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Additive Technologies in Architectural Modeling: A Modern Way of Restoring the Historical Environment

Technologie addytywne w modelowaniu architektonicznym – nowoczesny sposób na odtworzenie historycznego otoczenia

Keywords: Monument of architecture, reconstruction, additive technologies, architectural models

Słowa kluczowe: zabytki architektury, rekonstrukcja, technologie addytywne, modele architektoniczne

Introduction

Preserving masterpieces of architecture and art of the past is currently especially relevant. Aggressive environmental impact, human carelessness, merciless time and other factors have a negative impact on their safety. Therefore, additive technologies are increasingly often used to preserve and restore cultural heritage sites. The purpose of this study was to identify a modern method of restoration of architectural heritage, the use of additive technologies in the creation of architectural models. To substantiate the role of modeling in restoration activities, it is necessary to consider the very concept of "model," as well as the content of this concept in the framework of design and artistic activity in the general sense.

The academic and methodological basis of the research was the works related to issues of sustainable urban development, as well as those devoted to the historical aspects of architectural monuments and urban planning.

Methods and sources

The focus of this research is on the study of modern technologies for creating models of the historical environment and further implementation in the restoration of architectural monuments. The use of additive technologies in various fields of activity is studied by various Ukrainian and foreign researchers. The term "building information model" was first used by G.A. Van Nedervin and F.P. Tolman in 1992 [van Nederveen, Tolman 1992, p. 215].

In this paper, we are interested in the use of additive technologies in the practice of working with historical buildings—architectural monuments. S. Vitasek presented the use of Building Information Modeling (BIM) to create design documentation for a historic building (HBIM). Vitasek displayed how a BIM model can be linked to various database tools on the example of a specific historical building (All Saints' Church) at the basic methodological level [Vitasek 2022, p. 4].

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J. Castellazi and colleagues presented a case study that demonstrates an adapted online database developed to include BIM models of architectural monuments and related historical documents [Castellazzi et al. 2023, p. 7320].

H.M. Levchenko, P.S. Beiner, and N.V. Beiner studied the use of BIM technologies in the reconstruction of buildings during the urban renewal in Ukraine. They took into account the specifics of damage to structures during the war, emphasized the need for a comprehensive study before carrying out design work, and clearly demonstrated an example of the use of BIM in reconstruction practice [Levchenko et al. 2022, p. 65].

The analysis of the literature on the use of additive technologies in the work with historic buildings showed that there are currently theoretical and practical developments in the field of information modeling, but the field of restoration of architectural monuments is poorly understood. It is more about the graphic reconstruction of lost or rebuilt structures, which can be more likely attributed to conventional 3D modeling. The use of ad hoc technologies is most widespread in new design and construction, in the reconstruction of structures that do not have cultural and historical value for various purposes. This necessitates a detailed study of the possibilities of additive technologies in the restoration of architectural monuments.

Results

As a result of research on the use of additive technologies in architectural modeling, models of both individual elements of historic buildings in places like Kyiv (Figs. 5–6), and the entire historic quarter of Odesa were created for visual study, preservation, and restoration of historical and cultural heritage (Fig. 7). The quarter in Odesa, shown in the Figure, contains a model of the building of the Odesa Transfiguration Cathedral, which was destroyed by rocket attacks on July 23, 2023. Modeling the environment with the help of additive technologies allowed us to improve the methodology for comparing the model of the current state of the structure (with traces of destruction) with the ideal model of graphic reconstruction of that structure, made on the basis of previous research/fixations (architectural monument passport, registration sheet, archival materials, etc.).

History of creating architectural models

The architectural layout has accompanied architectural design work since ancient times. Models were created in ancient Greece and the Renaissance to represent architectural designs. These models were made by professional sculptors and carpenters. The architectural layout has a long history. The ancient Egyptians placed miniature houses and temples in tombs. In Ancient Greece, the sacred gave way to earthly practicality—with the help of wax and wooden models. The ancient Greeks evaluated the quality of a project and demonstrated new

Fig. 1. Model of the Tripoli temple, sixth to third century BC, burnt clay, National Museum of the History of Ukraine, Kyiv; source: www.architektonix.com/maketuvannya/istoriya-maketuvannya/ (accessed: 1.08.2024)

