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Heritage Building Information Modeling (HBIM) of the ruined and damaged architectural heritage in Upper Kama Region (Russia)

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Abstract
Building Information Modeling is a tool for the disappearing architectural heritage and environment recreation in 3D virtual reality. The article presents the information modeling experience of ruined and damaged architectural heritage, located in theUpper Kama region in the north Perm Kray (Russia) . The Scan to HBIM technology applied for modeling: information modeling based on laser scanning and a photogrammetric survey. The challenges of the work process are specified. Using the collected data (archival documents and engineering survey results), the parameters of each building's elements are supplemented with information about the history, damage, transformation, and condition of structures and architectural elements. Historic photographs helped to restore the buildings' 3D appearance. Archival descriptions provide the colour and coating materials' characteristics. Full-fledged virtual copies of ruined Orthodox churches of the Upper Kama region were created. The article proposes further work using obtained 3D-information models, including gamification, and virtual and augmented reality.
Keywords: Architectural Heritage; Heritage Building Information Modeling; Laser scanning; Virtual reconstruction.

1. Introduction

Upper Kama is an area located in the north of Perm Region in Russia. Old towns significant for the history of the Russian Urals are situated here: Solikamsk (founded in 1430), Cherdyn (1451), and Usolye (1606). Throughout their history, Russian and European architectural traditions have developed and intertwined in these towns, leaving their traces in the form of typical regional architectural ensembles and individual buildings (Braitseva, 1977; Kaptikov, 2014). Many of them have survived to the present day in a dilapidated or ruined condition, but have not lost their cultural, historical, and architectural value. The possibilities of information modeling make it possible to restore such objects in a digital format and use virtual reality technologies to prevent a complete loss of historical memory about the architectural heritage of the 17th-19th centuries.

This work aims to restore and preserve in digital form three-dimensional information models of the Bell Tower of the Transfiguration Cathedral (1730), Rubezhskaya Church (1774) in Usolye, and the Holy Cross Cathedral in Solikamsk (1709) (Fig.1). All of them do not have any conservation measures and are exposed to destruction, which is accelerated by the harsh Urals climate.

Building Information Modeling (BIM) has already proved to be an effective and practical tool at various stages of design, construction, and operation (Carbonariet al., 2015; Talapov, 2015). Information modeling is now actively applied in the architectural heritage preservation field transforming to Heritage building information modelling (HBIM) technology. It is the tool that can include different levels of information and a common environment between different stakeholders. (Barazzetti &Banfi, 2017, Amen, 2021, Aziz Amen, 2022, Amen et al., 2023).

HBIM combines multidimensional visualization with the complex parametric databases and allows to integration of graphic and metadata management, and provides a common environment for different professionals to work on a project.

2. Related works and methodology

Scan-to-HBIM technology includes laser scanning and photogrammetric surveying with subsequent information modeling.It was used in the work on the information models formation of the Upper Kama region's disappearing architecture. This technology is gradually becoming widely used to document and work with the heritage in a digital form. Information models are being built today in such a way as to open up the possibilities of gamification and the use of virtual and augmented reality technologies.

To obtain point clouds Scan-to-HBIM technology was used, including laser scanning (ground laser scanner Leica Scanstation C10) and photogrammetric survey (digital photo camera Sony for photos on-ground, DJI Mavic for aero photo).The results are combined into a entire point cloud (Fig. 2). The point cloud was processed using Leica Cyclone, Autodesk ReCap, and Agisoft Metashape (Photoscan).

We considered visual representation of the point model in Recap in detail earlier (Maksimovaet al., 2019, Amen & Nia, 2020).

Bell tower of the Transfiguraion Cathedral in Usolye (the central ensemble)

Cathedral of the Exaltation of the Holy Cross in Solikamsk (the central ensemble)

Rubezhskaya (Vladimirskaya) Church in Usolye

Figure 1. Destroyed monuments of architecture and the condition of the decorative elements of the facades (Photo by Author).

A single point cloud was processed in CAD systems to obtain measurement drawings and profiles of facade decoration for subsequent modeling. Information modeling was conducted in Autodesk Revit and Graphisoft ArchiCAD. During the creation of the final digital models, deformations of the building as a whole were taken into account, as well as damage and loss of some structural and decorative elements of the facades.

