A novel pedagogical approach to equipping prospective IT professionals with skills in 3D modelling and reconstruction of architectural heritage

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Abstract

This paper presents a novel pedagogical methodology developed and tested for teaching prospective IT professionals cutting-edge 3D technologies for graphical reconstruction of architectural heritage. The effectiveness of the proposed approach is demonstrated through a case study involving the reconstruction of the Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s. The methodology encompasses a comprehensive set of stages: analysis, modelling, design, and 3D printing, underpinned by a synthesis of archival data analysis, parallax estimation from stereo image pairs, and contemporary 3D modelling techniques. 3DS Max was selected as the optimal software for creating the detailed 3D model, while Cura was employed to prepare the model for 3D printing. The experimental evaluation confirmed the efficacy of the proposed teaching methodology in equipping students with a robust theoretical and practical foundation for deploying modern digital technologies in the reconstruction and preservation of architectural heritage. This work makes a significant contribution to the pedagogy of IT and digital heritage conservation.

Keywords

architectural heritage, 3D reconstruction, pedagogy, IT education, digital technologies

1. Introduction

The rapid advancement and pervasive integration of digital technologies across all domains of human endeavour necessitates a re-evaluation of the substance and methodology of educating IT professionals, particularly those engaged in environmental object design. In this context, 3D technologies are emerging as a crucial component of modern education, offering novel opportunities for their application in the graphical reconstruction of architectural heritage [1].

3D graphics empowers the creation of spatial models of diverse objects, faithfully replicating their geometric forms and material textures [2, 3, 4, 5]. Notably, 3D technologies can digitally resurrect architectural artefacts that have been lost to time [6], facilitating detailed analysis of architectural features, reconstruction of object structures, and generation of highly realistic models. The significance of this research domain is underscored by the "Declaration of Cooperation on advancing the digitisation of cultural heritage", endorsed by 27 European nations [7]. Specifically, the European Commission's expert group on cultural heritage digitisation has formulated comprehensive guidelines for holistic 3D documentation of Europe's cultural heritage sites [8].

3D modelling enables the assessment of an object's technical and physical properties prior to fabricating a physical prototype. Model analysis techniques allow for the examination of dimensions, materials,

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and constituent elements.

Conventionally, object or project concepts are communicated through videos or images based on 3D graphics. However, this imposes limitations on user interaction, as static images preclude scenario manipulation or detailed inspection.

The confluence of advancements in 3D graphics and computational capabilities has enabled the real-time rendering of complex scenes without compromising speed or quality. This has piqued the interest of professionals across various fields in the potential applications of 3D visualisation.

In the realm of architecture and civil engineering, virtual buildings with immersive interiors and virtual cities are gaining traction. Photorealistic object reconstruction facilitates the utilisation of object models in museum, reconstruction, and commercial projects, as well as in educational contexts [9].

The preservation and dissemination of cultural heritage are paramount for contemporary society. The evolution of computers and 3D graphical tools has made it possible to conserve cultural achievements not merely as images or photographs, but as models in their original form or as digital replicas of physical objects [10].

Numerous architectural monuments have vanished, leaving no traces of dimensions, plans, or photographic records. For such historical structures, graphical reconstruction serves as the sole means of resurrecting the lost or destroyed architectural object from a specific time period. Graphical reconstruction of historical architectural heritage encapsulates the totality of contemporary knowledge concerning the object [11].

In recent years, there has been a proliferation of museums, including virtual ones, showcasing digitised artefacts. These museums provide detailed insights into historical achievements, their origins, and contribute to the cultural advancement of society.

Consequently, the study of 3D technologies for the graphical reconstruction of architectural heritage by prospective IT professionals constitutes a crucial area of research within the broader context of their professional training.

2. Related work

A substantial body of scientific and pedagogical research has been dedicated to the application of 3D technologies in the training of prospective IT professionals. The selection of software for 3D modelling and associated workflows are described by Osadcha and Chemerys [12]. The role of 3D modelling in architectural design is explored in the works of Borodkin [9], Rumyantsev et al. [10], Rozhko [11].

3D modelling as a tool for design and architecture is indirectly addressed in publications by Danylenko [13].

