CARRYING OUT SURVEY WORK OF HISTORICAL MONUMENTS USING A LASER SCANNER

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Abstract: The article notes that the use of digital technologies and innovations in the preservation of architectural monuments and restoration of their interiors has become more effective. The use of digital technology in the restoration process, three-dimensional laser devices, and the creation of three-dimensional models required for architectural monuments are described. As an example, the results of the research based on the data obtained from the Mausoleum Ishrat Khana in Samarkand are presented in detail. The Mausoleum Ishrat Khana in Samarkand was built in a short period of time, namely 3-4 years. The construction work was completed in May 1463. Originally built for Khawand Sultan, this magnificent mausoleum later became a family burial vault for the women and children of the Timurid dynasty. The mausoleum has undergone several restorations and strengthening works. A three-dimensional digital model of the mausoleum was created using a laser scanner. Scientific studies were conducted on the digital model of the mausoleum and information about the current state of the mausoleum was obtained. As a result of the research, the difference in the dimensions of the foundations at the base of the mausoleum and the deformations of the portal were determined.

1. INTRODUCTION.

The reconstruction of architectural monuments using modern methods is one of the most important problems in the world. The use of digital technologies and innovations in the conservation of architectural monuments, the reconstruction of their interiors, and the restoration of the facades of unique objects is increasingly being supported in this field.

Three-dimensional modeling methods should be implemented in practice at present. This computer technology allows us to more accurate measurements of architectural monuments and create a digital three-dimensional model, providing with complete information about the building, including external damages, internal defects and other updated information. This information will serve as a three-dimensional model for the future restoration of architectural monuments.

History shows that, in recent times, many architectural monuments around the world have been destroyed due to the effects of the external environment, military conflicts, and terrorist attacks. In the mid-19th century, a number of problems began to arise in reconstruction works.

Many architectural complexes are included in the UNESCO World Cultural Heritage List. Today, the governments of Afghanistan, Syria, Cambodia, Libya face the task of preserving and reconstructing them.

Digital and innovative technologies can help solve these issues. A library of three-dimensional models necessary for the restoration of architectural monuments should be created for this purpose.

1.1. The purpose of writing the article.

A computer cannot replace the work of a researcher in the restoration process, but it can eliminate the need for a pencil, ruler, and drawing board. Recently, modern computer technologies have been used in the study and restoration of architectural monuments. Laser scanning of architectural monuments is a modern method of obtaining volumetric and spatial data. It is possible to get an exact three-dimensional digital copy of the scanned object using this method. The use of digital technologies (innovations) in the reconstruction process will make the tasks more effective. For this reason, we believe that it is necessary to widely introduce three-dimensional modeling methods into practice.

1.1.2. The main part.

The capabilities of computer programs give an opportunity to create digital models not only of individual structures, but also of entire complexes. Creating a three-dimensional model of an architectural monument is not a technically difficult task, it is only important to have a planning solution, as well as to have a copy of the historical material collected by the historian-architectural researcher in order to create a model as close as possible. It should be noted that the reliability of the restored object directly depends on the work and knowledge of the researcher. The possibility of damage is not excluded when restoring historical monuments using computer technology. In the practice of restoration, the integration of traditional knowledge with the potential of electronic technologies forms the basis for implementing "virtual" projects that would be impossible to turn into reality. Restoration specialists working with computer programs have great opportunities to create "electronic" archives, which include key elements of interior decoration, certain parts of the facade appearance, and specific stylistic ornaments, offering the possibility of extensive use of the materials obtained in the future [1].

Parametric design and modeling are very necessary to apply a modern look to historical architectural monuments. The development of modern technologies is a powerful tool in the fight against the disappearance of the architectural monument. In order to prevent the destruction of architectural monuments, initiative in this field is required. Innovations can stop the destruction of historical places, rebuild them and perhaps is the key to complete recovery [16].

Fig. 1. Virtual technology helps to travel anywhere and feel as though you are among the ruins of any archaeological sites.

1.1.3. Virtual Reality (VR).

One of the most popular technologies is virtual reality (VR), which allows the creation of interactive digital models of buildings, monuments and other heritage objects. With the help of VR devices, you can explore these models and even immerse yourself in the historical environment in a very realistic way, and you can be tens of thousands of kilometers away from their famous and not so historical places without leaving your home. (Figure 1). This technology is now very well received, especially in the field of education or thematic events. It is worth noting that laser scanners are often used to create certain virtual models, which help to create high-resolution three-dimensional digital models of buildings, monuments, statues, various objects of special cultural importance and requiring preservation. These models are used to document the current state of objects, as well as to plan restoration or conservation work [17].

In addition to virtual reality, there are also digital reconstruction and augmented reality (AR). If before, special knowledge, understanding of the values and trends in the art of a certain period, as well as a well-developed imagination were needed to understand the ruins, today, with the help of augmented virtual reality, visitors can use "smart glasses". Digital reconstruction of ancient objects in real time for viewing on smartphones and tablets with their built-in applications can be imagined as if seeing the ruins in real life. It is a very impressive sight, allowing you to stand surrounded by the beauty and ruins of the historic environment and watch the buildings and other objects take their former forms and the streets come alive.