Ryc. 1. Model świątyni Trypillian, VI–III w. p.n.e., wypalana glina, Narodowe Muzeum Historii Ukrainy, Kijów; źródło: www.architektonix.com/maketuvannya/istoriya-maketuvannya/ (dostęp: 1.08.2024)

solutions in the field of architecture. During the Renaissance, a very large model of St. Peter's Basilica, more than 7 m long, was built and was impressive in its details. Most experts claim that during the times of Ancient Egypt, Assyria and Ancient Greece, architects did not use drawings, but models [Burdo 2008, pp. 135–136]. Among what is considered the oldest surviving models are the Trypillia models of residential (Fig. 1) and religious buildings (Fig. 2). Discovered in excavations in Ukraine, they date back to between the sixth and third centuries BC. They conveyed the appearance of the building with its vertical pillars or smooth painted walls, sometimes depicting the interior of a house with a stove, benches and even utensils [Burdo 2008, p. 142].

Architectural models of buildings are found during archaeological excavations not only in Europe, but also in America, as well as in Asian countries. For example, ritual and architectural models from ancient India and China (Fig. 3) dating from between the tenth and twelfth centuries have survived.

In Peru, there is a unique model of pre-Columbian America, the archaeological artifact dubbed the Sayhuite Stone (Fig. 4). It depicts a city with a functioning irrigation system. Presumably created by the craftsmen of the Inca Empire between the tenth and fifteenth centuries, the model was carved from a solid granite boulder with a diameter of about 4 m. It is assumed that mercury was used to accurately model the hydrodynamic properties of water.

On the frescoes and mosaics in the churches of Byzantium and the Kyivan Rus, one can find images of prominent figures of the respective eras with models of churches in their hands. For example, on a fresco of the eleventh century depicts Yaroslav the Wise with a model of the Church of St. Sophia of Kyiv. Similar images of authors or customers with models in their

Fig. 2. Model of a Tripoli house, 4600–3900 BC, burnt clay, History Museum of Romania, Bucharest; source: www.architektonix.com/maketuvannya/istoriya-maketuvannya/ (accessed: 1.08.2024)

Ryc. 2. Model domu trypolitańskiego, 4600–3900 p.n.e., wypalana glina, Muzeum Historyczne Rumunii, Bukareszt; źródło: www.architektonix.com/maketuvannya/istoriya-maketuvannya/ (dostęp: 1.08.2024)

hands are found in paintings and pictures of medieval Europe. For example, a seventeenth-century painting by Domenico Fetti depicts the architect Antonio Maria Viani presenting a model of the Church of St. Ursula to Margherita Gonzaga d'Este.

Giuliano da Sangallo, Giacomo della Porta, Michelangelo Buonarroti, Filippo Brunelleschi, Christopher Wren, Antoni Gaudí—it is impossible to list all the prominent architects who used models in their work. Modern modeling, like other areas of design, relies on innovative technologies. Thus, we can conclude that over its thousands of years of history, modeling has not only not lost its relevance, but has also acquired new forms and continues to improve and help people in various areas of design.

Architectural model as an integral part of restoration

Modern modeling, like other areas of design, is experiencing favorable times. The centuries-old developments of previous generations have been preserved, information is available, technology is rapidly developing, the variety of materials used is great, numerous interesting directions are in demand. Modeling effectively works in the areas of restoration and reconstruction of both buildings and the architecture of entire cities. In the international practice of the reconstruction of historical centers, there is experience of chaotic mass demolition of historical buildings and construction of modern ones. So, in Brussels in the 1960s and 70s, under the pretext of building a "city of the future" entire neighborhoods were cleared of their populations and redeveloped with office buildings. The "reconstruction" of Brussels was distinguished not in scale, but in the absence of a single plan and any aesthetic restrictions on new construction. "This practice has received the name 'Brusselization'—in the narrow sense, 'peaceful' resettlement of historical buildings with their subsequent 'natural' destruction over the course of decades" [Kotsiubivska, Baranskyi 2020, pp. 59–68]. In modern Europe, historic buildings are preserved with greater care, adapting to needs, including the preservation of historic facades.

Also, models of dwellings, temples and other structures serve as an important auxiliary material for recreating the picture of the architectural and construction activity of long-disappeared cultures. The architectural model's method was especially widely used by specialists to recreate the architecture in its reduced scale of the ancient cities of Greece and Rome. For this, there were many archaeological and historico-architectural materials, and many monuments of Ancient Greek and Roman architecture have come down to us with a high degree of preservation. Both individual elements of the ancient order and temple ensembles, residential buildings, quarters, city squares and entire cities were subject to modelling [Rallev, Vanchugov 2005, pp. 4–17].

