The Method of Teaching Graphic 3D Reconstruction of Architectural Objects for Future IT Specialists

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Abstract: The method of teaching future IT specialists modern 3D-technologies of graphic reconstruction of architectural objects has been developed and tested in the educational process. The peculiarity of the implementation of the stages of the proposed methodology of graphic reconstruction is exemplified through building the model of the Parochial Cathedral of St. Mary of the Perpetual Assistance of the 1950s. Sequence and content of operations for analytical and design engineering stage are substantiated. After analysing and assessing the most popular specialized software means, the 3DS Max environment is chosen to build a three-dimensional model. The complex method of graphic reconstruction of historical architectural objects is proposed. This method consists in constructing a three-dimensional model of an object, based on a combination of a design technique using modern 3D technologies and methods for analysing archival descriptive information and data on a set of images using parallax estimation of a data array of stereopairs of images. The cathedral model is built on the basis of archive photographs and drafts. Reconstruction of spacious configuration of the objects is based on parallax assessment of images. There are described methods of implementing modelling by 3DS Max tools and preparing the model for 3D printing in Cura. Substantiated the effectiveness of the proposed training method to teaching future IT specialists of 3D technologies of graphic reconstruction. This method contributes to the formation of students' system of theoretical and practical knowledge on the design of buildings and structures using modern digital technologies for their graphic reconstruction it has been proved.

1 PROBLEM STATEMENT

The current level and pace of development of information technology prompts a new look at the essence and methodology of training IT specialists, whose activities are related to the design of environmental objects. In connection with the rapid development and introduction of digital technologies in all branches of human activity, 3D technologies are becoming an important component of modern education. Now there are new opportunities for their use in the graphic reconstruction of architectural objects and are constantly progressing.

3D graphics allows you to create spatial models of various objects, repeating their geometric shapes and imitating the texture of materials (Kozak, 2016). It is impossible to replace 3D models in all spheres of human activity including industry, medicine, architecture, construction, design, education, cinema, etc. Using 3D technologies for design and graphic reconstruction of architectural objects, we can recreate architectural objects that have been destroyed (Seidametova et al., 2021). This allows you to analyse the features of the architecture, to recreate the structure of the object and to correct its model with a high degree of realism. The importance of researching this issue is confirmed in the "Declaration of Cooperation on advancing the digitisation of cultural heritage", which was signed by 27 European countries (Commission européenne, 2019b). In particular, the European Commission's expert group on the digitization of cultural heritage has developed general guidelines for a comprehensive, holistic 3D documentation

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of European cultural heritage sites (Commission européenne, 2019a).

3D model design enables assessing technical and physical properties of a modelled object before creating a real sample. The methods of studying a model allow analysing its size, material and package contents.

The concept of an object or a project is mainly exemplified by videos or pictures based on 3D graphics. This sets constraints on viewing, as static pictures cannot enable plot change or detailed examination.

Modern potential of 3D graphics and computer hardware capacity enable processing complex scenes on-line without reducing rendering speed and quality. This has evoked professionals' interest to 3D visualization in various activity spheres.

In architecture and bridge engineering, wider application is given to virtual buildings with inside walks and virtual cities. Photorealistic reconstruction of objects makes it possible to work with object models in museum, reconstruction and commercial projects and while studying (Borodkin, 2015).

Maintaining and promulgation of cultural heritage are essential for modern society. Development of computers and 3D graphic tools enables preserving cultural achievements not only as pictures or photographs but also as models in their original form or as electronic replicas of real-life objects (Rumyantsev et al., 2011).

A great number of architectural monuments have disappeared without any sizes, drafts or photographs left. For such historical objects, graphic reconstruction as a scientific study is the only means of identifying the lost or destroyed architectural object of a certain time period. Graphical reconstruction of architectural historical heritage reflects the whole bulk of knowledge concerning it available to date (Rozhko, 2013).

In recent years, there have been numerous museums including the virtual ones with their exhibits being computerized objects. Museums of this kind enable obtaining detailed information on historical achievements, getting to know their origin and facilitating cultural development of society.

Therefore, the study of 3D technologies for the graphic reconstruction of architectural objects by future IT specialists is one of the topical areas of research into the problem of their professional training.

2 LITERATURE REVIEW

Nowadays, innovative technologies of 3D graphics, modeling and design enable restoring lost historical objects. Analysis of the degree of investigation reveals only certain aspects of 3D modelling covered in modern scientific literature.

A significant amount of scientific and pedagogical research is devoted to the consideration of the problem of using 3D technologies in the process of training future IT specialists. Technologies for selecting software for 3D modelling and methods of working with them are described by Osadcha and Chemerys (Osadcha and Chemerys, 2017). The issues of 3D modeling in architectural design are revealed in (Borodkin, 2015; Rumyantsev et al., 2011; Rozhko, 2013).

3D modeling as a design and architecture tool is indirectly touched upon in (Danylenko, 2005).

Despite this, works devoted to the problems of theory and methods of engineering and graphic training of students (Bakum and Morozova, 2015; Lavrentieva et al., 2021). The issues of professional training of future IT specialists was examined in (Babkin et al., 2021; Ozhha, 2012; Osadchyi et al., 2019; Semerikov et al., 2020; Varava et al., 2021).