Despite this, studies focused on the theory and methods of engineering and graphical education of students (Holub et al. [14], Korniienko et al. [15], Kuznietsov and Moiseienko [16], Lavrentieva et al. [17], Modlo et al. [18, 19], Morkun et al. [20], Rashevska and Soloviev [21], Shepiliev et al. [22, 23], Sitsylitsyn et al. [24], Striuk and Semerikov [25], Striuk et al. [26], Tkachuk et al. [27], Zelinska et al. [28]. Babkin et al. [29], Chemerys and Osadcha [30], Korotun et al. [31], Lehka and Shokaliuk [32], Markova et al. [33], Ozhha [34], Osadchyi et al. [35], Semerikov et al. [36], Striuk and Semerikov [37], Vakaliuk et al. [38, 39, 40], Varava et al. [41] examined the issues of professional training of prospective IT specialists.

However, the challenge of teaching 3D technologies to prospective IT professionals possesses distinct theoretical and methodological nuances, as it demands consideration within the context of a specifically graphical domain. To effectively cultivate students' practical skills in modelling and printing 3D objects, it is imperative to integrate the study of such technologies as an essential component of their educational journey [42, 43].

The intricacies of creating and deploying 3D models of historical architectural objects in educational settings are investigated in the works of Milkova et al. [44], Maietti et al. [45]. The capabilities of 3D modelling tools in the computer-based reconstruction of historical and cultural heritage objects are the focus of studies by Butnariu et al. [46], Kotsiubivska and Baranskyi [47], Riabokon [48].

Nevertheless, it is important to note that comprehensive scientific approaches to the methodology of employing 3D technologies in the graphical reconstruction of architectural heritage, as an integral facet of the professional training of prospective IT specialists, remain underexplored.

Thus, analysis of the literature reveals the necessity for further scientific inquiry into 3D technologies for the graphical reconstruction of architectural heritage and the development of pertinent guidelines for training future professionals.

The relevance of this issue led to the articulation of the paper's objective – to demonstrate the efficacy of the methodology for teaching prospective IT specialists cutting-edge 3D technologies for the graphical reconstruction of architectural heritage.

The research object is the process of teaching 3D technologies for the graphical reconstruction of architectural heritage in the preparation of prospective IT specialists, as exemplified by the creation and printing of a 3D model of the Parochial Cathedral of St Mary.

The novelty of the research lies in the proposal of a comprehensive methodology for studying the graphical reconstruction of historical architectural objects. This methodology involves developing skills in constructing a 3D model of an object based on design technologies in conjunction with image analysis using parallax estimation from a stereo pair data array of images of the studied objects.

3. Methodology

3.1. Rationale for teaching methods in 3D reconstruction

The experts of the Declaration on the Promotion of the Digitisation of Cultural Heritage recommend the inclusion of 3D technology skills as part of the core knowledge of IT professionals involved in cultural heritage restoration [8]. Graphical reconstruction professionals must possess the requisite knowledge and skills to effectively design a project, preserve raw data, and 3D layouts. To address this need, the development of training courses for the study of 3D technologies in the context of cultural heritage preservation or 3D technologies in general is crucial.

Proficiency in employing 3D technologies for the graphical reconstruction of architectural heritage is a vital component of the professional training of prospective IT professionals, equipping them with practical skills in 3D technologies that are highly sought after in the contemporary job market.

Therefore, based on the conducted research, we propose a methodology for teaching graphical 3D reconstruction. This methodology aims to foster a system of theoretical and practical knowledge among students for designing buildings and structures using modern digital technologies for graphical reconstruction.

The proposed methodology is grounded in the following principles: systematic and consistent approach, accessibility, clarity, connection between theory and practice, and a blend of individual and collective learning.

The principle of a systematic and consistent approach involves the structured formation of knowledge, skills, and abilities, ensuring that each lesson is interconnected and new knowledge builds upon previously acquired knowledge while laying the foundation for subsequent learning. Within each topic, the complexity of the material gradually increases. The logical culmination of the course is the implementation of a group project, through which students refine and consolidate their knowledge and experience teamwork.

The principle of accessibility ensures that the forms, methods, and content align with the students' capabilities and their level of knowledge in the field. Therefore, students should already possess an understanding of graphics and have learned to construct simple models before progressing to the modelling of complex objects.

The principle of clarity is directly applied in the classroom: the instructor demonstrates how to build individual elements in the software, and after a short period, students are assigned the task of replicating the process. This approach encourages attentiveness to enable task completion and cultivates interest in the course.

The principle of connecting theory and practice is realised when students perform laboratory work or tasks of various types, preceded by the study of relevant theory.

The final principle is the combination of individual and collective learning. It encompasses not only individual work but also tasks that require group collaboration. This approach facilitates knowledge exchange among students and fosters active listening skills to efficiently complete assignments.

