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Techniques for creating and printing historical architectural artifacts in 3D

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Abstract

The authors outline a technique for creating and printing three-dimensional models that can be used for graphic reconstruction of old architectural objects. An illustration of the sequence of implementation of the methodology is the creation of a model of the Parochial Cathedral of St. Mary. To reveal the implementation of the methodology, the authors demonstrate the sequence of execution of the stages of architectural-spatial modeling: analysis, construction, design, printing of the model. The analytical stage of designing the model of the cathedral was carried out on the basis of archival photographs and drawings. A stereogram miniature of the destroyed cathedral was used to create a three-dimensional model. Measurement of image parallax serves as the basis for reconstruction of the configuration of a spatial object. The stages of project implementation are defined. The methods of modeling using 3DS Max tools and preparing the model for 3D printing in Cura are presented.

Keywords: methods building and printing; 3-D models; historical architectural objects.

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INTRODUCTION

Problem setting. An important task for modern society is the preservation of cultural heritage, in particular architectural and historical objects, which, unfortunately, are often destroyed not only for objective reasons (time), but also because of wars, human cruelty and indifference. Architectural objects, which quite often carry significant historical value, are demolished or reconstructed, and then they can be found only in preserved pictures or descriptions (Rozhko, 2013). Reconstruction of architectural artifacts was usually carried out only in the form of descriptions, paper sketches and

drawings. However, this method of reproduction does not always allow to convey the compositional features and authenticity of the reconstruction. Therefore, for such historical objects, graphic reconstruction as a scientific study is the only means of identification of a lost or destroyed architectural artifact (Remeshylo-Rybchynska & Brych, 2013).

The development of computer modeling and 3D graphics technologies makes it possible to reproduce historical artifacts not only in the form of images or photographs, but also in the form of spatial models (Hevko, Potapchuk, Lutsyk, Yavorska, & Tkachuk, 2020). The use of digital technologies in architectural modeling and historical research has given rise to the emergence of new techniques and methods that create the possibility of deeper analysis of sources and also expand the tools of research.

Thus, mastering the technologies of three-dimensional modeling and printing, identifying their possibilities in the study and reconstruction of the historical and cultural heritage is an urgent task. Reproduction of architectural artifacts in the form of three-dimensional models can fill the information vacuum in the study of cultural heritage, which are currently presented only in the form of a description or individual photographs.

Analysis of recent research and publications. In modern scientific literature, a number of studies are devoted to the issue of 3D modeling techniques and the selection of appropriate software, in particular, D. Banach, T. Boardman, J. Jones, M. Giambruno, H. Chemerys covered this issue (Chemerys, Osadcha, Osadchyj, & Kruhlyk, 2019). V. Rozhko, K. Osadcha, M. Ozhha, I. Hevko, O. Bodnar, O. Boichuk, V. Danylenko, and others revealed the peculiarities of solving three-dimensional modeling tasks for architectural projects in their research (Osadcha, & Chemerys, 2017; Ozhha, 2015; Hevko, Potapchuk, Sitkar, Lutsyk, & Koliasa, 2020; Danylenko, 2005).

The research of Kateryna Kotsiubivska, Stepan Baranskyi, Riabokon is devoted to the study of the possibilities of 3D modeling tools in the tasks of computer reconstruction of objects of historical and cultural heritage (Kotsiubivska & Baranskyi, 2020; Riabokon, 2002). In the work of O. Remeshylo-Rybchynska and M. Brych (2013), it is stated that "It is impossible to reproduce a destroyed work, ... but there are ways to "recreate" a building by creating a modern engineering structure instead of the original monument – an architectural installation of a building that imitates certain historical architectural forms, a

life-size model. Such means... will be able to preserve and convey to posterity the priceless images of the artistic heritage of mankind."

At the same time, the analysis of scientific literature allows us to draw conclusions about the need for further scientific research, which is devoted to the disclosure of the features of the application of 3D modeling in architecture, which will focus on the reconstruction of architectural artifacts and is aimed at preserving the cultural heritage of society.

The relevance of the mentioned problem made it possible to determine **the purpose of the article** – to reveal the features of the technique of creating and printing 3D models of historical architectural artifacts using modern digital tools.

