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METHODOLOGICAL AND TECHNOLOGICAL ASPECTS OF 3D MODELLING OF HISTORIC MEMORIALS AND STATUES IN ORDER TO DOCUMENT AND PRESERVE OBJECTS OF CULTURAL HERITAGE

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Summary

The article deals with the main aspects and contemporary methods in 3D modelling of historical memorial structures in order to preserve objects of cultural heritage. Results of experiments using various combinations of software and technology have been presented: geographic information systems, ground laser scanning and computer graphics programs for rendering. On the basis of comparison between these methods and technologies, conclusions have been drawn, and recommendations for their application in the field of heritage preservation have been given.

Keywords

Historic preservation • preservation of cultural heritage objects • monument • geographic information systems • ground laser scanning • computer graphics • rendering • digital terrain model • attribute database • visualization • generation • 3D modelling • photo texture • video archiving

1. Introduction

The protection of historical and cultural monuments is a special sphere of society's life, which ensures its spiritual development, and maintains historical memory as well as the connection between the past and the future of the state. Activities pertaining to that sphere have an extensive structure; they are fixed at the legislative level, controlled by the state and a number of civic organizations. The main tasks of monument protection include their registration, scientific studies, classification, preservation, and restoration, in order to make them suitable for visiting and sightseeing, and to ensure their proper maintenance and use, carried out through the implementation of a set of various measures [Kot 2010]. Application of modern scientific methods and the latest digital technologies allows us to bring monument protection activities to a new level. In particular, modern remote sensing methods, such as thermal imaging or radar shooting, make it possible to accurately determine the location of otherwise inaccessible objects; laser scanning or stereophotogrammetry allow quick

collection of quantitative and qualitative information about the objects of historical and cultural heritage; and with the help of specialized software products of computer graphics, we are able to get their high-precision digital models. Classification, cataloguing, description and documentation of monuments are more easily carried out with the aid of geographic information systems and electronic databases. Due to the use of digital technologies, the traditional documentation of objects in the form of registration sheets, plans and drawings, and other paper documents became the thing of the past; instead, a new structure emerged, namely the digital audio-archive of historic monuments.

The purpose of this article is to describe and analyse experiments in the field of monument protection. Modern methods and sets of software and technical tools, such as geographic information modelling, ground laser scanning, and the use of specialized computer graphics programs for rendering, provided us with the necessary data for further modelling of historic monuments and statues.

According to the dictionary, in the context of art history, a monument is a man-made object of a certain size; a sculptural structure, designed to perpetuate the memory of people, events, objects, and sometimes animals [Dictionary of the Ukrainian language 1973]. The most common types of monuments include a statuary, a statue, a bust, a memorial plaque, a triumphal arch, a column, an obelisk, and a landscape decorative form. Statues are three-dimensional structures, and usually they are set on the pedestal. From the moment when the monument acquires a concrete form, it ceases being just a piece of gypsum, bronze or marble, and it receives a semantic load as well as becoming an integral part of the surrounding space, and to a certain extent, an element forming the social values [according to Ukrainian Soviet Encyclopaedia 1983]. However, in this case, we are not interested in the social or spiritual significance of the monument, but in the possibility of documenting the object itself, and the choice of modern digital technology that would be appropriate for this. In terms of geometry, the monument and its elements are described by quantitative parameters and descriptive characteristics. Among quantitative parameters we point out those, which can be measured and recorded, for instance height, length, width, volume, perimeter, depth and radius. By the descriptive characteristics of the monument we mean the semantic data, such as for example: name, material, date of construction, architect's and sculptor's name, as well as historical, biographical or other data – namely, any useful information regarding the monument, the person, or the event pictured.