Additive technologies and the restoration of architectural monuments

In the age of modern technology, the use of innovative devices and technologies greatly simplifies and at the same time accelerates the work of architects and designers when developing documentation for the reconstruction of architectural monuments. The preservation of historical buildings has been very important at all times, because architectural monuments reflect the greatness and uniqueness of the country.

According to UNESCO, as of February 19, 2025, damage to 485 structures has been confirmed in Ukraine since February 24, 2022—149 religious structures, 249 buildings of historical and/or artistic interest, 33 museums, 33 monuments, 18 libraries, 1 archive and 2 archaeological sites. Therefore, at present, the issue of the reconstruction and redevelopment of Ukrainian cities is one of the highest priorities.

The basis of additive technologies for building renovation was such digital technologies as laser scanning, GIS systems, photogrammetry, visual anthropology, architectural endoscopy; later an attempt was made to avoid flat projections in drawings and move on to the creation of three-dimensional compositions (3D models), circular panoramas using special computer programs. BIM is currently successfully used in the UK, the USA and other developed countries.

The information model as a tool for working with architectural heritage is used in two main areas: virtual graphic reconstruction of lost cultural heritage sites (Fig. 5, 6) and graphic reconstruction of existing architectural monuments, which involves creating a duplicate of the building in the virtual world in order to predict possible changes in the characteristics of the real building (Fig. 7). Thanks to information technologies, the prerequisites for the emergence of new methods in restoration in the process of reproducing valuable architectural objects are already being created.

Fig. 3. Earthenware funerary model of a house complex, 1450–1600 (circa), Ming dynasty, earthenware, British Museum, London; source: www.britishmuseum.org/collection/object/A_1937-0716-8 (accessed: 1.08.2024)

Ryc. 3. Gliniany model grobowy kompleksu mieszkalnego, [ok.] 1450–1600, dynastia Ming, ceramika, British Museum, Londyn; źródło: www.britishmuseum.org/collection/object/A_1937-0716-8 (dostęp: 1.08.2024)

Fig. 4. City model, tenth to sixteenth century (circa), Peru, Apurimac Region, granite; source: www.theancientconnection.com/megaliths/peru/cuzco-golden-city/ (accessed: 1.08.2024)

Ryc. 4. Model miasta, [ok.] X–XVI w., Peru, region Apurímac, granit; źródło: www.theancientconnection.com/megaliths/peru/cuzco-golden-city/ (dostęp: 1.08.2024)

In the context of working with historic buildings, models using additive technologies must include information related to various requirements for facility management and collecting statistics. Thus, the model itself constitutes a significant part of the design documentation in the form of graphical and non-graphical information. A key agent involved in the standardization of this information is the Data Standard for Buildings (DSB). HBIM models are generated based on the DSB.

Let us consider the possibilities of additive technologies in the context of working with historical buildings. Unfortunately, in practice we constantly encounter the lack of comprehensive documentation even for significant architectural monuments. The introduction of additive technologies allows us to manage fragmented historical data, supplement them at any time and interpret them in order to create accurate models [Kysil et al. 2020, pp. 5–18]. The integration of BIM tools with traditional conservation practices is possible through collaboration between BIM specialists and restoration architects. This will provide an opportunity to study the model in detail from the standpoint of authenticity and introduce new technologies during the development of design documentation and direct work on the site. Additive technologies allow for the implementation of a multi-faceted structure for architectural and restoration research. The detail of the original model may not always meet the standard required for restoration and design work, but it serves as an important starting point. The ability to improve the model with the emergence of new data is very promising. At the same time, it is possible to gradually create a library of parametric elements (from typical objects or analogues), which will allow optimizing future modeling efforts, ensuring greater accuracy of architectural details, especially in the event of their complete loss.