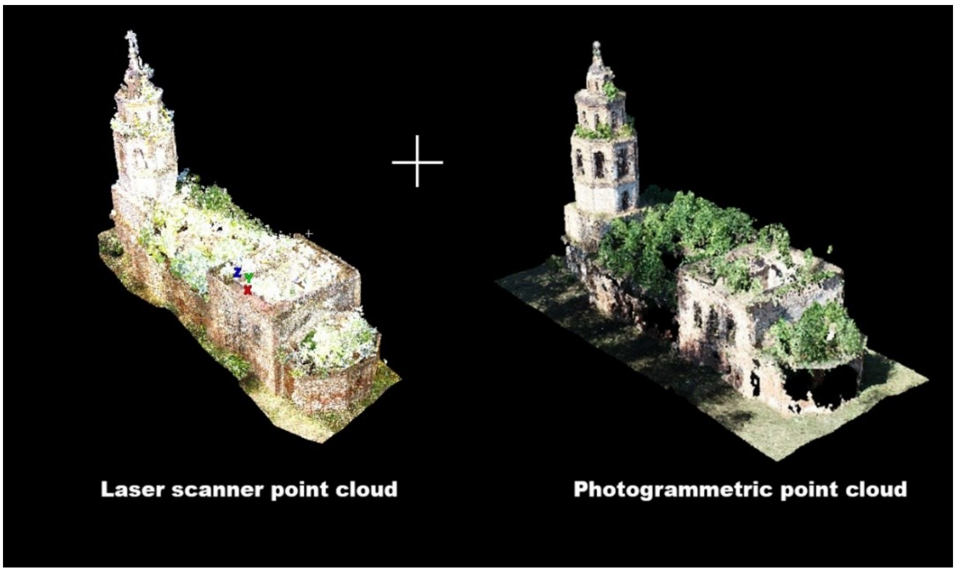


Figure 2. Combining point clouds by the example of Rubezh Church in Usolye.

Various archival data were used to visualize the architectural monuments: museum collections, data from city archives, and data from surveys ofpast years. With the help of photographs it was possible to restore the exterior appearance of the buildings. The text descriptions helped to understand the color characteristics and the information about the materials of coatings.

3. Features HBIM in the digital documentation process of the damaged buildings

There is the difference between the newly designed objects modeling and the existing and destroyed architecture modeling. Creation of the damaged buildings models requires a different approach. Damaged monuments and ruins do not have defined and precise geometric shapes, which gives the difficulties in modeling with standard building information modeling tools (Barazzetti&Banfi, 2017).

The final model depends on the available full-scale geometric characteristics and theadditional metadata. The fixation of the current state at the point cloud construction stage has an error depending on the point cloud creation tool (Table 1).

Table 1. Errors of different point cloud technologies.

TECHNOLOGY/TOOL	ERROR
Ground laser scanning LeicaScanStationC10	Up to 1mm
Ground laser scanning Faro FOCUS M70	Up to3mm
Photogrammetric ground survey	Up to 3 sm
Photogrammetric aerial survey	Up to 7 sm

At the stage of building the information model, this error increases significantly due to the inconsistency of the geometry of the elements from which the model is built. Many decorative elements of the facades, which are partially lost and damaged (Fig. 3a), also bring their peculiarities during modeling.
The modeling of damaged elements in an information-modeling environment has its own specifics. Point cloud data and CAD drawings often have more accurate geometric data, especially for damaged elements. However, the bottom line in a BIM model is the most visual and allows you to link parametric characteristics of elements: specify material, year of construction, and any other metadata that is needed to describe a particular object. Figure3b shows the results of digital data extraction at different stages of processing field digital data: point clouds, CAD drawing, building information model. Some loss of damage data at the 3D modeling stage is evident, which does not interfere with the work on virtual restoration of lost elements and structures.

