D printing in relation to conventional production approaches [11].

The classification method was used to systematize the types of small architectural forms that are potentially suitable for production using 3D printing technologies. The classification included functional, decorative, landscape, informational, and recreational elements of the urban environment. In this study, particular attention was given to benches, urban furniture, planters, decorative panels, landscape modules, information stands, shading structures, small pavilions, and sculptural objects. This classification made it possible to determine which categories of small architectural forms may be most appropriate for the initial implementation of 3D printing in Uzbekistan.

SWOT analysis was used to assess the strengths, weaknesses, opportunities, and threats associated with the implementation of 3D printing technologies in the production of small architectural forms in Uzbekistan. This method was selected because the research focuses not only on the technological characteristics of 3D printing, but also on its practical prospects in local architectural and urban conditions. The SWOT analysis made it possible to evaluate internal factors, such as design flexibility, material optimization, equipment costs, and professional skills, as well as external factors, including urban development priorities, regulatory uncertainty, dependence on imported equipment, and climatic adaptation requirements.

Table 1

SWOT matrix for the implementation of 3D printing in small architectural forms in Uzbekistan

Strengths	Weaknesses
Design flexibility — ability to create complex and customized forms	High initial equipment cost — expensive printers, software, and maintenance
Material optimization — more efficient use of concrete and composite materials	Limited local experience — lack of specialists in construction 3D printing
Customization of urban elements — adaptation to specific parks, streets, campuses, and tourist zones	Limited technical infrastructure — insufficient availability of digital fabrication facilities
Reduction of material waste — additive production minimizes unnecessary material consumption	Absence of specific standards — lack of clear regulations for 3D-printed urban elements

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Opportunities	Threats
Modernization of public spaces — improvement of parks, pedestrian zones, and recreational areas	Slow adoption by the construction sector — conservative attitude toward new technologies
Use in parks, campuses, and tourist areas — practical application in urban improvement projects	Dependence on imported equipment — possible increase in costs and technical limitations
Development of local digital fabrication — creation of new architectural and technological competencies	Regulatory uncertainty — absence of certification and approval procedures
Support for sustainable urban design — resource-efficient and environmentally oriented production	Climatic and material adaptation risks — need to adapt mixtures and printed elements to local conditions

The research also considered the urban and climatic context of Uzbekistan. Public spaces such as parks, pedestrian areas, university campuses, tourist routes, residential courtyards, and recreational zones were analyzed as potential environments for the application of 3D-printed small architectural forms. The study assumes that small architectural forms may serve as the most appropriate initial stage for introducing construction 3D printing into architectural practice, as they require lower structural complexity compared to buildings while still providing significant opportunities for design innovation and urban improvement.

Thus, the selected methodology makes it possible to evaluate 3D printing not only as a manufacturing technology, but also as an architectural and urban design tool. This approach provides a basis for identifying practical directions for the gradual introduction of 3D printing technologies into the design and production of small architectural forms in Uzbekistan.

Table 2

Research methods used in the study

Research method	Purpose of application	Expected result
Literature review	To analyze scientific studies on construction 3D printing, additive manufacturing, and digital design	Identification of the theoretical basis and current research directions
Comparative analysis	To compare traditional production methods and 3D printing technologies	Determination of advantages and

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		limitations of 3D printing
Classification method	To group small architectural forms suitable for 3D printing	Identification of the most applicable types of urban elements
SWOT analysis	To assess strengths, weaknesses, opportunities, and threats in Uzbekistan	Evaluation of practical prospects and implementation barriers
Contextual analysis	To consider urban, climatic, and technological conditions of Uzbekistan	Adaptation of research findings to local conditions

RESULTS AND DISCUSSION.

The results of the study indicate that small architectural forms represent one of the most appropriate initial areas for the implementation of 3D printing technologies in Uzbekistan's architectural and urban design practice. Compared with full-scale buildings, small architectural forms require lower structural complexity, smaller material volumes, and more flexible regulatory procedures. This makes them suitable for experimental implementation in parks, pedestrian zones, university campuses, tourist areas, recreational spaces, and residential courtyards.