For historical buildings, it is important to preserve authenticity. Reconstruction of the facade must take into account certain conditions in order to most accurately recreate the former appearance. Specialists can also decide on fragmentary restoration, which is characterized by a lack of desire for stylistic unity. In this case, it is advisable to fit the building into the existing building. Therefore, the preliminary development of the BIM model comes to the fore. If, before the reconstruction, a virtual model of the building is created, the

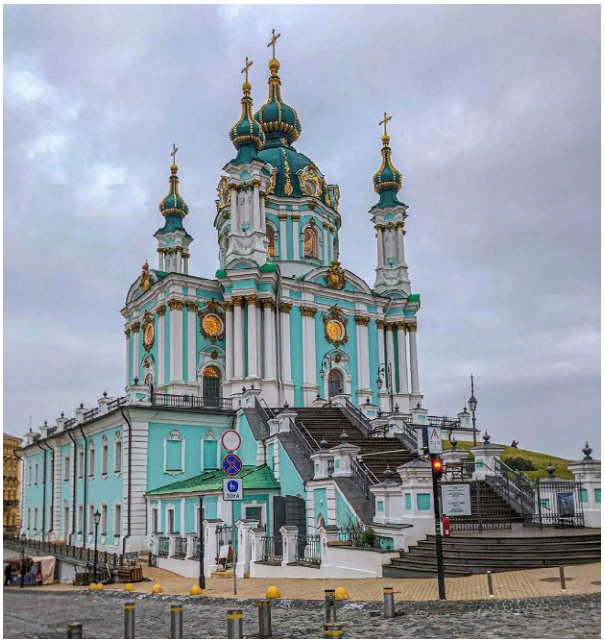

Fig. 5. St. Andrew`s Church, Kyiv, 2024; photo by G. Kyselova
Ryc. 5. Kościół św. Andrzeja, Kijów, 2024; fot. G. Kyselova

Fig. 6. The graphic model created using 3D scanning; figure by G. Kyselova
Ryc. 6. Model graficzny stworzony za pomocą skanowania 3D; rys. G. Kyselova

facade is processed, and small architectural elements are paid attention to, it is possible to control the quality and speed of repair work, minimize possible errors and inaccuracies, and avoid expensive rework (Fig. 7). All this leads to a reduction in the cost of construction. A carefully thought-out reconstruction project using BIM technologies for historical buildings, old structures and cultural heritage monuments allows for significant optimization of costs not only during the restoration of structures but also at the operation stage.

Working with additive technologies is an example of combining advanced technologies with the preservation of historical and cultural heritage. BIM provides a transformative platform for the documentation, analysis and preservation of cultural heritage, going far beyond the market of architecture, design, construction and operation, serving a wide range of professionals and researchers. In addition, it is about the broader use of opportunities: in addition to academic research to virtual reality applications, cloud accessibility democratizes historical and cultural heritage data, making them accessible on a global scale.

The potential of implementing BIM programs for planning and managing the reconstruction of the affected building was determined in sequential stages:

1. 3D BIM application: development of a 3D BIM model of the proposed conceptual solution of the building unit. The BIM model was created in compliance with the features and characteristics of the selected historical prototype and is based on a system of preliminary research of traditional buildings.
2. 4D BIM application: this application assesses the time efficiency of adopting the proposed reconstruction approach. At this stage, the potential of BIM implementation in planning the development and implementation timelines of the project is tested. This BIM software conducts time-based research by linking the developed BIM model to a set of construction works, each of which has a defined time period associated with a specific element or stage of construction.
3. 5D BIM Application: This program evaluates the cost-effectiveness of the proposed reconstruction paradigm—it performs cost calculations using the quantities generated from the BIM model and then links them to construction prices to provide a real-time cost estimate.
4. 6D BIM Application: This program tests the expected operational behavior of the proposed reconstruction model compared to conventional building systems in the city. The developed BIM model is linked to a specific geographical setting, then exported to Green Building Studio (a cloud-based BIM tool) which performs energy consumption calculations using the geographical settings of the city of Mosul and the building characteristics of the BIM model.
5. 7D BIM Application: This program investigates the deconstruction phase of the proposed prototype development [Saeed et al. 2021, pp. 1–23]

Conclusions

The problem of research, preservation and restoration of architectural monuments does not lose its relevance, since it is a significant part of our culture.