All these developments are not only aimed at creating impressive models, but they are also used to create digital copies that are stored in a special archive. Digital archiving allows us to preserve the most valuable manuscripts and other information that has come down to us.

For example, a digital three-dimensional model of an architectural monument was created using a laser scanner, and research was conducted through various simulations, documented, and an electronic archive was created. After some time, if reconstruction work needs to be carried out on this architectural monument, we will refer to the documents in the electronic archive [18].

Periodic monitoring is also necessary when deformations are observed in a historical object. In this case, every 3-4 years, a three-dimensional model of the object is created using a three-dimensional laser scanner and the object is studied, comparing its condition over time. Archiving ensures that even if the original copy is eventually lost, the digital record will remain for future generations. At the same time, such preservation makes research more convenient for scientists around the world, because you can send an electronic document to any point in the world and to several dozen people at the same time.

A team led by University of California professor Shahzad Tahirov began scanning the famous Registan ensemble in Samarkand in 2013. Later, in 2015, it was expanded to include more cities and monuments, and was conducted in Tashkent, Bukhara, Samarkand, and Shakhrisabz using laser scanning [2]. This group conducted scientific research at the Kuk Gumbaz Mosque, an architectural monument belonging to the Timurid dynasty, built in 1437, which is included in UNESCO's World Heritage List in Shakhrisabz.

2. Architectural reconstruction and laser scanning of objects.

Laser scanning of complex architectural forms allows for computer-aided modeling of data and the electronic storage of detailed information about architectural structures. In this case, the information obtained can be further used in various computer programs for planning reconstruction, restoration and construction work. Modern instruments create the data systems that are compatible with Autodesk, AutoCAD, Revit, Cloud Compare and other digital design tools. Due to its versatility and high level of automation of measurement processes, the laser scanner is a tool for the restoration of destroyed and damaged structures. Laser scanning allows for fast and accurate data acquisition [3]. The operation of the laser scanner is controlled using a laptop or tablet with a set of programs, or using the touch control panel built into the scanner. A specialist should choose the right points for shooting and plan scanning sessions should be performed, and it is also necessary to involve other methods of collecting information about the object. For instance, to use scanning from the air, photography and aerial photography, mobile scanning. And of course, we must not forget about the traditional collection of information: historical documents, drawings, photos and video files.

If the destruction has occurred recently, then for the restoration process it is necessary to involve witnesses who saw this object intact. This is exactly what is done when restoring the objects of architectural heritage in Damascus and Aleppo in Syria [3]. However, for some monuments, it is necessary to involve all possible methods of data collection to build a three-dimensional model of the object for restoration, since restoration work is needed there, practically from scratch. And only then carefully create an architectural complex that closely reminds us of a real object before destruction. In our scientific research, we will examine the example of the Mausoleum Ishrat Khana, built in the 15th century in the city of Samarkand. We will begin our research by studying the brief history of the Ishrat Khana.

2.1. History of construction.

The Ishrat Khana is disproportionately important (its name is translated from Uzbek as “House of Joy, House of Pleasure, House of Entertainment, Place of Fun”). Today, it is a ruined building with a high portal located in the southeastern part of the modern city of Samarkand, next to the mausoleum of Khoja Abdi-Dorun. Once there was a tall minaret with a turquoise dome, a mosque and several various outbuildings. Unfortunately, the domed tower collapsed during the 1903 earthquake, and only photos of it remain [4] (Fig 2).

Fig. 2. Ishrat Khana. Photo by G. Pankratiev, 1895

The Mausoleum Ishrat Khana is one of the most remarkable monuments of the Timurid era in Samarkand. Even in its ruins, despite losing much of its ceiling and decorative elements, it still attracts attention with the uniqueness and harmony of its forms [5].

Fig. 3. Ishratkhana over the years.

The mausoleum is located on the southeast side of Registan Square, on the outskirts of the old city. During the reign of Amir Temur, a busy road passed through here, connecting the “Darvozai Feruz” with “Bogi Dilkusho” and “Bogi Boldi” gardens.

According to Abu Tahirkhodja's work "Samaria", this building was built by order of Habiba Sultan Begum, the wife of one of the Timurid rulers, Abu Said Mirza, for her daughter Sultan Khawand Beka. The mausoleum was built in a short period, specifically within 3-4 years.

The construction work was completed in May 1463. Originally built for Khawand Sultan, this magnificent mausoleum later became a family burial vault for the women and children of the Timurid dynasty. As a result of archaeological excavations, the burial vault with 20 tombs discovered here differs from the other burial vaults known in Central Asia in its splendor and size [6].

The mausoleum, like the mausoleum of Amir Temur, consists of a hilkhana (burial vault) and a shrine. However, the distinguishing feature of this mausoleum, compared to other Timurid monuments, is that it has a second floor beneath its dome. The hilkhana of the mausoleum, like that of Amir Timur, has a diameter of 8-9 meters and is constructed in an octagonal shape, with its roof being well-preserved.