Considering the alignment with the established objectives, we deem it appropriate to divide the methodology of graphical reconstruction of architectural objects using 3D technologies into the following main stages: analysis, modelling, design, and model printing (figure 1).

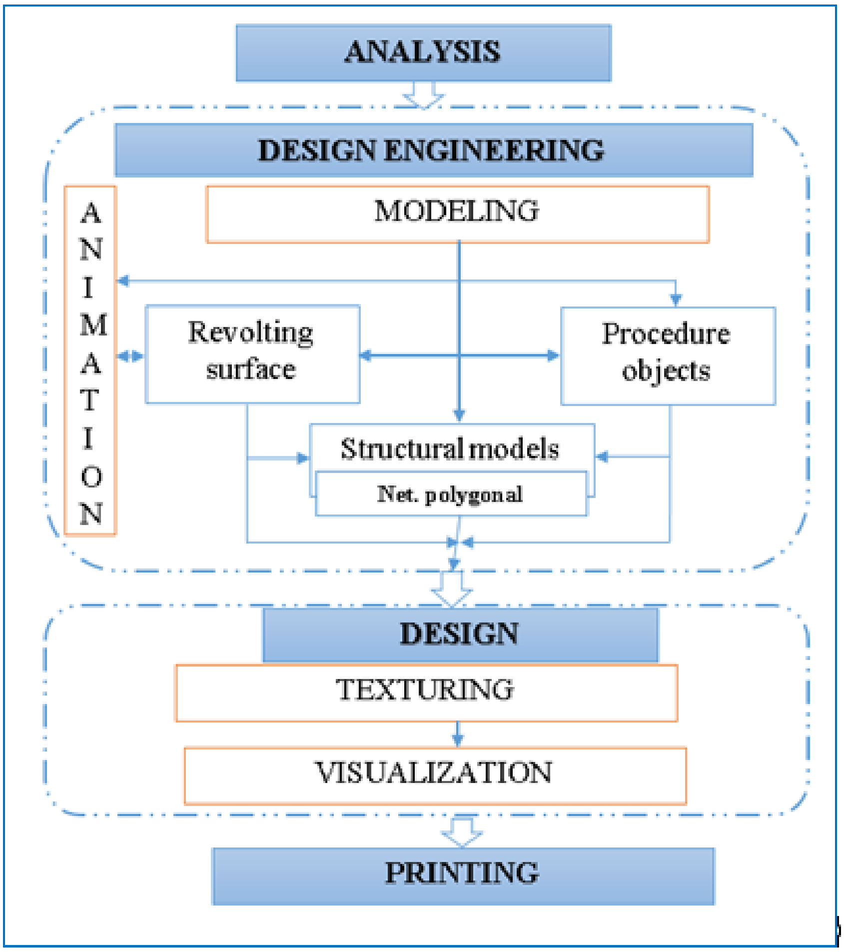

Figure 1: Stages of project development.

During the analysis stage, students gather the necessary data about the object and the operations required to build a 3D model. Solving such problems enables students to develop analytical skills and a creative approach to object synthesis based on available information.

The modelling stage encompasses the process of creating a 3D model and animation (driving existing models or adding and moving additional cameras along specific trajectories). At this stage, students cultivate engineering skills through the utilisation of modern software tools and associated techniques.

The design stage involves texturing and rendering. Solving design problems allows students to develop the ability to compose objects while adhering to colour schemes, select materials and textures, choose light sources, and adjust camera angles.

The final stage of the methodology is the production of a model using 3D printing. At this stage, students acquire technological skills in working with modern equipment, including setting the parameters of the 3D printing process, calibrating the printer table, and selecting printing materials.

Thus, we consider it expedient to provide a detailed account of the implementation of each stage using the example of creating a 3D model of the Parochial Cathedral and to substantiate the effectiveness of the proposed methodology.

3.2. Sequence and content of the analytical stage

3D modelling is a distinct domain of computer graphics that incorporates essential tools and techniques for constructing a model of an object in 3D space. The 3D modelling techniques for a graphical object comprise the following main cycles: the analytical cycle (collection of input materials; calculation of object dimensions and parameters) and the modelling cycle (drafting the object form; accumulation, carving, stamping, etc.).

Currently, 3D modelling finds application in virtually all domains of human activity, including advertising, marketing, industry, computer games, cinema, architecture, design, and animation. 3D models of buildings and facilities form an integral part of modern design, serving as the foundation for creating highly detailed object prototypes.