Recently, additional factors in the destruction of monuments have appeared, which require separate

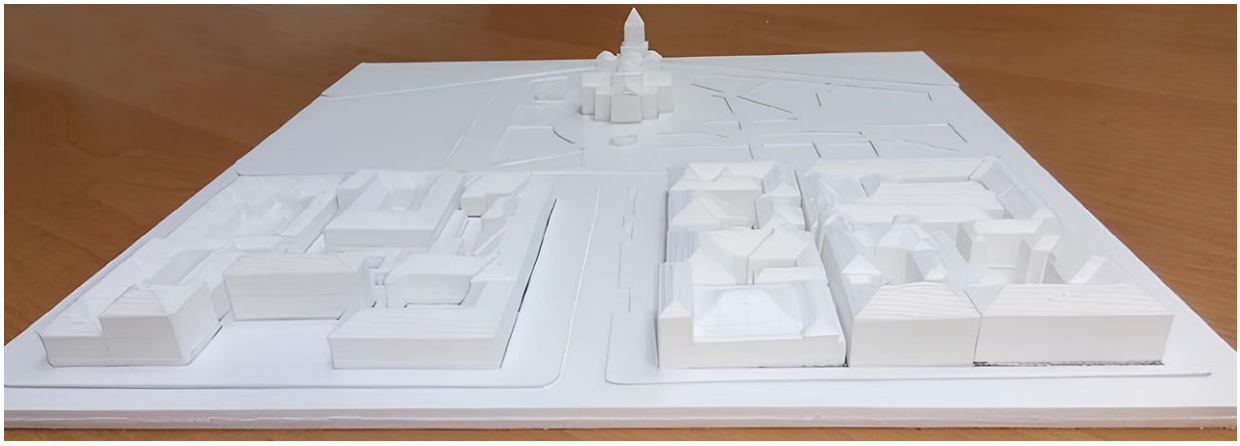

Fig. 7. 3D model of a fragment of Cathedral Square Odessa, Ukraine; by V. Kyselov
Ryc. 7. Model 3D fragmentu placu katedralnego w Odessie, Ukraina; oprac. V. Kyselov

study. We are talking about the consequences of the armed aggression of Russia against Ukraine. Buildings suffer significant damage, which often have their own specifics, which manifest themselves even over time. Some buildings can be saved only in the case of carrying out emergency conservation work in order to stabilize the structure. For this, it is necessary to conduct a survey in a short time and formulate a technical solution that will allow for rescue work.

Summarizing all of the above, we can speak of a new contribution to the modeling and management of cultural heritage sites through the integration of Building Information Modeling (BIM) and cloud solutions. The construction of BIM models provides innovative solutions to the problems associated with the preservation, research, restoration and operation of historical buildings, including incomplete data and additional threats during war.

The study revealed difficulties in processing archival information on architectural monuments, the absence or incomplete presentation of the construction history of objects (no detailed research or data has been preserved), and the poor repair of monuments. These challenges highlight the importance of continuous improvement of software adapted to the unique needs of heritage conservation and rehabilitation.

Fig. 8. 3D model Corinthian capital; by V. Kyselov
Ryc. 8. Model 3D kapiteli korynckich; oprac. V. Kyselov

References / Bibliografia

Secondary sources / Opracowania

Antonini Ernesto, Kaya Fuat Emre, Palermo Michele, Pretelli Marco, *Applications of additive manufacturing in construction and historic building restoration/rehabilitation*, Bologna 2021.

Burdo Nataliia, *Сакральний світ трипільської цивілізації*, Kyiv 2008.

Feilden Bernard, *Conservation of historic buildings*, London 2009.

Gibson Ian, Rosen David, Stucker Brent, *Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing*, New York 2015.

Gumen Olena, Lebedeva Olha, *Additive technologies in restoration and reproduction of elements of architectural objects*, "Applied Geometry, Design, Intellectual Property Objects and Innovative Activities of Students and Young Scientists" 2017, pp. 269–274.

Levchenko Nataliia, Beiner Petro, Beiner Nadiia. *Реконструкція будівель з використанням BIM технологій при відновленні міст в Україні*, "Матеріалознавство та технічна обробка металів – Metallurgy and heat treatment of metals" 2022, vol. 4, iss. 99.

Kotsiubivska Kateryna, Baranskyi Stepan, *3-D моделювання при відновленні історико-культурних цінностей*, "Tsyfrova platforma: informatsiini tekhnolohii v sotsiokulturnii sferi" 2020, no. 3, iss. 1.