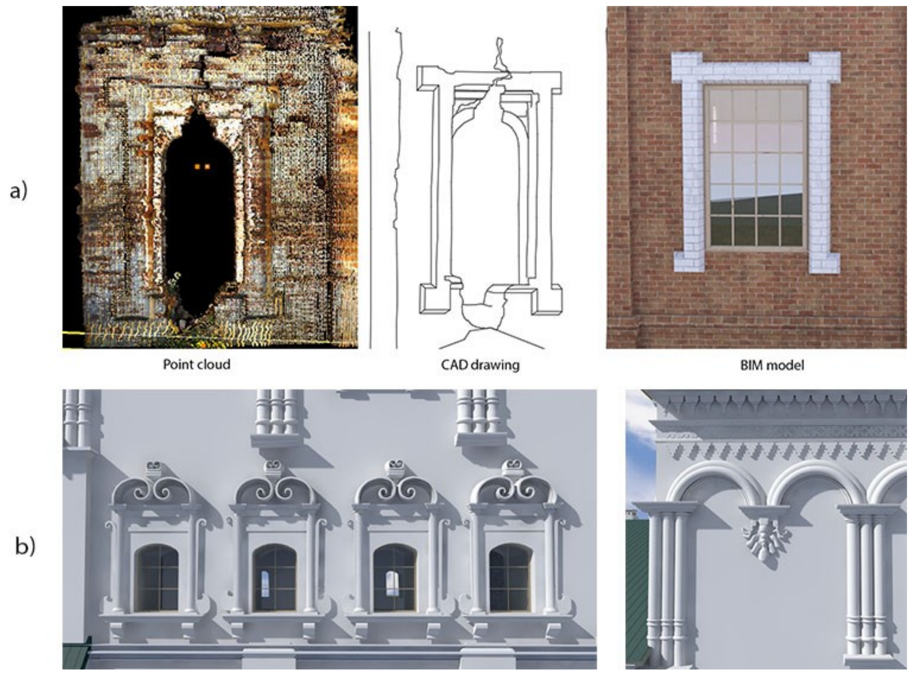


Figure 3.a)the difference in digital data of different software
b)modeling of complex elements of the facade of the Cathedral of the Exaltation of the Cross in Solikamsk.

Modeling and compiling libraries of the architectural element families were carried out manually, taking into account the repetitiveness of some decorative and structural details and the uniqueness of others. The families of modeled elements were created using field data, photographs, measurement drawings, and descriptions.
The use of simulation software products depends on the accuracy of the final model related to the final visualization task. For example, to use a web engine, the accuracy of the model will be related to the capabilities of the server that hosts the model. In this case, it is necessary to optimize the model, reducing the number of polygons and common weight without loss of model's quality.

4. Virtual Reconstruction Results

The multi-tiered bell tower of the Savior Transfiguration Cathedral, with its figured roof bends and high spire, is the main dominant feature of the historical and architectural ensemble of Usolye. The bell tower decorates with two tiers of the "beetle" ornament and barely noticeable corbel arches on the facets of the crowning part of the middle octagon. As it is known, after the fire in 1848, a bulbous head replaced the spire, and the end of the bell tower tiers acquired a semicircular dome form. These historical details are taken into account in the modeling (Fig. 4).

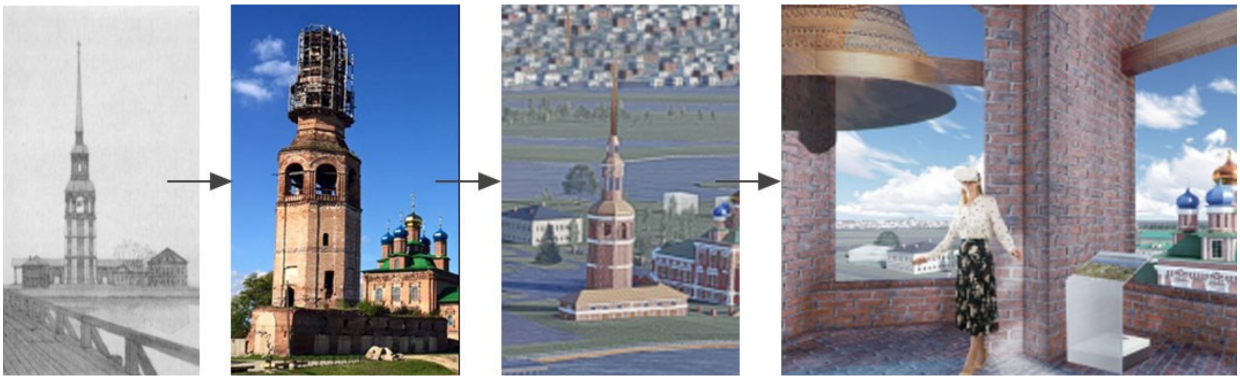


Figure4. Digital transformation of the bell tower of the Spaso-Preobrazhensky Cathedral in Usolye.

The Cathedral of the Holy Cross was restored according to historical photographs from the early 19th century. Virtual reconstruction made it possible to fully restore the appearance of the building, in particular, the unique decor of the facades, created in the Upper Kama region in the late 18th century and known in architecture as "uzorochye" (stone patterns) (Fig. 5).

Archive photo of the 19th century beginning (funds of the Solikamsk Museum of Local Lore)

3D building information model

Figure 5. Cathedral of the Holy Cross in Solikamsk.

Rubezhskaya church in Usolye (1754-1774) is a monument of provincial cult architecture of the second half of the 18th century. The monument has an important compositional meaning in the development of Usolye. This building is one of the architectural dominant of Usolye. Rubezhskaya Church differs from it by laconism of architectural forms and modesty of decoration because was built a quarter of a century after the main Stroganovsky ensemble. The facades are decorated with the old local elements (rod, plinth, corner endings), which are combined with Baroque elements in the outlines of window apertures, roofs, and temple parts. The porch portico of the southern facade, added later, has the Tuscan order stylistic features (Makovetskij, 2004).