Based on the literature review and classification analysis, the most suitable categories for 3D printing include benches, urban furniture, planters, decorative landscape elements, sculptural objects, information stands, shading elements, and small pavilions. This result is consistent with recent studies emphasizing the potential of additive manufacturing for producing customized urban furniture and complex architectural elements for public spaces [12]. The possibility of creating non-standard geometries is particularly important for architectural design, because many small architectural forms perform not only a functional role but also contribute to the visual identity of public spaces.

The suitability assessment shows that benches, urban furniture, decorative elements, and planters have the highest potential for 3D printing. These elements are relatively compact, structurally manageable, and can be produced with a high degree of customization. Shading structures, information stands, and small pavilions also demonstrate considerable potential, although they require more careful attention to structural stability, weather resistance, material durability, and safety requirements.

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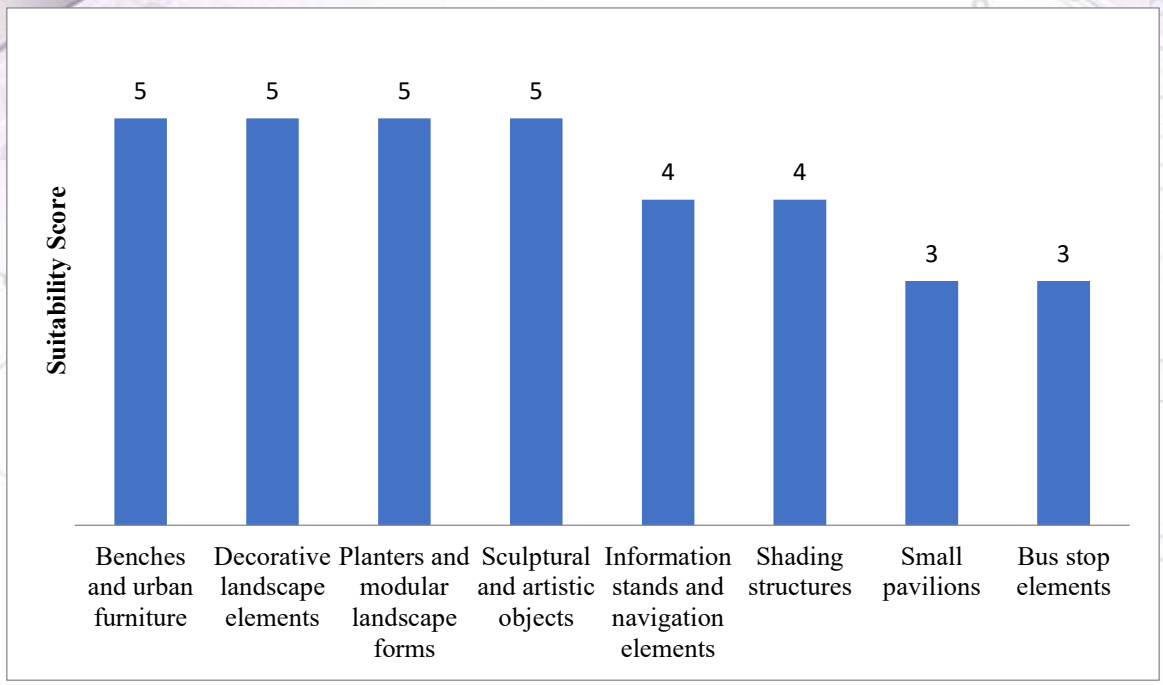


Figure 1. Suitability assessment of small architectural forms for 3D printing

Comparative analysis of traditional production and 3D printing. The comparative analysis demonstrates that 3D printing has several advantages over traditional production methods in the context of small architectural forms. The most significant advantages are design flexibility, customization, material optimization, and suitability for complex geometric forms. These characteristics are especially important in contemporary urban design, where public spaces increasingly require individualized, context-sensitive, and visually expressive solutions.

Traditional production methods are generally effective for standard and repetitive elements. However, they often limit formal diversity and require molds, formwork, or manual finishing for complex shapes. In contrast, 3D printing allows direct production from a digital model, reducing dependence on formwork and enabling the fabrication of complex geometries. Recent research on construction 3D printing also emphasizes its ability to reduce material waste through precise deposition and support more resource-efficient construction processes [13]. Systematic reviews of 3D printing in construction similarly note that additive manufacturing can improve production efficiency and reduce unnecessary material consumption.