However, the problem of studying 3D technologies by future IT specialists has its own both theoretical and methodological features, since it requires consideration in the context of a specifically graphic type of activity. For the qualitative formation of students' practical skills in modelling and printing 3D objects, it is necessary to introduce the study of such technologies as an obligatory component of their educational process (Hevko et al., 2020b, 2021).

The features of creating and using 3D models of historical architectural objects in the educational process are considered in (Milkova et al., 2019; Maietti et al., 2019). The works (Butnariu et al., 2013; Kotsiubivska and Baranskyi, 2020; Riabokon, 2002) are devoted to the study of the capabilities of 3D modelling tools in the tasks of computer reconstruction of objects of historical and cultural heritage.

At the same time, it is worth noting that integral scientific approaches to the method of using 3D technologies in the graphic reconstruction of architectural objects, as a component of the professional training of future IT specialists, are not sufficiently disclosed.

Thus, analysis of the scientific literature makes it possible to draw conclusions about the need for further scientific research on 3D technologies for the graphic reconstruction of architectural objects and the development of appropriate guidelines for training future specialists.

The relevance of this problem made it possible to determine the aim of the paper – to reveal the effectiveness of the method of teaching future IT- specialists modern 3D technologies of graphic reconstruc-

tion of architectural objects.

The research object involves is the process of teaching 3D technologies for the graphic reconstruction of architectural objects in the preparation of future IT specialists on the example of creating and printing a 3D model of the Parochial Cathedral of St. Mary.

The novelty of the research – a comprehensive methodology for studying the graphic reconstruction of historical architectural objects has been proposed. This methodology consists in developing the skills of constructing a 3D model of an object based on design technologies according to image analysis using a parallax assessment of a stereopair data array of images of the objects under study.

3 RESULTS

3.1 Substantiation of Teaching Methods of 3D Technologies of Graphic Reconstruction

The experts of the Declaration on the Promotion of the Digitization of Cultural Heritage recommend that the skills of using 3D technologies be included as part of the basic knowledge of IT professionals regarding the restoration of cultural heritage (Commission européenne, 2019a). Graphic reconstruction professionals need to have the necessary knowledge and skills to design a project well, save raw data and 3D layouts. To solve this problem, an important condition is the development of training courses for studying 3D technologies in order to preserve cultural heritage or 3D technologies in general.

The skills of using 3D technologies for the graphic reconstruction of architectural objects is an important component for the professional training of future IT professionals who can develop practical skills in working with 3D technologies that are in demand in the modern labour market.

Therefore, on the basis of the research carried out, we propose a methodology of teaching graphic 3D reconstruction. The methodology provides the formation of a system of theoretical and practical knowledge of students for designing buildings and structures using modern digital technologies of graphic reconstruction.

The proposed methodology is based on the following principles: systematic and consistent, accessibility, clarity, connection between theory and practice, a combination of the individual and the collective.

The principle of systematicity and consistency consists in the formation of knowledge, skills and abilities systematically, in order that each lesson has little interconnection, and new knowledge is based on previously acquired knowledge and creates the foundation for the following knowledge. In each topic, the lesson gradually increases the complexity of the material. The logical completion of the course is the implementation of the project in groups, with the help of which students will improve and consolidate their knowledge, and will be able to try themselves in teamwork.

The principle of accessibility is that the forms, methods and content correspond to the capabilities of students and their level of knowledge in this area. Therefore, students should already know what graphics are and learn how to build simple models, and only then start modelling complex objects.

The principle of clarity is applied directly in the classroom: to demonstrate how to build individual elements in the program and after a while we give students the task to reproduce it. Thus, we encourage them to be attentive in order to be able to complete tasks and thus develop interest in the course.

The principle of connection between theory and practice is implemented by students when performing laboratory work, or tasks of different types. This is preceded by the study of theory.

The last principle is the combination of the individual and the collective. It provides not only work that is performed individually, but also tasks that require group execution. It will help students exchange knowledge, listen to each other in order to complete the assignment efficiently.

Taking into account the correspondence of the set tasks, we consider it expedient to divide the method of graphic reconstruction of architectural objects by means of 3D technologies into the following main stages: analysis, construction, design, model printing (figure 1).

At the analysis stage, students collect the necessary data about the object and the necessary operations to build a 3D model. Solving such problems allows students to form analytical skills and a creative approach to the synthesis of objects based on the available information.

The construction of an object includes the process of modelling (creating a 3D model) and the process of animating (driving existing models or adding additional cameras and moving them along certain trajectories). At this stage, students develop engineering skills through the use of modern software tools and techniques for their use.