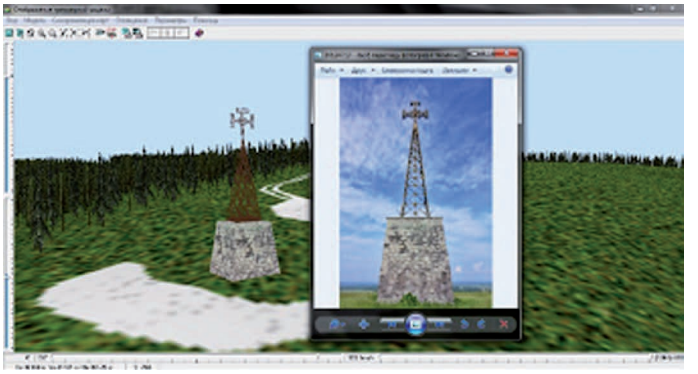
All data about the given monument corresponds to the original, and it is stored in the computer memory, entered into the database for the purpose of registration and documentation of the object. The stored data is available for further, multiple uses, for instance for the purpose of designing, restoration works, and processing in GIS or specialized programs for three-dimensional modelling.

3D modelling of statues, in contrast to the architectural modelling of geometrically correct and symmetric forms, has a number of features that need to be taken into account when choosing software for rendering.

2. Application of GIS for complex modelling of monuments and landscape

Contemporary multifunctional GIS possess not only the necessary modules for the input, classification, storage, display and analysis of spatial data, but also tools for generating spatial objects, assigning attributes to them, and storing them in a structured database with the ability to display on a digital terrain model, taking into account relief and topological connections [Svitlychnyi et al. 2006]. Therefore, the geographic information system can be considered as a comprehensive way of integrating heterogeneous data, as well as analysing and synthesizing that data in order to create new models that will reflect the real world in the virtual space of information. This property and advantage of informational and referential GIS is appropriate to use for objective documenting, studying and simulation of historical and cultural monuments in conjunction with the natural landscape, taking into account the terrain and the internal context of the area [Kuzyk 2013].

For the purpose of this study, a digital model of a national memorial site complex of Bila-Pidlysetska Hill with a monument constructed in 1911 to honour of the 100th anniversary of the birth of poet Markiyan Shashkevich was created in the GIS Map 2011, based on the topographic map vectorization, while taking into account appropriate classification and coding systems, and using the 3D standard signs library (Figure 1).



Source: authors' study

Fig. 1. The digital terrain model of the "White Mountain" memorial complex and a photograph of the monument

The "Semantics" window contains attribute information about the monument: its name, date of foundation, status, and historical information. Generating and developing a 3D model of complex design is accomplished with the addition of a new template in the "Edit Sign" window by programming new primitives, and overlaying the texture selected from the photo. As a result, a realistic model of a 25-meter-high memorial in the form of a lattice metal cross on a stone pedestal has been obtained. Using the "3D Topo" function, a 3D conditional symbol is created, that is displayed on a digital terrain model as a point object with a set of required attributes (Figure 2) stored in the database.

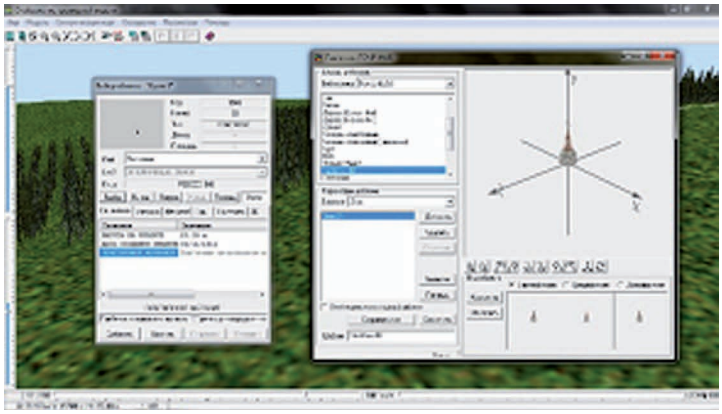


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Fig. 2. Attribute assignment (left) and generation of a 3D-symbol (right) of the memorial in GIS. Karata 2011

As you can see, the model of the memorial, based on the precise measurements of the latter, its proportions, and the photo texture (Figure 1, on the left), is set as a scale point mark on the DTM, and is quite similar to the actual object. Rotating of the DTM is carried out in different directions with the right mouse button, thus the model of the memorial can be observed from different angles. The video review function allows you to automate this process, and to save the file in a video format.