At the same time, the results also show that 3D printing should not be interpreted as a universal replacement for traditional methods. In the current conditions of Uzbekistan, the technology is more appropriate as a complementary tool for selected categories of small architectural forms rather than as a fully dominant production method. The main limiting factors include high initial

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equipment costs, limited local experience, dependence on imported technologies, and the lack of specific standards for 3D-printed urban elements.

Table 3

Comparative analysis of traditional production and 3D printing for small architectural forms

Evaluation criterion	Traditional production	3D printing	Analytical interpretation
Design flexibility	Limited by standard forms and molds	Allows complex and customized forms	3D printing provides greater architectural freedom
Production speed	Requires several production stages	Enables faster digital fabrication	3D printing can reduce production time
Material efficiency	Often produces surplus material and waste	Uses material more precisely	3D printing supports resource optimization
Customization	Individual design is usually costly	Customization is easier and more flexible	Useful for site-specific urban design
Environmental potential	Depends on conventional material use	Can reduce material waste	Supports sustainable urban improvement
Complex geometric forms	Difficult and labor-intensive	Highly suitable for complex shapes	Strong advantage for innovative forms
Adaptability to public spaces	Mostly standardized solutions	Can be adapted to parks, campuses and tourist areas	Suitable for context-sensitive design
Initial equipment cost	Lower, because tools are already available	Higher due to specialized equipment	Cost remains a key barrier
Technical accessibility	Familiar to local builders and manufacturers	Requires trained specialists	Training is necessary for implementation
Regulatory readiness	Existing standards are well established	Specific standards are still limited	Regulatory support is required

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Long-term innovation potential	Moderate	High	3D printing has strategic future potential

The comparative analysis shows that 3D printing has clear advantages over traditional production methods in terms of design flexibility, customization, material efficiency, and the creation of complex geometric forms. These advantages are especially important for small architectural forms, because such elements must respond not only to functional requirements, but also to the aesthetic identity and spatial character of public spaces. For parks, university campuses, tourist zones, pedestrian areas, and recreational spaces in Uzbekistan, 3D printing can provide more individualized and context-sensitive design solutions.

At the same time, traditional production methods remain stronger in terms of technical accessibility, lower initial investment, and regulatory readiness. Existing production technologies are already familiar to local manufacturers and construction specialists, while 3D printing requires specialized equipment, digital modeling skills, material adaptation, and professional training. Therefore, 3D printing should not be considered an immediate replacement for traditional production, but rather as a complementary and innovative tool for selected categories of small architectural forms.

The results suggest that the most reasonable strategy for Uzbekistan is a gradual implementation model. At the first stage, 3D printing can be applied to benches, planters, decorative landscape elements, and urban furniture. At later stages, after gaining technical experience and developing regulatory support, the technology may be expanded to shading structures, information stands, small pavilions, and modular public space elements.

Implementation potential in the urban environment of Uzbekistan. The analysis of the urban context of Uzbekistan shows that the application of 3D-printed small architectural forms may be especially relevant for public space modernization. International development projects in Uzbekistan already emphasize the improvement of selected urban infrastructure, public spaces, and access to urban services. Project monitoring materials also identify the improvement of urban services and enhancement of public urban spaces as one of the project components [14].

In this context, 3D-printed small architectural forms can be considered a practical technological response to several urban design needs: modernization of public spaces, improvement of pedestrian comfort, development of recreational areas, enhancement of tourist routes, and creation of more expressive urban environments. Since the World Bank reports that Uzbekistan's urban population

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accounted for 50.63% of the total population in 2024, the quality of public urban spaces is becoming increasingly relevant for architectural and planning practice [15].

The proposed implementation model suggests that the introduction of 3D printing in Uzbekistan should be gradual. In the first stage, the technology may be applied to decorative and functional urban elements such as benches, planters, and landscape modules. In the second stage, it may be expanded to shading structures, information stands, and modular urban furniture. In the third stage, after the development of technical experience and regulatory support, 3D printing may be used for more complex objects such as small pavilions, bus stop elements, and integrated public space modules.

Discussion of key findings. The findings demonstrate that the main value of 3D printing for small architectural forms lies not only in technological innovation, but also in its architectural and urban design potential. The technology can support the creation of customized public space elements that respond to specific functional, aesthetic, climatic, and cultural requirements. This is particularly important for Uzbekistan, where public spaces in historic cities, tourist areas, university campuses, and residential neighborhoods require both modernization and preservation of local identity.