The design phase includes texturing and rendering. Solving design problems allows students to form

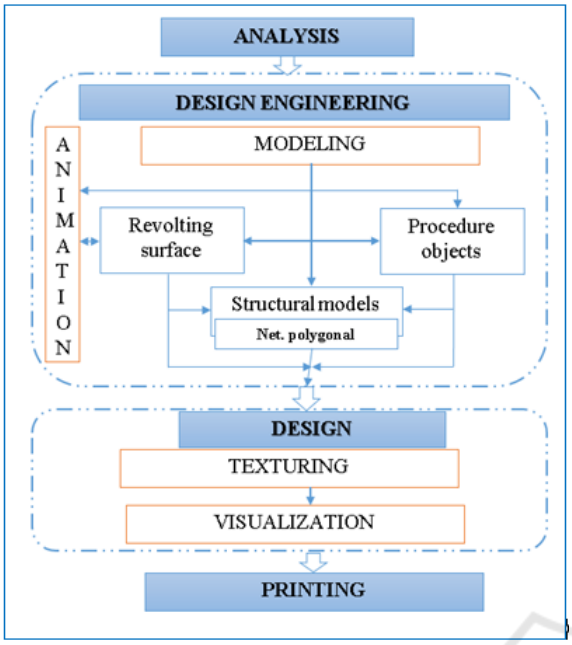

Figure 1: Stages of project development.

the ability to compose objects in compliance with the colour scheme, select materials and textures, choose light sources, change and adjust camera angles.

The final stage of the technique is the manufacture of a model using 3D printing. At this stage, students develop technological skills in working with modern equipment: setting the parameters of the 3D printing process, calibrating the printer table, selecting materials for printing.

Thus, we consider it expedient to reveal in detail the implementation of each of the stages using the example of creating a 3D model of the Parochial Cathedral and substantiate the effectiveness of the proposed method.

3.2 The Sequence and Content of the Analytical Stage of the Proposed Technique

3D modelling is a separate type of computer graphics, which incorporates necessary tools and techniques applied to building a model of an object in the 3D space. 3D modelling techniques of a graphic object include the following main cycles: the analytical cycle (collection of input materials; calculation of object sizes and parameters) and the modelling one (building a draft of an object form; accumulation, carving, stamping, etc.).

Nowadays, 3D modelling is used in almost all fields of human activity including advertising, marketing, industry, computer games, cinema, architecture, design and animation. 3D models of buildings and facilities are an integral part of modern design providing the basis for making object prototypes with maximum granularity.

Stages of building 3D models of monuments and landscapes are specific in their character depending on set tasks and software chosen. However, the most essential components of the methods are general for different modelling objects. While setting a task for modelling, it is necessary to determine the rate of granularity and realism of the end product (Krejdun, 2014). Realism of a model depends on selected materials for overlaying textures onto an object. Virtual 3D modelling for architectural buildings is based on solving the task of the efficient layout widespread in the theory of pattern recognition.

Nowadays, there are many software means of various parameters and applications in computer graphics. Choice of software primarily depends on the task set. After selecting functions and means required for solving the task, it is necessary to choose efficient software to build 3D models.

Architects and designers make good use of 3D graphics technologies because they are efficient and easy to use for project implementation. To select the required software environment, a survey was conducted among experts in this field and students who study the basics of 3D modelling. Based on the survey, the following software products are identified as the most popular: Blender, 3D Max, SweetHome 3D, SketchUpMake, Pro 100, FloorPlan 3D, ARCON 3D Architect, ArchiCAD, Maya, LUMION, Cinema 4d. It should be noted that the most appropriate is the use of environments SweetHome 3D, 3DS Max, FloorPlan 3D, ARCON 3D Architect, ArchiCAD in the architectural direction (Osadcha and Chemerys, 2017).

As our task is to build a model of an object, we should analyse the above-mentioned programmes to choose appropriate software. Parameters of evaluation quality are chosen according to ISO 9126:2001 Standard in which each characteristic is described by its several attributes (Danylenko, 2005). In this case, they include functionality, user-friendliness, efficiency, the programme interface and render quality (the final image after processing) as the most important parameter. As these criteria are not equivalent, importance factors are determined for each of them relevant to the set task (table 1).

Evaluation is performed in the system from 1 to 10 points for each parameter on the basis of working with similar programmes. So, evaluating the characteristics of software that would be advisable to use for graphic 3D reconstruction of architectural objects, we obtained the following rating results: FloorPlan 3D –

Table 1: Assessment parameters.

Parameter	Importance factor
Functionality	3
User-friendliness	2
Efficiency	2.5
Program interface	1.5
Render quality	4

44 points, ARCON 3D Architect – 50, SweetHome 3D – 80, ArchiCAD – 97, 3ds Max – 135 points.

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

Graphic reconstruction of lost or destroyed architectural objects is a specific type of activity aimed at studying these objects in order to restore their appearance as of the time of their existence by 3D graphics means being guided by the preserved documents, drafts or photographs (Borodkin, 2015; Rozhko, 2013).

Graphic reconstruction provides for absence of precise data on an object from a single data source. It is applied to restoring a lost appearance by means of graphic and document data through collecting and combining it from various sources. Graphic reconstruction being an activity is thought of as a set of operations including data collection, object investigation and fixation prior to modelling options of a destroyed architectural monument.

The Parochial Cathedral of St. Mary of the Perpetual Assistance of the 1950s (hereafter – the Parochial Cathedral) is one of the lost historical objects of Ternopil that decorated the city centre at the corner of Ruska and Mitskevich Streets (modern Shevchenko Boulevard). Photographs and drafts are basic data sources concerning the Cathedral.