3. Features of terrestrial laser scanning for the visualization and 3D-modelling of memorial structures

Following is the example of a three-dimensional modelling of a contemporary cultural object: a monument to a prominent figure, Metropolitan Archbishop Andrey Sheptytsky, erected in 2015, which was designed to best to fit in and complement the historical and architectural ensemble of St. George's Cathedral in Lviv. It takes the form of a bronze sculpture, 3.6 m high, standing on the pedestal and marble arms of the inexactly shaped Maltese cross (Figure 3).

The method and technology of terrestrial laser scanning (TLS) is used to document this memorial. This relatively new engineering method of measurement, based on the principle of obtaining information about the object by referencing and reflecting the laser signal from the points of the object, has gained widespread recognition in various scientific and applied branches. As a result of the TLS, due to a high-precision automated active shooting system and a built-in camera, a structured "cloud of points" as well as five geometric and optical parameters: spatial coordinates of points (X, Y, Z), intensity and colour, are received [Dorozhinskyi 2014]. The method of TLS involves the phased implementation of a complex of field and camera work, namely: design, laser scanning and modelling of the object.

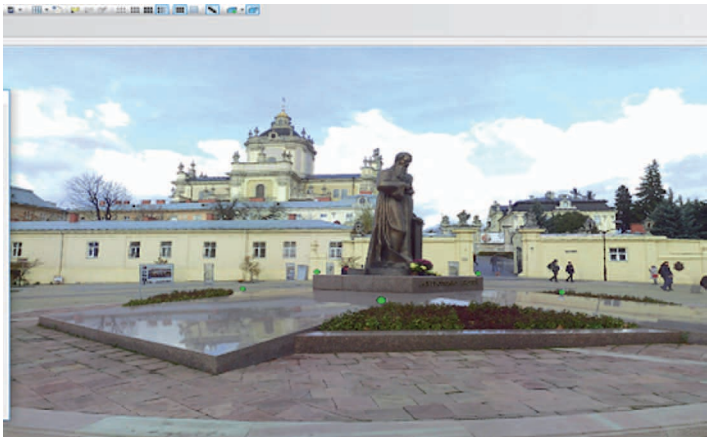

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Fig. 3. Monument to Metropolitan Archbishop Sheptytsky in Lviv (image taken during TLS with an integrated camera)

Terrestrial laser scanning of the memorial to Andrey Sheptytsky was performed using the FaroFocus3D scanner (the principle of distance-to-point measurement) with high resolution and image quality, from 5 stations located around the monument.

Figure 4 shows the scheme of the stations' placement around the monument and glass "spheres", the display of which is subsequently used to "cross-link" the scans. The scheme is designed taking into account the technological features of the TLS and the requirements for the further processing of TLS data in a special program whose purpose is to generate a three-dimensional virtual model of the monument.

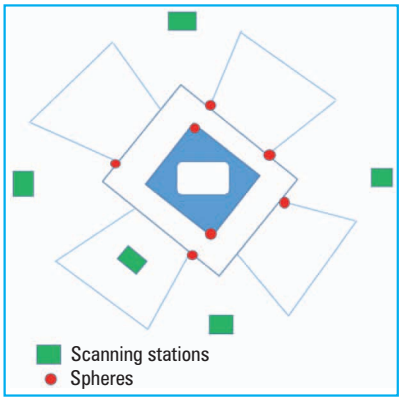

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Fig. 4. The layout of the TLS stations (green) and the glass recognition spheres (red) around the monument

As a result of the scanning, five scans were obtained, the files of which were uploaded to the Faro Scene5.5 workspace. A number of standard functions are used in further elaboration and generation of a three-dimensional image. Filtration was performed in turn for each scan, i.e. the removal of excess measurements, the recognition of the reference points (spheres), their registration, the choice of reference scans and the "sewing together" of scans into one point model in the selected coordinate system. We thus obtain the "cloud of points" of the model, as shown in Figure 5. Based on the results of the automatically calculated internal convergence of scans, the accuracy of the digital model is between the minimum = 1.6 mm, and the maximum = 6.7 mm.