From an architectural perspective, 3D printing expands the possibilities of form-making. Curvilinear benches, modular planters, ornamental panels, and integrated urban furniture can be produced more efficiently than with conventional methods. This opens new opportunities for combining contemporary design with local ornamental traditions. For example, parametric patterns inspired by Uzbek geometric ornamentation could be integrated into 3D-printed concrete or composite elements, creating a connection between digital fabrication and regional architectural identity.

From an environmental perspective, the main advantage of 3D printing is related to material optimization. Since additive manufacturing deposits material only where it is needed, it can reduce excessive material consumption and waste generation compared with conventional subtractive or mold-based production methods. This is especially important for sustainable urban design, where resource efficiency and reduction of environmental impact are becoming key principles of architectural practice [16].

From a practical implementation perspective, however, the study reveals several limitations. The use of 3D printing in Uzbekistan requires specialized equipment, trained professionals, suitable material mixtures, digital modeling skills, and technical regulations. In addition, climatic conditions such as high summer temperatures, dust, freeze-thaw effects in some regions, and solar

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radiation must be considered when designing 3D-printed elements for outdoor public spaces. Therefore, the introduction of this technology should begin with pilot projects in controlled urban environments, such as university campuses, parks, and tourist zones.

Overall, the results suggest that small architectural forms can serve as a realistic first stage for introducing 3D printing technologies into the architectural and construction practice of Uzbekistan. Unlike large-scale printed buildings, small architectural forms allow experimentation with design, material behavior, production techniques, and urban integration at a lower level of risk. This makes them an appropriate platform for developing local expertise in digital fabrication and additive manufacturing.

Practical directions for application in Uzbekistan. The practical application of 3D printing technologies in the creation of small architectural forms in Uzbekistan should be considered as a gradual and strategically planned process. At the current stage, the most appropriate direction is not the direct transition to large-scale 3D-printed buildings, but the introduction of additive manufacturing through smaller, functionally clear, and architecturally expressive urban elements. Small architectural forms provide a flexible platform for testing material properties, production methods, design approaches, and public acceptance with lower technical and financial risks [17].

One of the most promising areas of application is the modernization of public parks and recreational zones. In these spaces, 3D-printed benches, planters, modular landscape elements, decorative panels, and sculptural objects can improve both functional comfort and visual identity. Such elements may be adapted to the specific character of each urban environment, including historical areas, newly developed parks, university campuses, tourist routes, and residential neighborhoods.

Another important direction is the use of 3D printing in tourist and cultural zones. Uzbekistan has a rich architectural heritage, and contemporary small architectural forms should not contradict this context. On the contrary, digital fabrication may allow the reinterpretation of traditional geometric patterns, ornamental motifs, and regional architectural forms in a modern technological language. This approach can create a balance between innovation and cultural continuity.

In university campuses, 3D printing can be used as both a practical design tool and an educational platform. Architecture and construction students may participate in the development of experimental prototypes, including urban furniture, landscape modules, information stands, and shading structures. This would contribute to the development of digital design competencies, parametric

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modeling skills, and a deeper understanding of additive manufacturing technologies.

For residential areas and mahalla environments, 3D-printed small architectural forms may be used to improve courtyards, playgrounds, pedestrian paths, and small recreational spaces. In this context, the technology can support the creation of customized, durable, and context-sensitive elements that respond to the needs of local communities.

Recommendations for gradual implementation. Based on the results of the comparative analysis and SWOT assessment, the implementation of 3D printing technologies in the production of small architectural forms in Uzbekistan should be organized in several stages.

At the first stage, pilot projects should be developed for simple and low-risk elements, such as benches, planters, decorative landscape modules, and small urban furniture. These objects require relatively limited structural complexity and can be tested in controlled environments, such as university campuses, parks, and exhibition areas. The main purpose of this stage is to evaluate material behavior, production accuracy, surface quality, durability, and public perception [18].

At the second stage, the technology may be expanded to more functionally complex elements, including information stands, shading structures, modular seating systems, and decorative panels for public spaces. At this level, greater attention should be paid to ergonomics, climatic comfort, safety, maintenance, and integration with the surrounding architectural environment.