The historical and architectural key plan of Ternopil indicates that “the majestic and delicate building in the neo-Gothic style was striking in its beauty and perfection. The slim tower-spire of 62m high was hovering over the city as if striving upward into the sky. It was even used as a fire tower built upon the project of the famous Lviv architect Professor Theodor Marian Tal‘ovskyi” (here and after the translation is ours) (Rymar, 2012).

Boitsun says that “in 1954, there were some explosions heard during several days when the Catholic Church was blasted. In 1959, a supermarket was opened there to celebrate the anniversary of the October Revolution. Many elements of the Church ornamentation were taken to Poland. Part of high reliefs of the sacred procession and the sculpture of Madonna were preserved in the Medium Church (the Church of the Nativity of Christ)” (Boitsun, 2003). That is why, we consider it of great importance to restore this architectural monument to preserve Ternopil’s cultural heritage.

3.3 Methodology of the Design Engineering Stage

The creation of a 3D model of an object from its two-dimensional projections (photographs), that is, its 3D reconstruction, is carried out according to the following basic techniques: using design using 3D scanners, by obtaining a sequential series of images of an object from all sides, using a stereopair (Andrianova and Danilova, 2020).

It is a priori impossible to use the 3D scanning technique for the graphic reconstruction of the lost historical architectural objects. Therefore, we consider it inappropriate to consider this technique.

Graphic reconstruction by design involves the creation of a digital model using specialized software products. When creating a model, you can use ready-made drawings or develop a new one. Thus, it is possible to reproduce various objects that already exist in the real world, create those that have not yet been built, or carry out a graphic reconstruction of those that have been destroyed. This reconstruction method provides for modelling in various ways: based on primitives, sections, Boolean operations, arbitrary surfaces constructed using various mathematical models.

This method has a number of advantages, one of which is the construction accuracy. However, for the reconstruction of lost historical architectural objects, this method requires additional information, because, as a rule, in such cases, there are not enough drawings, plans of the area and the building. Therefore, it is advisable to combine it with the method of graphic reconstruction based on a set of images of an object from different sides.

The method of graphical reconstruction of an object from a set of images uses a sequential series of its images. In this case, the required percentage of overlap of two adjacent frames should be more than half, and the minimum 0 – the number of frames, overlap is equal to three.

The algorithm for implementing the work of this method consists of the following stages:

1) analysis of photographs of the object under study;

2) search for singular points and solution of a system of equations obtained on the basis of a set of data points;
3) search for "identical" points on different sets of adjacent images of an object;
4) calculating the coordinates of points from the "base" image of the object;
5) mapping of points in the coordinate system most convenient for object analysis and structure imposition.

The disadvantage of this method is the need for a large number of photographs for analysis in order to obtain high-quality results of graphic 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 stereopair. The method is based on obtaining and processing a set of pairs of images. In this case, the selection of points of correspondence, their comparison and geometric transformations are carried out. Obtaining a pair or series of images in which parallax is observed is the main task of this method. Here, to build a 3D model, you need to perform an algorithm of actions: determining the fundamental matrix, finding the corresponding points, building a point cloud, texturing. However, the model built using this method cannot be considered a full-fledged method of graphic reconstruction, since in this case only a surface view of the object is built.

Based on the analysis, we have proposed a comprehensive methodology for the graphic reconstruction of historical architectural objects for the implementation of the design stage. This technique consists in constructing a 3D model of an object, based on modern 3D design technologies, using methods for analysing archival descriptive information and data on a set of images and processing technology for a stereopair data array.

So, according to our proposed methodology for constructing a 3D model for the graphic reconstruction of a historical building, it is carried out on the basis of the cyclical execution of the following stages (Hevko et al., 2020a):

1. Search for information to create an accurate model from a set of images.
2. Creation of a model in the 3DS Max software environment.
3. Selection of the correct dimensions and construction of small parts diagrams based on the analysis of parallax image evaluation.

Thus, the programmed reconstruction process provided for the restoration of the building according to the data indicated in the sources (description, photographs, drawings), as well as on the basis of certain parameters according to the comparison of descriptions and data on the construction technologies of cathedrals of that time. The construction of a 3D model is based on a stereopair layout of the image of the destroyed Parochial Cathedral.

To restore the spatial configuration of objects, a parallax estimation of images was carried out. The principle of this assessment is that after processing a pair of stereo images, for each element of the left image, the corresponding element is found on the right image. The difference in the horizontal coordinates of the corresponding points (parallax) qualitatively reflects the distance to the image point (Riabokon, 2002).

Collection of data involves searching for cartographic materials as well as images and texts to facilitate accomplishment of the set task. Digital data are preferable followed by vector and raster images. While searching for information, we use a photograph of the Parochial Cathedral with sharp images of elements of the architectural object to create its precise model (figure 2).

In applying 3D modelling methods, special attention is paid to geometrical modelling considering the type of the modelled object (engineering, design, architectural, etc.) and the technology applied (Lytvyn, 2015).

Guided by detailed analysis of over 20 photographs of the Cathedral and its layout, we build a 3D model of the object. Thus, the above-described procedures result in a primary platform of the model.