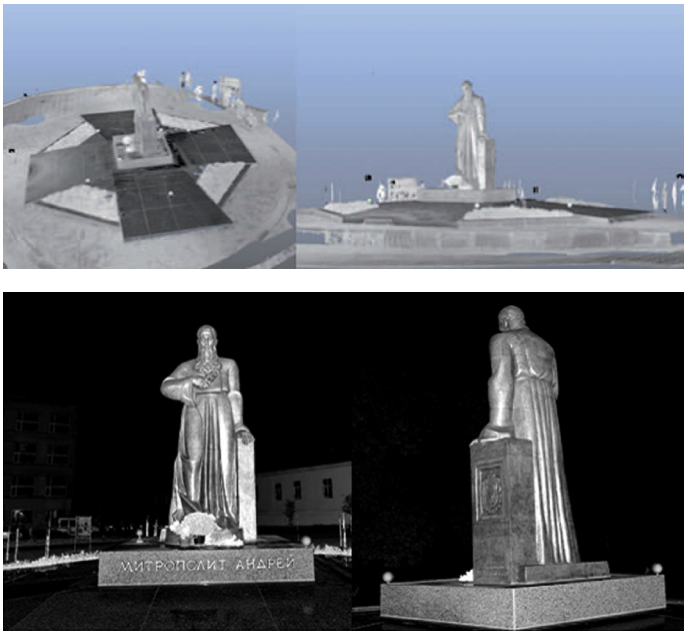

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Fig. 5. Structured "cloud of points" from TLS (left), and 3D model of the memorial (right), without photo texture

Object visualization requires the assignment of colour values to the RGB system obtained from the image, after which the object's model becomes realistic. For this purpose, using the Colour/Pictures – ApplyPictures function, we apply a photo texture and get a high-precision virtual volumetric model of the memorial that can be zoomed in, rotated, and viewed in a three-dimensional space.

In the FaroVideo software module, after adjusting the differentiation and choosing a trajectory around the laser model of the memorial, as shown in Figure 6, a demonstration video was created and saved in the .mp4 format.

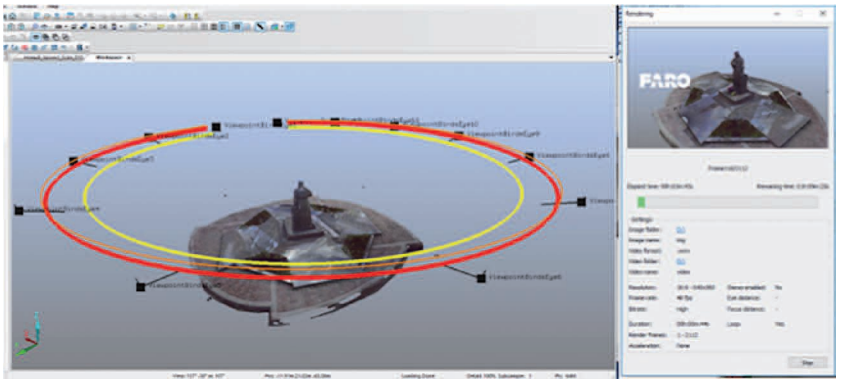

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Fig. 6. Creation of a demo video file in FaroVideo

4. Investigation of the methodology and functionality of three-dimensional computer graphics programs for modelling of monuments

The rapid development of computer technology and computer graphics software over the past decade has opened up new opportunities for the rendering and creation of virtual products in various scientific and applied areas [Vasilyuk, Melnikova 2016]. The trend of our time is the dematerialization of problem solving, and 3D modelling of objects – not in the real, actual, but a virtual environment. This topic is relevant not only for cinema, design or animation, as was the case until recently, but in almost all spheres of human life. The most advanced achievements and ideas of 3D graphics (and computer graphics in general) are reported and discussed at the annual SIGGRAPH Symposium, which is traditionally held in the United States [Riznyk 2012]. The tasks of 3D modelling are solved using special compiler programs based on embedded mathematical and physical formulas in programming languages. The market offers a wide range of different complex software applications for computer graphics. Although most people, who work in the protection of cultural monuments, are of non-technical professions – historians, archaeologists, art historians, culturologists or managers – modern times dictate new requirements, and motivate the development of state-of-the-art technologies and software tools that can easily solve the tasks of documenting, restoration, surface modelling and preservation of cultural heritage objects.