The stages of constructing 3D models of monuments and landscapes are specific in nature, contingent upon the defined objectives and selected software. However, the essential components of the methodologies are common across different modelling objects. When defining a modelling task, it is crucial to determine the required level of detail and realism of the final product [49]. The realism of a model is contingent upon the selected materials for texture mapping onto the object. Virtual 3D modelling for architectural structures is predicated on solving the task of efficient layout, which is prevalent in pattern recognition theory.

Presently, there exists a wide array of software tools with varying parameters and applications in computer graphics. The choice of software is primarily dictated by the task at hand. After identifying the functions and tools necessary for task completion, it is essential to select the most suitable software for constructing 3D models.

Architects and designers extensively leverage 3D graphics technologies due to their efficiency and ease of use in project implementation. To determine the most appropriate software environment, a survey was conducted among experts in the field and students studying the fundamentals of 3D modelling. Based on the survey results, the following software products were identified as the most popular: Blender, 3D Max, SweetHome 3D, SketchUpMake, Pro 100, FloorPlan 3D, ARCON 3D Architect, ArchiCAD, Maya, LUMION, and Cinema 4D. It is worth noting that SweetHome 3D, 3DS Max, FloorPlan 3D, ARCON 3D Architect, and ArchiCAD are particularly well-suited for architectural applications [12].

As our objective is to construct an object model, we must analyse the aforementioned software to select the most appropriate tool. The evaluation quality parameters are chosen in accordance with the ISO 9126:2001 Standard, wherein each characteristic is described by several attributes [13]. In this case, the criteria include functionality, user-friendliness, efficiency, program interface, and render quality (the final image after processing) as the most critical parameter. Given that these criteria are not equivalent, importance factors are assigned to each of them based on their relevance to the defined task (Table 1).

Table 1
Assessment parameters.

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

The evaluation is performed on a scale of 1 to 10 points for each parameter based on experience with similar software. Thus, in assessing the characteristics of software that would be advisable for the graphical 3D reconstruction of architectural objects, we obtained the following rating results: FloorPlan 3D – 44 points, ARCON 3D Architect – 50, SweetHome 3D – 80, ArchiCAD – 97, and 3ds Max – 135 points.

According to the rating, it was determined that 3ds Max and ArchiCAD are the most convenient and effective for graphical 3D reconstruction, offering a user-friendly and efficient workflow. However, the final model renders produced by the 3DS Max system are of significantly higher quality. Therefore, the 3DS Max environment was chosen to create the Cathedral model, as it possesses all the necessary tools for rendering with a high degree of realism.

Graphical reconstruction of lost or destroyed architectural objects is a specific type of activity aimed at studying these objects to restore their appearance at the time of their existence using 3D graphics tools, guided by preserved documents, plans, or photographs [9, 11].

Graphical reconstruction assumes the absence of precise data on an object from a single data source. It is employed to restore a lost appearance by means of graphical and documentary data through collecting and combining information from various sources. As an activity, graphical reconstruction is conceptualised as a set of operations encompassing data collection, object investigation, and fixation prior to modelling options of a destroyed architectural monument.

The Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s (hereafter referred to as the Parochial Cathedral) is one of the lost historical objects of Ternopil that adorned the city centre at the corner of Ruska and Mitskevich Streets (present-day Shevchenko Boulevard). Photographs and plans serve as the primary 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, soaring 62m high, hovered 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" [50].

Boitsun [51] recounts that "in 1954, there were several days of explosions heard 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 the high reliefs of the sacred procession and the sculpture of Madonna were preserved in the Medium Church (the Church of the Nativity of Christ)" [51]. Consequently, we consider it of great importance to restore this architectural monument to preserve Ternopil's cultural heritage.

3.3. Methodology of the modelling stage

The creation of a 3D model of an object from its two-dimensional projections (photographs), i.e., its 3D reconstruction, is carried out according to the following basic techniques: using design with 3D scanners, obtaining a sequential series of images of an object from all sides, and using a stereo pair [52].

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

Graphical reconstruction by design involves the creation of a digital model using specialised software products. When creating a model, one can utilise existing drawings or develop new ones. 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 graphical reconstruction of those that have been destroyed. This reconstruction method provides for modelling in various ways: based on primitives, sections, Boolean operations, and arbitrary surfaces constructed using various mathematical models.