The next actions are aimed at editing forms of the basis according to the photographs available. After completing detailed analysis of sizes and architectural features, we make amendments by means of relevant 3DS Max tools (Smith, 2006). After that, the building acquires a more realistic appearance. The complex character of building the model involves numerous fine details, their asymmetry and location in different planes.

Next, we perform detailed processing of walls and domes. To reduce labour-consuming procedures of model building, repeated details like windows can be copied and dragged to the required location. If you need to resize the element, its plane or angle, then it is possible to do it using the functions of the software environment.

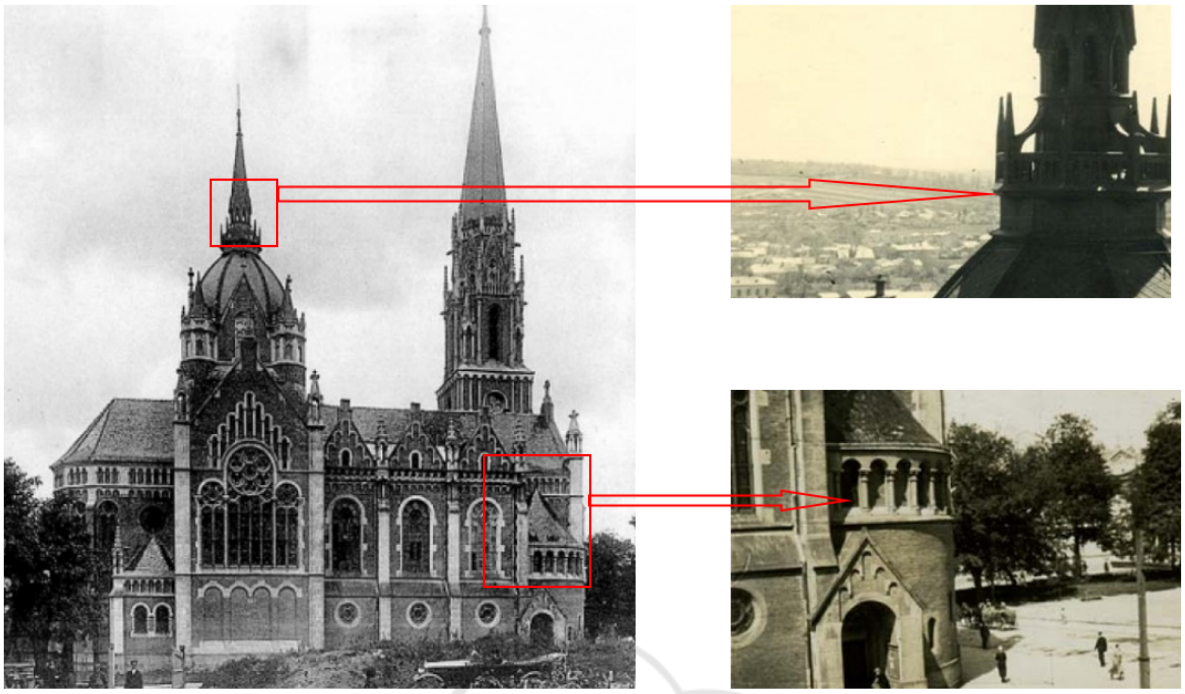

Figure 2: Analysis of the spatial configuration and details of the cathedral of the Parochial Cathedral of St. Mary.

3.4 Implementation of the Design Stage of the Proposed Methodology

For the sake of convenience, we apply appropriate functions to revolving and moving the model. Thus, after completing a series of actions and operations, we obtain a 3D model of the Parochial Cathedral. To make the image of the model more realistic, we perform its rendering.

Rendering is responsible for applying various special effects, detailing and fine-tuning components. A texture map is also being prepared. First of all, materials are assigned, after which parameters are set, such as roughness, reflection, transparency, etc. Also, light sources and cameras are set. So, at this stage, the 3D visualization settings are clarified and adjusted.

The primary and the resulting 3D models of the cathedral after the stage of analyzing the dimensions and features of the architecture are shown in figure 3.

Before making a printed miniature of the 3D model, we should analyse and adjust it properly. As the target result of modelling is a printed miniature, the built model should be exported into the STL-format. It should be noted that due to the intensive development of 3D printing, most specialized programs support this feature. This type supports 3D objects by preserving them as a bulk of triangular data describing a surface.

3.5 The Sequence and Content of the 3D Printing Stage

The first stage of preparing the model for printing provides for analysis of 3D model geometry, which involves its testing for available open spaces in the polygonal net, some displacements of polygons and defects in geometry.

The next stage includes analysis of all parameters, sizes and their test for conformity with printing materials. As the built 3D model has sizes of a real-life building, it requires scaling to create its printable miniature (figure 4).

Nowadays, there is a great variety of software for 3D printing, among which one should mention Cura, CraftWare, Slic3r, 3DTin and Repetier-Host. These software products are quite widespread due to their advanced features and relative complexity.

Yet, being guided by convenience and a relatively user-friendly interface, we apply Cura in which except for standard editing tools, printing quality adjustment and material parameters, there are functions of calculating weight of the end item, its print time, etc (Mitin, 2018).