Kutsevych Vadym, Marusyk Tamara, Korotun Iryna, Dyvak Viktor, Herych Kateryna, *Теоретичні і практичні основи реставрації*, Chernivtsi 2024.
Kysil Olga, Kosarevska Raddamila, Levchenko Oleksii, *The innovation of accounting and certification ofhistoric architectural monuments using BIM technology*, "Budownictwo i Architektura" 2020, vol. 19.
Labonnote Nathalia, Rønnquist Anders, Manum Bendik, Rüther Petra, *Additive construction: state-of-the-art, challenges and opportunities*, "Automation in Construction" 2016, vol. 72.
Rallev Aleksandr, Vanchugov Volodymyr, *Воссоздание поселения поздней бронзы Вороновка II методом макетирования,* "Uzhgorodskij naczionalnij universitet Press" 2005, vol. 33.
Saeed, Zaed, Almukhtar Avar, Abanda Henry, Tah Joseph, *BIM Applications in Post-Conflict Contexts: The Reconstruction of Mosul City*, "Buildings" 2021, vol. 11, iss. 351.
Subin-Kozhevnikova Alona, Khorosha Oksana, Oliinychenko Valerii, *Особливості та перспективи використання адитивних технологій в архітектурі*, "Сучасні проблеми архітектури та містобудування" 2023, vol. 67.
Monika Utěšená, Radka Pernicová, *Technology of 3D Print in Field of Renovation of Architectural*
Structures and Historical Buildings, "International Journal of Rapid Manufacturing" 2018, vol. 5.
van Woensel Remco, van Oirschot Teun, Burgmans Mats Johanes Henrikus, Mohammadi Masi, Hermans Kristel, *Printing Architecture: An Overview of Existing and Promising Additive Manufacturing Methods and Their Application in the Building Industry*, "The International Journal of the Constructed Environment" 2018, no. 9, iss. 1.
Xu Jie, Ding Lieyun, Love Peter E.D., *Digital reproduction of historical building ornamental components: From 3D scanning to 3D printing*, "Automation in Construction" 2017, vol. 76.

Documentation / Dokumentacja

ASTM International, ISO/ASTM 52900:2015: Standard Terminology for Additive Manufacturing
Technologies e General Principles – Terminology, American Society for Testing and Materials,
ASTM International, 2015.

Electronic sources / Źródła elektroniczne

Druk 3D w budownictwie, Botland blog, https:// botland.com.pl/blog/druk-3d-w-budownictwie/ (accessed: 6.03.2025).
Vitasek S. *The use of the BIM method for sustainable care of historic buildings: Methodological framework*, SHS Web of Conferences 132 01023,
https://doi.org/10.1051/shsconf/202213201023 (accessed: 6.03.2025)
Damaged cultural sites in Ukraine verified by UNESCO, https:// www. unesco.org/en/articles/ damaged-cultural-sites-ukraine-verified-unesco?hub=66116 (accessed: 6.03.2025)

Abstract

This paper presents a study on the possibilities of additive technologies in working with damaged architectural monuments, including those affected by military operations. The problem of preserving cultural heritage has always been relevant, but it has gained particular importance in recent years. The full-scale war on the territory of Ukraine is accompanied by significant destruction, including of architectural monuments. The purpose of this paper is to analyze the possibilities of additive technologies in terms of their use in the restoration of architectural monuments. This paper examines the history of architectural models, identifies the relationship between architectural models and restoration processes. Based on the materials studied, it can be argued that additive technologies have a serious prospect of being used in the work with architectural monuments. They allow to create complete and accurate documentation, enter additional information in the process of working on the site, conduct design work by specialists of different directions on a single platform, speed up decision-making, eliminate possible errors, and control project implementation.

Streszczenie

Artykuł poświęcony jest badaniom możliwości technologii addytywnych w pracy z uszkodzonymi zabytkami architektury, w tym uszkodzonymi w wyniku działań wojennych. Problem ochrony dziedzictwa kulturowego zawsze był aktualny, ale w ostatnich latach stał się szczególnie ważny. Pełnowymiarowej wojnie na terytorium Ukrainy towarzyszą poważne zniszczenia, w tym zabytków architektury. Celem niniejszego artykułu jest analiza możliwości technologii addytywnych pod kątem ich wykorzystania w renowacji zabytków architektury. W artykule rozważono historię modeli architektonicznych, ujawniono związek między tymi modelami a procesami renowacji. Na podstawie analizowanych materiałów można stwierdzić, że technologie addytywne mają duży potencjał zastosowania w pracy z zabytkami architektury. Pozwalają one na tworzenie kompletnej i dokładnej dokumentacji, wprowadzanie dodatkowych informacji w procesie pracy na miejscu, prowadzenie prac projektowych przez specjalistów z różnych dziedzin na jednej platformie, przyspieszanie podejmowania decyzji, eliminowanie możliwych błędów i kontrolowanie realizacji projektu.