In order to make 3D modelling of monuments for the purpose of this study, we have decided to use the Autodesk ReCap 360 software, which is relatively easy to use and readily accessible (in a demo version).

The object of the research was the memorial to the students of Lviv Polytechnic, who died during the Second World War. It was established in 1976 at the Lviv Polytechnic, in the form of a bronze statue of a woman – the allegory of Science, who carries fire of knowledge in her raised hands.

The Autodesk ReCap 360 allows users to perform 3D modelling of the object based on photos taken in a circle, with a small base of capture, and drawing from high quality textures. The program allows the user to express a variety of design ideas.

The photographs were taken around the statue, using a mobile phone with a camera of 10 mp, while the basis of shooting was approximately 1m, and the axis of photographing directed towards the centre of the object. In this manner, 45 photos were obtained. In the ReCap 360 Photo software environment, we have created a new project, consistently downloaded all the photos (Figure 7), and chose the high quality for the three-dimensional model.

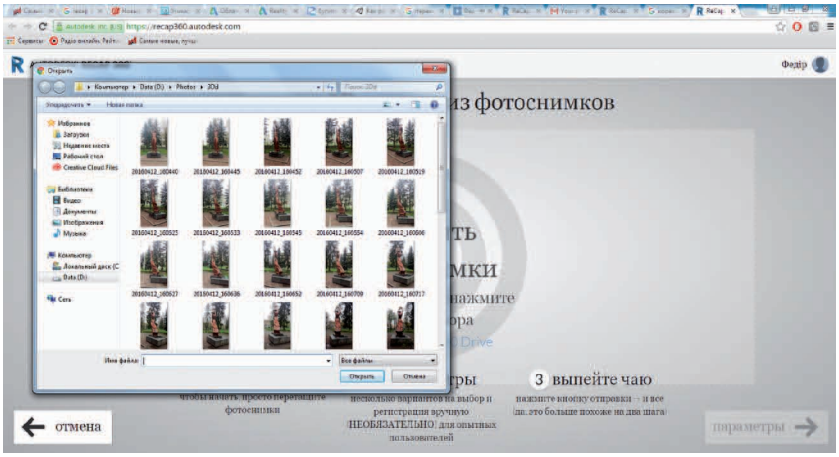

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Fig. 7. Consistent upload of photos in the ReCap 360 Photo software environment

Next, we chose the quality parameters for the 3D model, performed the so-called "Intelligent cropping" or filtering to remove unnecessary elements of the surrounding space, and set the format of the .obj, .rcm image file. The duration of the automatic generation of the model in our case was approximately 30 minutes. A three-dimensional model of the memorial, with a texture of photographs, and corresponding to the original, is presented in Figures 8a and 8b from two different angles. With the rotation tool, the model can rotate around the central axis of the figure by 360 degrees.

The ReCap 360 Photo program facilitates the creation of vector and raster volumetric models. Using the Wireframe function, we created a so-called vector "Frame" TIN-model, in which an arbitrary smooth surface is represented by a network of triangles and has a granular appearance (Figure 9a). The Shaded function allows to make a raster model of "shadows" (Figure 9b), which due to a dense matrix of pixels with different levels of grey tone reflects the voluminous surface of the memorial, smoothed and more realistic in the light-shadow palette.