Basic settings of technological parameters include printing quality, filling, printing speed and temperature, parameters of printing support and plastic threads. While setting the parameters of printing quality, the most essential one is the layer height

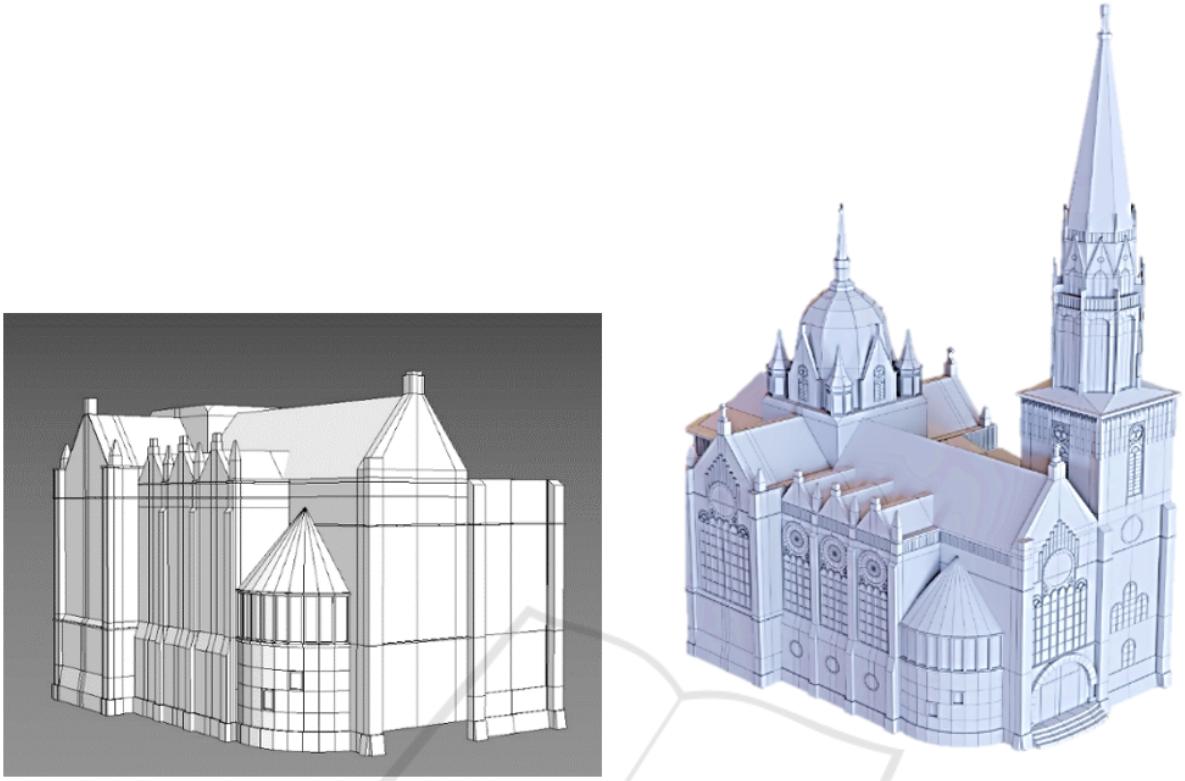

Figure 3: The primary and the resulting 3D models of the Parochial Cathedral.

(mm) determined by the nozzle diameter and it should not exceed its half.

Shell thickness (mm) determines thickness of printing walls of thin-wall objects or objects with the reduced in-fill ratio. Shell thickness is determined by corresponding geometrical parameters of an object. For small models, the thickness of 10–30 mm is optimal.

Economic factors of plastic consumption are determined by fill density (%). In most cases, the in-fill ratio makes 10%, yet, for inflexible models and considering structural features of a model, the in-fill ratio can reach 100%. However, printing time increases greatly.

Settings of print speed and temperatures enhance qualitative and technological parameters of printing. The most significant parameter is print speed that determines nozzle movements. As our model has many fine details, the set speed is 30 mm/sec to make printing accurate. It is caused by the fact that high print speed affects its quality because of vibration efforts on the supporting frame of a printer and accelerated wear of drive elements.

The technology also provides for printing auxiliary model elements (not specified in geometry) considering lack of possibility to form plastic mass in the air. This support is possible for both individual model elements (support type) and its platform (platform adhesion type). In this case, we select the function Brim to provide high-quality print of model elements, which are hanging (the roof, domes). The programme creates additional supports for these elements.

After setting the required parameters to make a miniature, the file is sent to the printer with automatically formed G-code and approximate print time and the amount of the required material are determined.

Figure 5 presents a printed model of the Parochial Cathedral based on the suggested 3D modelling technology, the advantages of which are availability and low costs of produced models.

The methodology for creating the 3D model and printing the layout of the Parish Cathedral has been carried out by specialists of the Innovative Center for 3D Technologies of Design and Production, which operates on the basis of the Chair of Computer Technologies of the Ternopil Volodymyr Hnatyuk National Pedagogical University.

Some specific features of the developed model indicate possible further application of the methods to reconstruction activity in order to preserve the city and the state cultural heritage.