The church belongs to the type of temples-ships with a bell tower above the narthex, and has a typical for them planning scheme: all the main volumes are located on one axis. Its composition resembles Moscow churches of the XVIII century, where the volume of the refectory is also crowned with a high bell tower.

After the Kama hydroelectric plant was built in 1954, the territoryof the church locationis almost annually flooded. The building is destroying and disappearingmore every day. Therefore a virtual restoration is the only way to save its architecture (fig.6).

Modeling Rubezhskaya Church was quite a complicated process, as the structures of the roof, porch, and decorations were lost. The church was restored in virtual form based on point clouds (to get the exact dimensions) using archival photographs (to reconstruct the lost elements).

Virtual reconstruction

3D model of existing condition

Figure6. Rubezhskaya Church in Usolye.

5. Application of virtual reconstruction models for digital museumification

The resulting simulation models are the best representative tool for introducing architectural heritage in a multimedia environment. Digital copies and reconstructions of the building are not only modern sources for research but also new exhibits of museums, and means of popularization of architectural heritage (Bush,2015; Kozlova, 2014). Information stands, QR codes, and VR technology can be used both in the virtual tours we are already familiar with and in more daring ideas - VR concerts, lectures, exhibitions, and games.

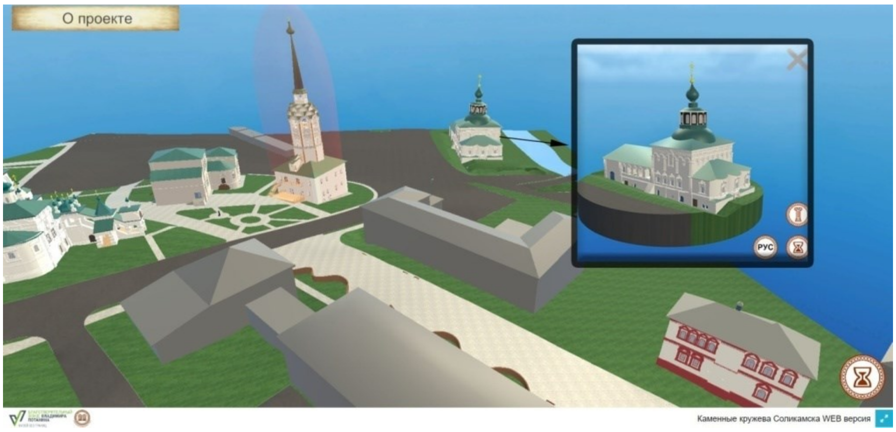
Web technology opens access to the resulting models to all visitors of the digital museum, at the same time telling the history of architecture. We applied web technology in creating a virtual tour of the central ensemble in Solikamsk. The information model of the Cathedral of the Exaltation of the Cross was embedded into the general scene of the virtual copy of the central architectural ensemble of Solikamsk and then uploaded into the Unity game engine. WebGL technology was used to publish the model in the public domain. Complementing the model are text boxes, which the user viewing the model, gets by clicking on each building.

It should be noted that due to the high requirements for the characteristics of the equipment, 3D-information was placed in the form of links on the server with a storage capacity of more than 100 GB. If necessary, it can also be stored on a cloud server or USB-drive.

Digital heritage museums tend to provide access to viewing and virtual interaction with digital models. One simple use of three-dimensional models of demolished buildings is to present the reconstructed architecture virtually so that the architect's original intent can be appreciated. Such models can be loaded into the application and can be accessed by QR code (Fig. 7).

5. Discussions and conclusions

Information models of ruined or lost architecture generate new boundaries of interaction with virtual space in which users can act as actors and creators of visible and "invisible" reality. The procedure of composition and decomposition of architectural objects based on the information model can become the basis of gamification technology gaining momentum in education (Utkina, 2023). Bringing game mechanics into non-game domains to explore and solve problems is one of the trends in the use of digital data today. Unity 3D game engine and Autodesk Maya are known applications in this area (Kontogianniet al., 2017). Gamification helps to get students interested in doing routines and improve their skills with point clouds and modeling software products. In the future, we plan to develop game content based on mLevel to improve students' item-matching skills with maximum point cloud matching.



Web-view of the model of the Cathedral of the Exaltation of the Cross

Example of using the Rubezh Church model in a mobile app

Figure 7. Web-technologies for presentation of the heritage.

Rethinking the digitalization process and subsequent use of digital data expands the boundaries of working with architectural heritage. The information model today is not only a tool to restore and preserve historic architecture, but also an opportunity to apply and create new learning technologies in the virtual architectural space.

Conflict of Interests

The authors declare no conflict of interest.

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