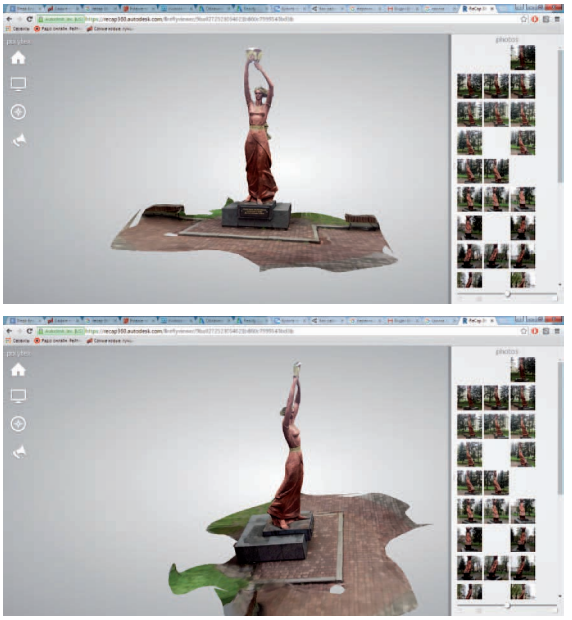

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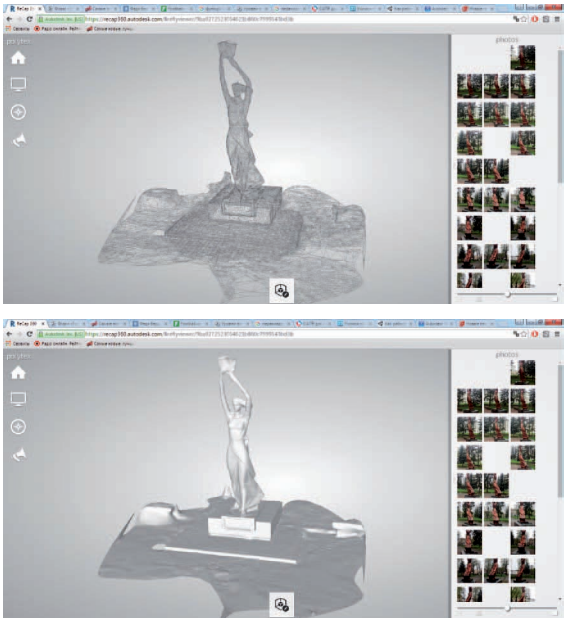
Fig. 8. 3D model of a monument with a texture of photos, presented from different angles



Source: authors' study

Fig. 9. a) TIN-model of the memorial; b) Raster model of the "shadows" of the memorial

Based on the 3D model, we have created a video in the Autodesk ReCap 360 software, which facilitates smooth viewing of the memorial's model on the move, in a circle, and saves the file in video format.

5. Conclusions and recommendations

Modern software and technological tools, including digital image processing and rendering methods, make it possible to carry out the construction, visualization, modelling, and storage of objects in a virtual environment. The scientific and practical developments of recent years, including software functionalities, are used in various fields of human activity. This statement is also valid in the field of monuments and memorials. Latest methods and digital technologies should be actively implemented and used in performing the tasks of documenting, archiving, modelling and restoration of historical and cultural monuments. The experiments carried out and described in the present article lead us to the conclusion that today tasks of the monument protection can be performed with the help of geographic information systems (GIS), terrestrial laser scanning (TLS) and specialized computer graphics software.

The GIS has a comprehensive solution to the problem: the generation of three-dimensional models of monuments and memorials from geometric primitives, introduction of descriptive characteristics, storage of information in an integrated attribute database, and visualization of monuments and memorials in a virtual environment, taking into account topological context within a digital terrain model.

Using the method of terrestrial laser scanning, the problem of accurate construction and visualization of three-dimensional models of monuments and memorials is solved. Although this high-precision technology today is quite expensive and may prove to be unprofitable for the recording and documentation of monuments and memorials, it is highly relevant in the context of exact restoration work. Typically, terrestrial laser scanning data is exported to other engineering software tools, such as AutoCad, to perform further measurement of the object and design. It should be noted that when scanning shiny marble or metal surfaces, texture deformation occurs, which in turn results in measurement errors and simulations.

Experimentally, research work gives grounds to assert that the method of TLS is a highly precise and operational method for obtaining spatial data, visualization and modelling of objects. As observed in the example of constructing a model of the Metropolitan Archbishop Andrey Sheptytsky's monument, it is recommended that TLS should be applied in architecture and for restoration of objects of cultural heritage.

The rendering program of the Autodesk ReCap 360 is quite user-friendly and easy to master, and it has a number of necessary functions for 3D-modelling of monuments and memorials, based on photographs captured around an object with any camera, even with a mobile phone or a smartphone. This method of modelling monuments and memorials is the most affordable, compared to the other two methods discussed in this article, as it does not require much cost or professional skills, however, it

does not claim high precision engineering measurements. If necessary, the files are exported to other software or graphic editors for further project-measuring or design works. They can also be added to the database for register, digital documenting and video archiving.

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