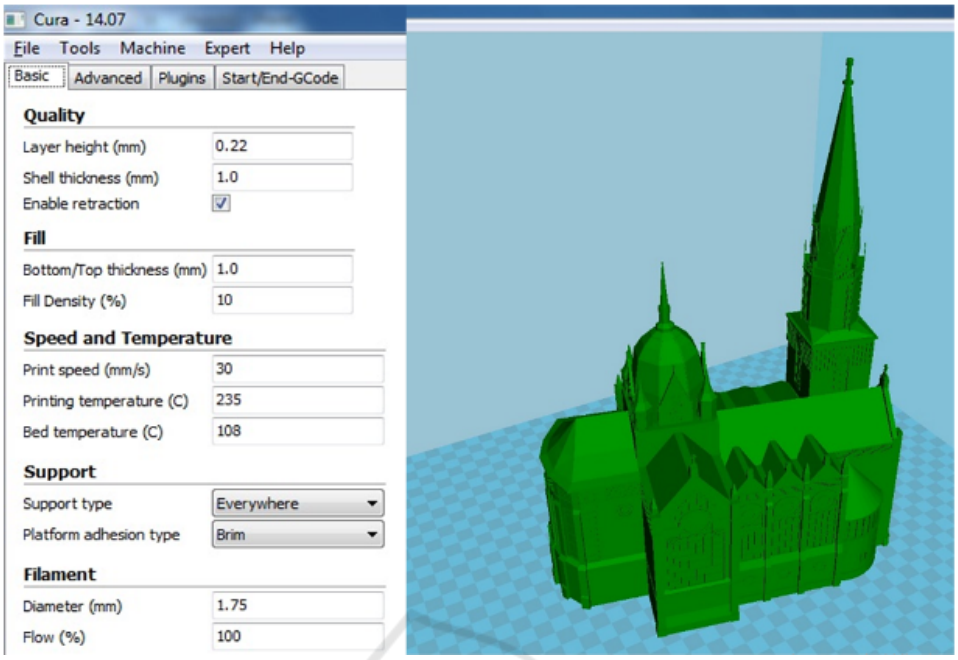

Figure 4: Adjusting the model sizes to printing.

4 JUSTIFICATION OF THE EFFECTIVENESS OF THE PROPOSED METHOD

Our research on improving the methodology for teaching of constructing 3D models of historic architectural objects was based on the proposed algorithm for performing architectural and spatial shaping in the process of reproducing an historic object.

In the process of teaching future IT specialists to 3D technologies, we focused on the use of a comprehensive methodology for studying the graphic reconstruction of historical architectural objects. This methodology consists in the formation of skills in constructing a 3D model of an object based on design technologies according to image analysis using parallax evaluation of the data array of stereopairs of images of the objects under study.

The proposed technique forms in students' certain preliminary skills for the implementation of graphic reconstruction, which are important for their future professional activities. To substantiate the effectiveness of the proposed technique, an experimental study was carried out. In the course of the study, methodological support was developed for conducting a cycle of laboratory studies.

Carrying out such a study helped to find out the effectiveness of the proposed methodology, to create conditions for the introduction of positive achievements into the educational process.

A pedagogical experiment to test the effectiveness of the methodology for the formation of graphical reconstruction skills in future IT specialists covered 27 students of the specialty "Professional Education (Computer Technologies)". The distribution of students for the experiment was carried out as follows: the EG (14 students) – the experimental group, and the CG (13 students) – the control group. The research consisted in the introduction of the proposed methodology into the educational process of the EG, while the CG studied according to the traditional method.

All participants in the experiment were familiar with the purpose of the experiment and provided personal consent to participate. To test the effectiveness of the methodology, diagnostic tools were developed in the form of indicators, which were used to track a positive result in the formation of the skills of future IT specialists to carry out graphical reconstruction.

These indicators were: 1) knowledge about the technique of graphic reconstruction and the necessary tools; 2) knowledge of methods of geometric spatial design; 3) the ability to use software tools for building 3D models; 4) the ability to use image analysis technologies based on stereo pairs and parallax assessment; 5) knowledge of 3D printing technology.

These indicators made it possible to characterize four levels of skills of future IT specialists to carry out graphical reconstruction:

1) low (characterized by low motivation to use

Figure 5: The printed miniature of the Parochial Cathedral of St. Mary of the Perpetual Assistance.

graphic reconstruction technologies in professional activity and creative self-realization; lack of geometric design skills; elementary theoretical and technological training in the use of specialized software for solving problems of graphic reconstruction and 3D printing; fragmented ability to analyse graphic information);

2) medium (characterized by a limited interest in graphic reconstruction technologies and in the use of computer visualization tools, partial skills to analyse graphic information and a situational desire to introduce software tools for the design of spatial objects in professional activities and the need for additional motivation, mediocre theoretical and technological training in the use of 3D print);
3) sufficient (characterized by significant motivation for the use of graphic reconstruction technologies, spatial modelling tools in professional activities, thorough training in the use of specialized software for solving typical tasks of graphic reconstruction and 3D printing, understanding of the process of analysing graphic information using arrays of digital data, readiness to reproduce typical models of graphic reconstruction);
4) high (characterized by a conscious and reasoned motivation for the use of graphic reconstruction technologies, means of spatial modelling in professional activities and for creative self-realization, thorough training in the use of specialized software for solving creative problems of graphic reconstruction and 3D printing, the ability to evaluate graphic information and analyse arrays digital data corresponding to a graphical representation of a spatial object, formed by a sense of willingness to create their own models of graphical reconstruction).