This method offers several advantages, one of which is construction accuracy. However, for the reconstruction of lost historical architectural objects, this method requires additional information, as there are often insufficient drawings and plans of the area and the building. Therefore, it is advisable to combine it with the method of graphical 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 between two adjacent frames should exceed half, and the minimum number of overlapping frames is equal to three.

The algorithm for implementing 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 based on a set of data points;
3) Search for "identical" points on different sets of adjacent images of an object;
4) Calculation of 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 to obtain high-quality results of graphical reconstruction.

To address the issue of insufficient graphical information based on image analysis, we propose using the method of graphical reconstruction using a stereo pair. This method is based on obtaining 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 main task of this method. To build a 3D model, one needs to perform the following algorithm of actions: determining the fundamental matrix, finding the corresponding points, building a point cloud, and texturing. However, the model built using this method cannot be considered a full-fledged method of graphical reconstruction, as it only constructs a surface view of the object.

Based on the analysis, we have proposed a comprehensive methodology for the graphical reconstruction of historical architectural objects for the implementation of the modelling stage. This technique consists of 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 stereo pair data array.

According to our proposed methodology for constructing a 3D model for the graphical reconstruction of a historical building, it is carried out based on the cyclical execution of the following stages [53]:

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 based on 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 stereo pair 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 [48].

Data collection involves searching for cartographic materials as well as images and texts to facilitate the 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 [54].

Guided by a 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 for the model.

The next actions are aimed at editing the forms of the basis according to the available photographs. After completing a detailed analysis of sizes and architectural features, we make amendments using relevant 3DS Max tools [55]. 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.

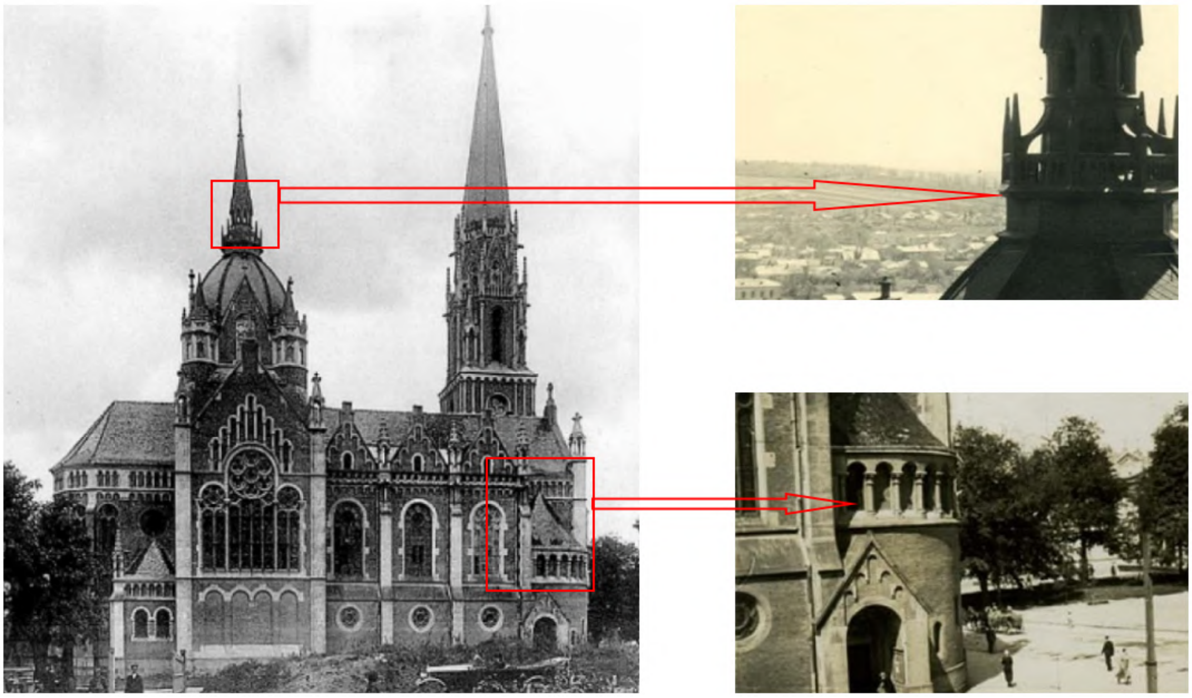

Figure 2: Analysis of the spatial configuration and details of the Parochial Cathedral of St Mary.

Next, we perform detailed processing of walls and domes. To reduce labour-intensive procedures of model building, repeated details like windows can be copied and dragged to the required location. If resizing the element, its plane, or angle is needed, it can be done using the functions of the software environment.