RESEARCH RESULTS

The technique of creating and printing three-dimensional models, which are expedient to use for the graphic reconstruction of historical architectural objects, is formed on the basis of the step-by-step implementation of the following processes: analysis, construction, design, printing of the model (Hevko, Potapchuk, Lutsyk, Yashchyk, & Makarenko, 2022):

- At the analysis stage, data is collected about the object and necessary operations are performed to create a 3D model based on the available information.
- Object design, which includes 3D modeling and animation processes using modern software tools and appropriate methods.
- The design stage – includes texturing and rendering with respect to color gamut, selection of textures, light sources and adjustment of camera angles. It should be noted that already in the formulation of the problem, it is necessary to determine the degree of realism of the projection of the projected object, which depends on the selected materials for overlaying textures on the object.
- Model printing – is the final stage in the production of the model, which requires preliminary adjustment of the 3D printing process, in particular, calibration and selection of materials.

Thus, the construction of models of historical monuments corresponds to the general sequence of the graphic modeling process for various objects: analytical stage (collection of initial information; calculation of dimensions and

parameters of the object) and modeling (construction of a sketch and determination of the main elements of the basic model; design of a computer model; printing of the model).

Analytical stage of research

Perhaps the most difficult stage in the reconstruction of the appearance of historical monuments is the analytical stage. After all, the graphic reconstruction of lost or destroyed architectural objects is a specific type of activity aimed at studying these objects with the aim of restoring their appearance during their existence with the help of 3D graphics, guided by preserved documents, drafts or photographs (Hevko, Potapchuk, Lutsyk, Yavorska, & Tkachuk, 2020). The main difficulty in graphic reconstruction is the lack of accurate data about the object.

The Parochial Cathedral of St. Mary of the Perpetual Assistance is one of the lost historical objects of Ternopil, which adorned the city center at the corner of Ruska and Mickiewicz streets (now – Shevchenko Boulevard). This architectural monument was completely destroyed in the 1950s, so today the main sources of information about the cathedral are photographs and drafts (Boytsun, 2003). The historical and architectural key plan of Ternopil shows that "the majestic and elegant building in the neo-Gothic style was impressive with its beauty and perfection. A slender tower-spire 62 meters high hovered over the city, as if reaching for the sky. It was even used as a fire tower, built according to the project of the famous Lviv architect Professor Teodor Maryan Talovskyi (Ukrzakhidproektrestavratsiya, 2012).

Descriptions, photographs and drawings of the Parochial Cathedral (Fig. 1), as well as information on the construction technologies of cathedrals of that era, were analyzed for computer reconstruction.

In order to solve the problem of insufficient graphic information based on image analysis, we propose to use the method of graphic reconstruction using a stereo pair. The method is based on receiving and processing a set of pairs of images. In this case, the selection of correspondence points, their comparison and geometric transformations are carried out. Obtaining a pair or series of images in which parallax is observed is the basis of this method. So, to build a 3D model, it is necessary to perform an algorithm of actions: determining the fundamental matrix, finding the corresponding points, building a cloud of

points, texturing. It should be noted that the model built using this method allows you to reproduce only the appearance of the object.



Figure 1. **Archival photos of the Parochial Cathedral of St. Mary of the Perpetual Assistance**

Modeling stage

The implementation of three-dimensional modeling methods is carried out taking into account the type of modeled object (engineering, design, architectural, etc.) based on the results of the analytical stage of research (Lytvyn, 2015). In this case, the choice of software is important, which will affect both the complexity of the modeling procedure and the quality of the final designed model.

On the basis of the analyzed scientific literature and a survey of experts, the software was evaluated according to the following criteria (Vavilov, 2015): functionality, ease of use, efficiency, program interface, visualization quality. For each of the criteria, coefficients of importance are determined, taking into account the specifics of a specific task. For comparison, the following software systems popular among architects and designers were selected: AutoCAD, ArchiCAD and 3DsMax.