Methods for determining achievements for the se-

lected indicators were as follows.

1. Knowledge about the technique of graphic reconstruction and the necessary tools were tested with an appropriate set of test tasks.
2. Knowledge of methods of geometric spatial design was verified by tests.
3. The ability to use software tools for building 3D models was tested by executing the project.
4. Ability to use image analysis technologies based on stereo pairs and parallax assessments were tested by an individual task.
5. Knowledge of 3D printing technology was tested with an individual assignment.

During the experimental study, there were significant changes in the relationships between the knowledge levels of students in the control and experimental groups, which are reflected in table 2.

Analysis of the results of the experimental study showed that the quality of knowledge in the experimental group increased by 23.1%, and in the control group only by 14.3%, the average score increased accordingly: $\Delta\mu$ (EG) = 6.9; $\Delta\mu$ (CG) = 1.4. The dynamics of changes in the quality of knowledge of students from the EG and CG is presented in figure 6.

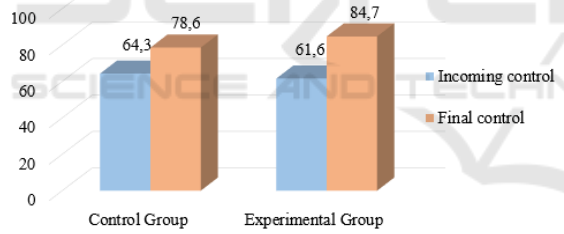

Figure 6: Dynamics of the quality of knowledge.

Consequently, conducting an experimental study using the proposed methodology proved its effectiveness in the educational process of future IT specialists. Thanks to the atypical approach to learning, a relaxed atmosphere is created, which contributes to a better assimilation of the material.

5 CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

Graphic reconstruction of historical architectural objects is possible due to new technologies of 3D graphics, modelling and design in specialized computer environments. The developed method 3D technologies of graphic reconstruction are exemplified by the modelling of the Parochial Cathedral of St. Mary of the Perpetual Assistance of the 1950s.

The proposed method of training of graphic 3D reconstruction is based on the principles: systematicy and consistency, accessibility, clarity, connection between theory and practice, combination of individual and collective. The stages of the proposed methodology (analysis, construction, design, model printing) are based on a general methodology, taking into account individual specifics, depending on the tasks to be solved, the selected software, the required degree of detail and realism.

Determination of the spatial configuration of objects provides for the restoration of the building according to the data indicated in the archival sources, as well as on the basis of the determined parameters according to the comparison of descriptions and data on the construction technologies of cathedrals of that epoch.

The complex method for the graphic reconstruction of historical architectural objects is proposed. This method consists in constructing a 3D model of an object, based on a combination of design techniques using modern 3D technologies, based on methods for analysing archival descriptive information and data from a set of images using a parallax evaluation of a stereopair data array of images of a destroyed Cathedral.

3ds Max is selected to build a 3D model of the object to enhance high accuracy, speed and granularity of fixing complex sets providing efficient tools of working with bulk data that incorporate new achievements of informational technologies.

Detailed analysis of images and determined sizes provides the basis for the 3ds Max model, which is then edited by relevant tools to make it more realistic. The complex character of building the model implies its numerous fine details, their asymmetry and location in different planes.

Creating a printed model of a 3D model requires its analysis and adaptation to 3D printing based on testing the model for the presence of open spaces in the polygonal mesh, defects in the geometry and checking for compliance with the print materials. To build a printed model of the Cathedral, guided by criteria of convenience and the user-friendly interface, the Cura software environment is applied.

The presented teaching methodology provides for the formation of a system of theoretical and practical knowledge of students in the process of model buildings design and structures using modern digital technologies of graphic 3D reconstruction.

To substantiate the effectiveness of the proposed

Table 2: Dynamics of the level of knowledge of students.

Group	Experiment stage	Total number of students	Grade Point Average, μ	Knowledge level							
				high		sufficient		medium		low	
				number of students	%	number of students	%	number of students	%	number of students	%
CG	I	14	78.7	4	28.6	5	35.7	4	28.6	1	7.1
	II		80.1	5	35.7	6	42.9	3	21.4	1	7.1
EG	I	13	75.3	3	23.1	5	38.5	3	23.1	2	15.3
	II		82.2	5	38.5	6	46.2	2	15.3	0	0

technique, an experimental study was carried out, during which the developed methodological support was tested. An analysis of the results of the experimental study showed that the implementation of the proposed methodology contributes to the high-quality training of future IT specialists. Carrying out such research helped to create conditions for introducing positive achievements into the educational process.

Prospects for further research are defined in two directions:

1) methodical: development of the training course "Graphic reconstruction of architectural objects" and its introduction into the educational process of the specialty "Professional education (Digital technologies)";
2) technological: reconstruction of the Cathedral interior that would enable creation of an object of the virtual historical museum of the architectural monument. Yet, this problem requires auxiliary data on the Parochial Cathedral of St. Mary of the Perpetual Assistance and remains unsolved to date.

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