3.4. Implementation of the design stage

For the sake of convenience, we apply appropriate functions for 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 prepared. First, materials are assigned, after which parameters such as roughness, reflection, and transparency are set. Additionally, light sources and cameras are positioned. So, at this stage, the 3D visualisation settings are clarified and adjusted.

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

Before creating 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 is worth noting that due to the intensive development of 3D printing, most specialised programs support this feature. This type supports 3D objects by preserving them as a bulk of triangular data describing a surface.

3.5. Sequence and content of the 3D printing stage

The first stage of preparing the model for printing involves analysing the 3D model geometry, which includes testing for open spaces in the polygonal net, displacement of polygons, and defects in geometry.

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

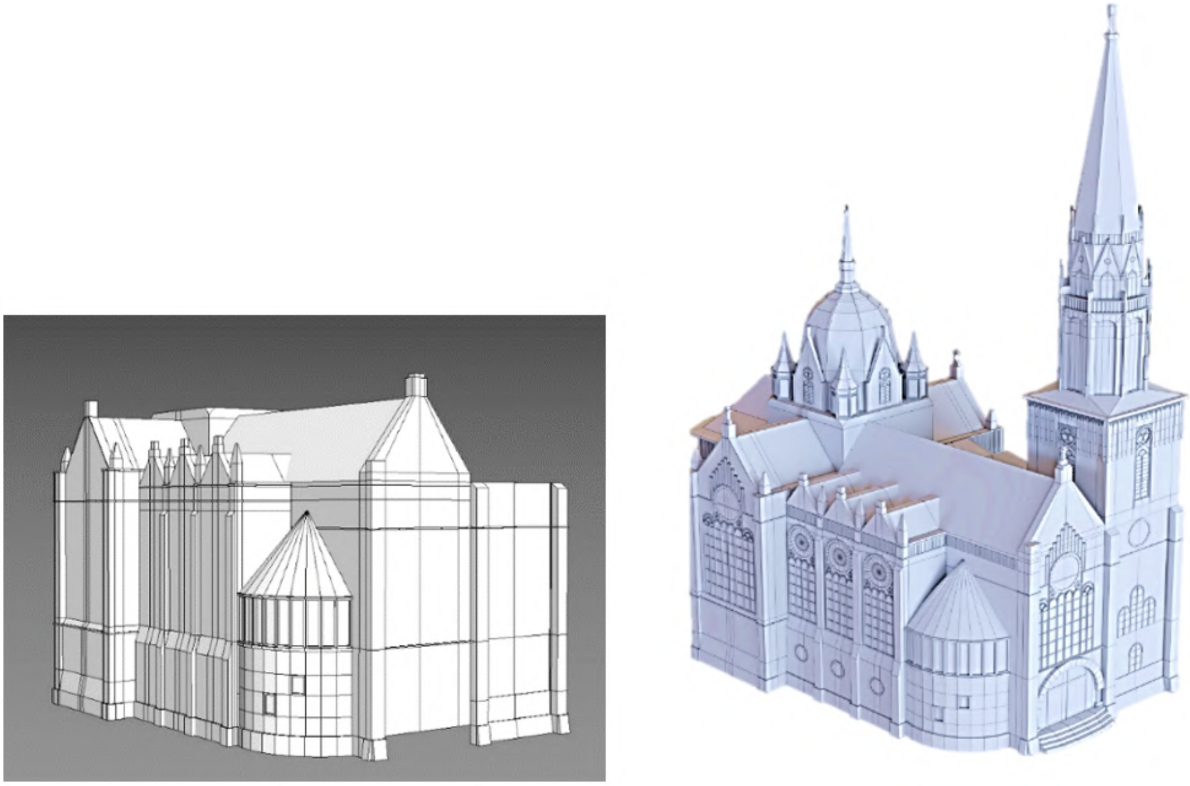

Figure 3: The primary and resulting 3D models of the Parochial Cathedral.