A feature of modeling in the ArchiCAD software environment is the concept of a virtual house, that is, the modeling object has a real size. In addition, the advantage of ArchiCAD is the interconnection between all project components: in the process of changing one detail of the object, the entire project adapts to the change, which significantly reduces the time of designing and correcting errors. However, there is a certain limitation for creating objects

of non-standard shapes, because the set. This complicates the design in our case, because here we are considering the process of building a model of a historical architectural monument, which contains a large number of non-standard elements.

The AutoCAD software complex allows you to design both in two-dimensional and three-dimensional planes. Here it is possible to use graphic primitives to create complex objects, using different types of modeling (solid, surface and polygonal) and rendering for visualization, support for 3D printing and scanning. However, the use of this program requires more accurate dimensional parameters (which, unfortunately, are not available in the case of our project). In addition, the visualization capabilities here are much smaller than, for example, Autodesk 3ds Max.

Autodesk 3D Studio Max is a full-featured 3D editor used for 3D modeling of buildings and animations (Ozhha, 2015). 3ds Max supports various types of modeling, for example, polygonal, NURBS, based on Bezier surfaces and splines, using parametric objects. The program contains a built-in library of objects that can be supplemented and has the ability to install additional plugins. The software has a convenient interface that allows for flexible control of settings, including exposure, depth of field, and much more.

Therefore, according to the results of expert evaluation, it was determined that the most convenient and effective for graphic 3D reconstruction are 3ds Max and ArchiCAD, which work is convenient and efficient in time. However, the final result of the model of the final renders in the 3ds Max system is much better. Therefore, to create a model of the Parochial Cathedral, the 3ds Max environment was chosen, which has all the necessary tools for rendering of high realistic quality.

So, guided by a detailed analysis of the illustrations of the cathedral, a description of its model and the parameters determined by the parallax evaluation of the stereo pair of images, we build the primary basis of the 3D model of the object. The next step is to edit the base model using the appropriate 3DS Max tools, taking into account the detailed analysis of the specified geometric parameters and architectural features of the model (Hevko, Potapchuk, Lutsyk, Yavorska, & Tkachuk, 2020). To give the building model a realistic appearance, it is necessary to take into account numerous small details, their asymmetry and location in different planes.

The available set of 3DS Max libraries and its software tools allow you to implement the process of building a model with a sufficient degree of realism. For convenience, we apply the appropriate functions for editing the model (copying, changing the size of the element, its plane, etc. To make the image of the model more realistic, we render it. Thus, we get a ready 3D model.

Model printing

Before printing a 3D model, it is necessary to configure it for optimal printing results. This includes geometry analysis, checking for open spaces and geometry defects, and checking that dimensions and parameters match the printing materials. The model is then exported to STL format, which is supported by most 3D printing programs (Kim & Yang, 2016).

There are many 3D printing software, but for convenience and simplicity, we can use Cura, which has extensive features and a user-friendly interface. In addition to the standard tools for editing, setting print quality and material parameters, Cura has functions for calculating the weight of the final position and printing time. After working out all the settings and checks, we can print the 3D model (Utěšená, & Pernicova, 2018).

The high quality of the printed model can be achieved by adjusting the technological parameters, setting the print speed and temperature settings. In our case, the printing speed is the most important parameter, because to ensure the accuracy of printing miniatures with many small details, the printing speed should be set to no more than 30 mm/s. High print speed can affect its quality due to vibrations and wear of drive elements.

Also, the Brim function, which provides the possibility of printing auxiliary elements not specified in the geometry of the model, is of no less importance. This technology ensures the formation of supports that can be installed separately for the attached elements of the model. This function is used to ensure high-quality printing of hanging model elements (for example, roofs or domes). This function allows you to create additional supports for these elements. After setting the necessary parameters for printing the model, the file is sent to the printer with an automatically generated G-code that determines the approximate printing time and the amount of material that will be used.

So, based on our proposed technique of creating and printing models of historical architectural artifacts, we get a computer and printed 3D model of the Parochial Cathedral (Fig. 2).