At the third stage, after the accumulation of practical experience, 3D printing can be applied to more complex small architectural forms, such as small pavilions, bus stop elements, modular recreational structures, and integrated public space systems. This stage requires more advanced digital modeling, structural verification, material testing, and regulatory support.

A separate recommendation is the development of local material solutions. Since the climatic conditions of Uzbekistan include high summer temperatures, solar radiation, dust, and regional temperature variations, 3D-printed elements must be designed with consideration of durability, surface protection, thermal behavior, and resistance to outdoor environmental impacts. Therefore, material adaptation should become one of the key research directions for future studies.

It is also necessary to develop professional training programs for architects, designers, engineers, and construction specialists. The successful implementation of 3D printing depends not only on equipment, but also on the ability to work with digital models, parametric design tools, material parameters, printing strategies, and post-processing methods.

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Finally, the introduction of 3D printing into the urban environment requires the development of technical and regulatory guidelines. These guidelines should define requirements for safety, durability, material properties, installation, maintenance, and public use of 3D-printed small architectural forms.

Table 4

Proposed stages for implementing 3D printing in small architectural forms in Uzbekistan

Implementation stage	Main objects	Main purpose	Expected result
Stage 1: Pilot application	Benches, planters, decorative modules, urban furniture	Testing technology in low-risk urban elements	Initial practical experience and prototype evaluation
Stage 2: Functional expansion	Information stands, shading elements, modular seating systems	Improving functional and ergonomic quality of public spaces	Wider use in parks, campuses, and pedestrian zones
Stage 3: Complex urban structures	Small pavilions, bus stop elements, modular public space systems	Integration of 3D printing into urban improvement projects	Formation of advanced digital fabrication practice
Stage 4: Local adaptation	Climate-resistant and culturally adapted elements	Development of local material and design solutions	Sustainable and context-sensitive urban design

CONCLUSION AND SUGGESTIONS.

The study examined the prospects for the use of 3D printing technologies in the creation of small architectural forms for the urban environment of Uzbekistan. The results show that this technology has significant potential to improve the functional, aesthetic, and environmental quality of public spaces. Compared with traditional production methods, 3D printing provides greater design flexibility, enables customization, improves material efficiency, and allows the creation of complex geometric forms that are difficult to achieve through conventional fabrication methods.

The analysis demonstrates that small architectural forms represent one of the most appropriate initial fields for introducing 3D printing into architectural

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and construction practice in Uzbekistan. Benches, planters, decorative landscape elements, sculptural objects, urban furniture, information structures, shading elements, and small pavilions can serve as practical examples for the gradual implementation of this technology. These elements are relatively small in scale, less structurally complex than buildings, and directly related to the modernization of public spaces.

At the same time, the implementation of 3D printing in Uzbekistan is associated with several limitations. These include high initial equipment costs, limited technical infrastructure, insufficient local experience, the need for trained specialists, material adaptation requirements, and the absence of specific regulatory standards for 3D-printed urban elements. Therefore, 3D printing should not be viewed as an immediate replacement for traditional production methods, but rather as a complementary and innovative tool for selected categories of small architectural forms.

The findings suggest that a gradual implementation strategy is the most appropriate approach for Uzbekistan. Pilot projects in university campuses, parks, tourist zones, and recreational areas can create the necessary experimental basis for further development. In the long term, 3D printing may contribute to the digital transformation of architectural design, the modernization of urban improvement practices, and the formation of more sustainable, expressive, and context-sensitive public spaces.

Based on the results of the study, several practical suggestions can be proposed. First, pilot projects should be developed for low-risk small architectural forms such as benches, planters, decorative modules, and urban furniture. Second, local material mixtures suitable for Uzbekistan's climatic conditions should be tested, particularly with regard to heat resistance, durability, surface protection, and long-term outdoor performance. Third, professional training programs should be organized for architects, designers, engineers, and construction specialists in the fields of digital modeling, parametric design, additive manufacturing, and post-processing technologies. Fourth, technical and regulatory guidelines should be developed to define safety, durability, installation, maintenance, and public-use requirements for 3D-printed small architectural forms.

Thus, 3D printing can be considered not only a technological innovation, but also a promising architectural and urban design instrument. Its application in small architectural forms may become an effective first step toward integrating additive manufacturing into the architectural and construction sector of Uzbekistan.

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