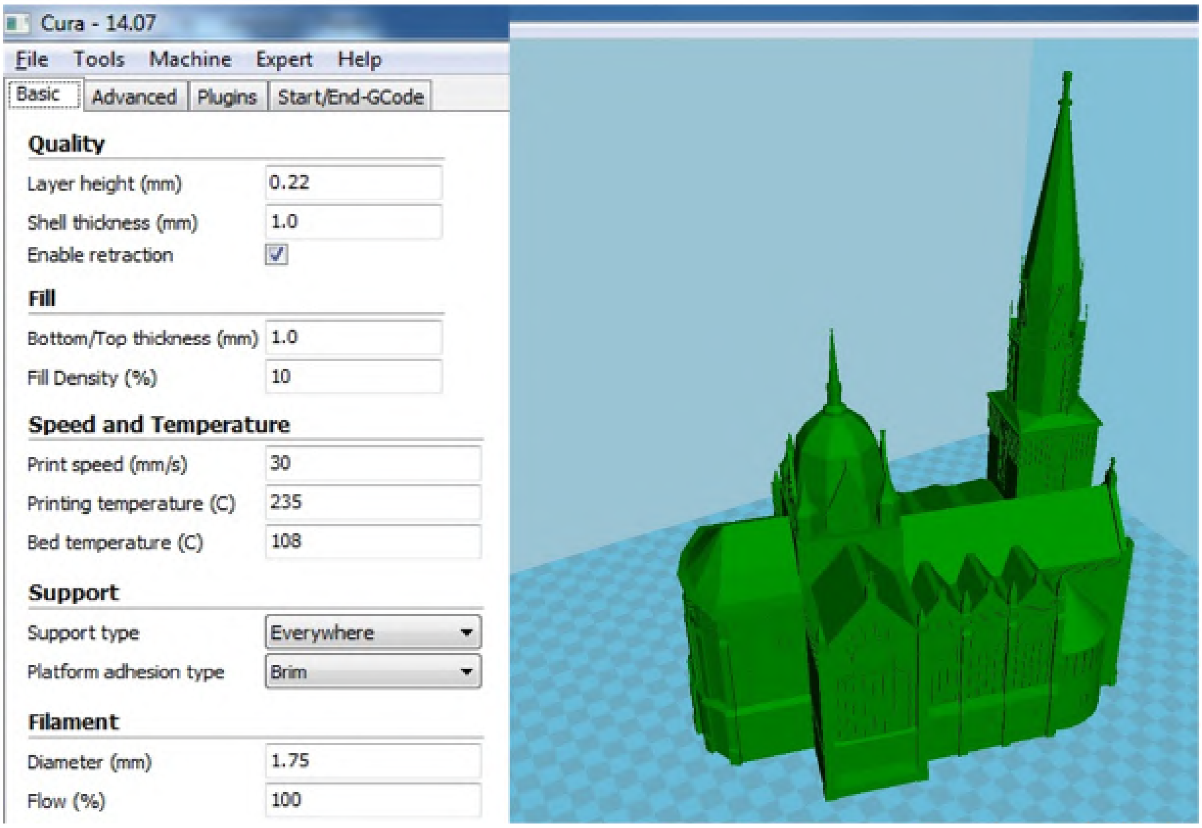

Figure 4: Adjusting the model sizes for printing.

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, guided by convenience and a relatively user-friendly interface, we apply Cura, which, apart from standard editing tools, printing quality adjustment, and material parameters, includes functions for calculating the weight of the end item, its print time, etc. [56].

Basic settings of technological parameters include printing quality, filling, printing speed and temperature, parameters of printing support, and plastic threads. When setting the parameters of printing quality, the most essential one is the layer height (mm), determined by the nozzle diameter, and it should not exceed half of it.

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

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

Settings of print speed and temperatures enhance the qualitative and technological parameters of printing. The most significant parameter is print speed, which determines nozzle movements. As our model has many fine details, the set speed is 30 mm/sec to ensure printing accuracy. This is because high print speed affects its quality due to 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 the 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 Brim function to provide high-quality printing of model elements that are overhanging (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 an automatically formed G-code, and the approximate print time and the amount of 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 Parochial Cathedral has been carried out by specialists of the Innovative Centre 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's cultural heritage.

4. Evaluation of the proposed methodology

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

In the process of teaching prospective IT specialists 3D technologies, we focused on the use of a comprehensive methodology for studying the graphical reconstruction of historical architectural objects. This methodology consists of 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 stereo pairs of images of the studied objects.

The proposed technique forms certain preliminary skills in students for the implementation of graphical reconstruction, which are important for their future professional activities. To substantiate

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

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 ascertain the effectiveness of the proposed methodology and 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 prospective IT specialists covered 27 students of the "Professional Education (Computer Technologies)" specialty. The distribution of students for the experiment was as follows: the experimental group (EG) consisted of 14 students, and the control group (CG) consisted of 13 students. The research consisted of 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 prospective IT specialists to carry out graphical reconstruction.