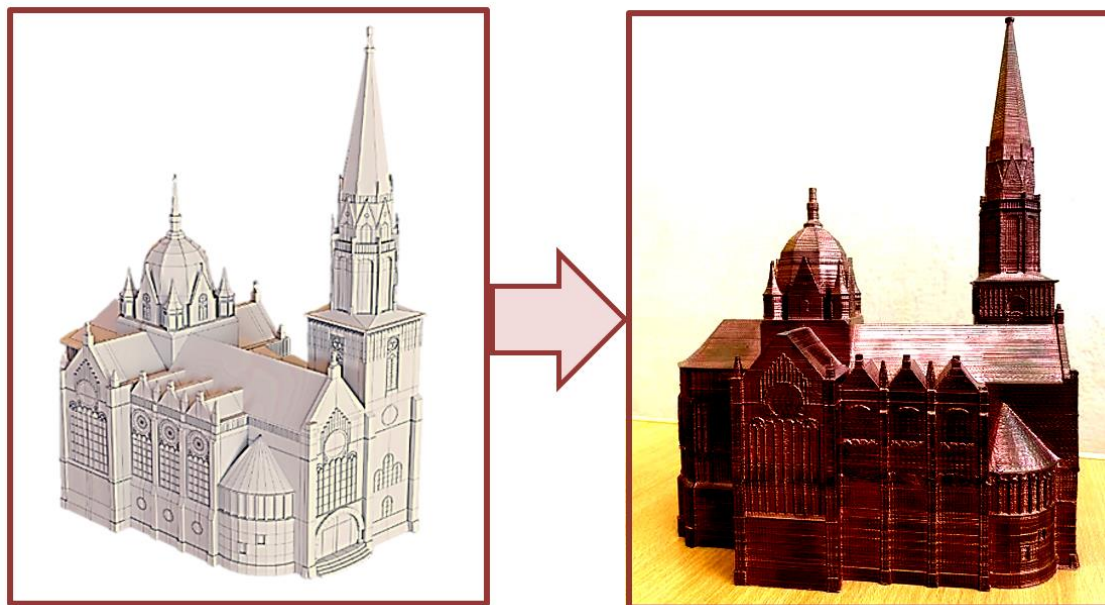


Figure 2. **Computer and printed model of the Parochial Cathedral of St. Mary of the Perpetual Assistance**

Each of these models has its own advantages and disadvantages. If the computer model can be fully edited in the future, then the printed model can only be partially modified, for example, by gluing certain details or repainting it. However, both models are an excellent visualization both for the study of modeling processes and for educational activities or in the study of historical monuments. Thus, the proposed technology for creating and printing 3D models of historical architectural artifacts allows for reconstruction activities aimed at preserving the cultural heritage of the city and the state.

CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

Graphic reconstruction of architectural artifacts is possible thanks to the technologies of three-dimensional graphics, modeling and printing in specialized software environments. The stages of construction of architectural 3D models are based on general design principles, taking into account the specifics of the tasks, the selected software, and requirements for detailing and

realism of the designed object. Therefore, in this case, we defined the following main types: analytical (gathering the necessary information, calculating the dimensions and parameters of the object), modeling (the process of creating a computer model in a specialized software environment) and 3D printing.

The technique of creating and printing 3D models of historical architectural artifacts is illustrated on the basis of the model of the Parochial Cathedral of St. Mary of the Perpetual Assistance. The graphic reconstruction was carried out on the basis of these archival sources. The parameters were determined after comparing descriptions and data on the construction of cathedrals of that era.

Analysis of images and determination of dimensions is the basis for creating a 3D model and editing it with the appropriate tools of the software environment. The nature of this artifact involves numerous small details, their asymmetry and location in different planes. Therefore, the reconstruction of specific configurations of the object was carried out on the basis of parallax estimation of stereogram images of the cathedral.

The 3DS Max environment was chosen to build the 3D model. The objects created here are characterized by high accuracy and detailing of complex elements, providing effective tools that take into account new advances in information technology.

The process of printing a 3D model requires its adaptation based on testing the model for the absence of gaps or cavities in the polygonal grid, geometry defects, and checking the compatibility of the printing materials. At this stage, guided by the criteria of user-friendliness of the interface, the software environment Cura was chosen.

The presented technology of construction and printing of three-dimensional models can be used both for graphic reconstruction of historical artifacts and for teaching restoration students, IT specialists, etc.

The development of methods for studying these technologies, as well as the use of augmented and virtual reality technologies for the reconstruction of artifacts, are the prospects of our further research.

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