These indicators were: 1) knowledge about the technique of graphical 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 characterise four levels of skills of prospective IT specialists to carry out graphical reconstruction:

1) Low (characterised by low motivation to use graphical reconstruction technologies in professional activity and creative self-realisation; lack of geometric design skills; elementary theoretical and technological training in the use of specialised software for solving problems of graphical reconstruction and 3D printing; fragmented ability to analyse graphic information);
2) Medium (characterised by a limited interest in graphical reconstruction technologies and in the use of computer visualisation 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 printing);
3) Sufficient (characterised by significant motivation for the use of graphical reconstruction technologies and spatial modelling tools in professional activities, thorough training in the use of specialised software for solving typical tasks of graphical reconstruction and 3D printing, understanding of the process of analysing graphic information using arrays of digital data, readiness to reproduce typical models of graphical reconstruction);
4) High (characterised by a conscious and reasoned motivation for the use of graphical reconstruction technologies and spatial modelling tools in professional activities and for creative self-realisation, thorough training in the use of specialised software for solving creative problems of graphical reconstruction and 3D printing, the ability to evaluate graphic information and analyse digital data arrays 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 selected indicators were as follows:

1. Knowledge about the technique of graphical reconstruction and the necessary tools was 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 a project.
4. The ability to use image analysis technologies based on stereo pairs and parallax assessments was 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 by only 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.

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

5. Conclusions and future work

Graphical reconstruction of historical architectural objects is made possible by new technologies of 3D graphics, modelling, and design in specialised computer environments. The developed method of 3D technologies for graphical reconstruction is exemplified by the modelling of the Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s.

Table 2
Dynamics of the level of knowledge of students.

Group	Experiment stage	Total number of students	Grade Point Average, μ	Knowledge level: High – Number of students	High – %	Sufficient – Number of students	Sufficient – %	Medium – Number of students	Medium – %	Low – Number of students	Low – %
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

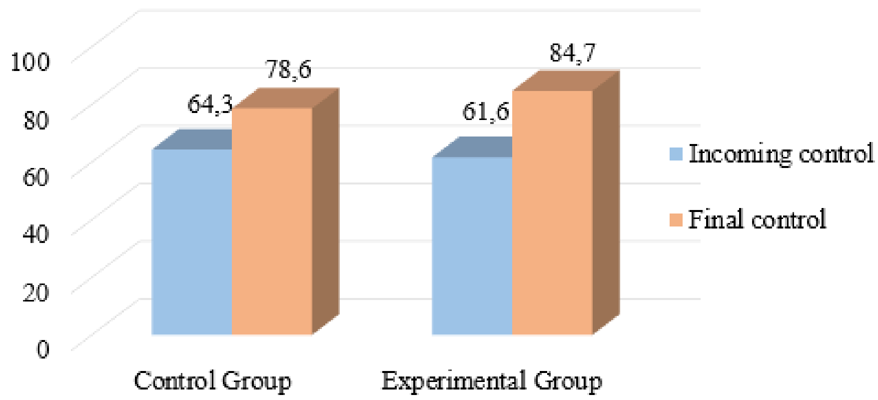

Figure 6: Dynamics of the quality of knowledge.

The proposed method of training in graphical 3D reconstruction is based on the principles of systematicity and consistency, accessibility, clarity, connection between theory and practice, and a combination of individual and collective learning. The stages of the proposed methodology (analysis, modelling, design, model printing) are based on a general methodology, taking into account individual specifics, depending on the tasks to be solved, the selected software, and 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 archival sources, as well as based on determined parameters according to the comparison of descriptions and data on the construction technologies of cathedrals of that epoch.

A comprehensive method for the graphical reconstruction of historical architectural objects is proposed. This method consists of constructing a 3D model of an object, based on a combination of design techniques using modern 3D technologies, methods for analysing archival descriptive information and data from a set of images, and processing technology for a stereo pair 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 for working with bulk data that incorporate new achievements in information 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 a 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 in students in the process of designing model buildings and structures using modern digital technologies of graphical 3D reconstruction.

To substantiate the effectiveness of the proposed 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 prospective 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 "Graphical Reconstruction of Architectural Objects" and its introduction into the educational process of the "Professional Education (Digital Technologies)" specialty;
2) Technological: reconstruction of the Cathedral interior that would enable the creation of a virtual historical museum of the architectural monument. However, this problem requires auxiliary data on the Parochial Cathedral of St Mary of Perpetual Assistance and remains unsolved to date.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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