The tombs in the hilkhana have not been preserved, and even if they were, they may have been covered under layers of soil that fell into the hilkhana in different years. The first floor of the mausoleum has additional rooms on both sides. A staircase leading down to the hilkhana has been built through the room on the southwest side.

There are stairs leading to the second floor of the mausoleum through the rooms on both sides. The total number of stairs is four. Additionally, there is one room on each side of the mausoleum's entrance porch [7].

In recent years, scientific research on the Mausoleum Ishrat Khana has mainly been conducted by Potsdam University of Applied Sciences. In 2007, a "summer school" was held in Samarkand with the participation of students from Uzbekistan and Germany. During the summer school, the structure, in particular the work of Prof. Dr. Steffen Laue, was studied in detail and documented. Samples of wall paintings and terracotta coatings were taken in the laboratory for pigment analysis, and microchemical tests were carried out. Based on these results, a fragment of the wall painting was restored as a sample to get an idea of the original color of the building. The remaining parts were proposed to be left in their preserved state [8].

2.2. Traditional measurement.

Water levels, triangular rulers, measuring tapes are used as traditional measuring tools. Such an in-depth study of an architectural monument is undoubtedly very useful. It allows us to truly feel and understand the value of the building.

Let us take a closer look at the measurement procedure. It is necessary to start by determining the level known as the zero-horizontal plane, that is, by establishing a conditional horizontal line, and then all measurements will be taken. To determine the horizon of the line, a special device called a "water level," consisting of two connected tubes with a long pipe, is used [15]. Water is poured into the pipe, and two people follow the water level marks in the tubes, moving the device along the measured object. When the water levels in both tubes align, corresponding marks are made on the tubes at the water level, and these marks are connected graphically. Additionally, all measurements are taken using a tape measure, starting from the established zero line.

It should be noted that for each architectural element, there are specific measurement methods using the listed tools, which can be found in detail in the methodological materials on architectural measurements. All obtained measurements (hand-drawn pencil drawings) are recorded, and with their help, you can later create the final drawings. Thus, this measurement method is quite labor-intensive, requiring a lot of time and effort. This can be considered both an advantage and a disadvantage.

Using a three-dimensional laser scanner based on modern technology, the dimensions of an architectural monument can be obtained faster. For example, with the Faro Focus S120 laser scanner it is possible to scan an object in one day, create its three-dimensional model in a computer program and conduct various studies on it.

2.3. Technical details of laser scanning.

3D laser scanning is the process of creating a digital model of an object using laser beams. This technology is non-contact, works at both short and long distances, and does not cause damage to objects during the scanning process. The principle of operation of 3D laser scanners is as follows: directed laser beams reflect off the object's surface, forming a point cloud. Each point has its own coordinates. The software identifies these coordinates and, based on this data, creates a ready 3D digital model.

The range of applications for the Faro Focus S120 laser scanner is very wide, and there is a special demand for this scanner in civil engineering, pipeline laying and architecture. During the preparation of a construction project, it is necessary to periodically monitor the characteristics of the territory and the geometry of buildings, including walls, corners, doors, and other elements. Laser scanning accomplishes this task more accurately and faster than traditional measuring technologies.

3D laser scanning also helps in the restoration of architectural monuments. In this process, a 3D model of the architectural object is created, and necessary simulations are carried out using computer programs, and deformations and displacements in the architectural object are detected. Based on these results, it becomes possible to carry out future restoration work effectively.

3D scanners are used in the following areas:

1. In Cartography and Geodesy - creating relief plans, maps, Geographic Information Systems (GIS).
2. Digitization of cultural heritage objects.
3. Used in Archeology to restore and preserve ancient artifacts.
4. In Paleontology, it is used to create missing parts of skeletons found during excavations.
5. In Medicine, including Plastic Surgery and Dentistry.

The main features of the Faro Focus S120 scanner:

Scanning range-120 m;
Point cloud noise from 2 mm to 25 m;
Scanning speed 978,000 points/sec;
Battery life - up to 5 hours;
Dust and moisture protection IP52;
70 MP Camera;
Operating temperature: 5°C - 40°C

Measurement work.

Our scientific research begins with taking measurements of the current state of Ishrat Khana using a 3D laser scanner (Fig. 4). In this process, we need to carry out the following tasks:

1. Measuring the front facade of the building using a 3D laser scanner (Faro Focus 3D S120).
2. Measuring the interior of the building using a 3D laser (Faro Focus 3D S120).
3. Point cloud processing in specialized FARO Scene software with further processing in FARO As-built software.

The Faro S120 3D laser scanner is one of the most advanced devices available today for performing measurement tasks and implementing projects, providing us with long-range measurements, as well as high accuracy and speed**.**

Fig. 4. The Mausoleum Ishrat Khana. Samarkand, 2024.

A 3D model will be created that precisely replicates the complete geometry of the building, which will serve as the basis for projects when using three-dimensional technologies.

In order to create a 3D model of the Mausoleum Ishrat Khana, a complete measurement procedure was carried out using the Faro Focus 3D S120 laser scanner over the one day. During this process, the following tasks were performed: a scanning project for the architectural monument was developed (Fig. 5).

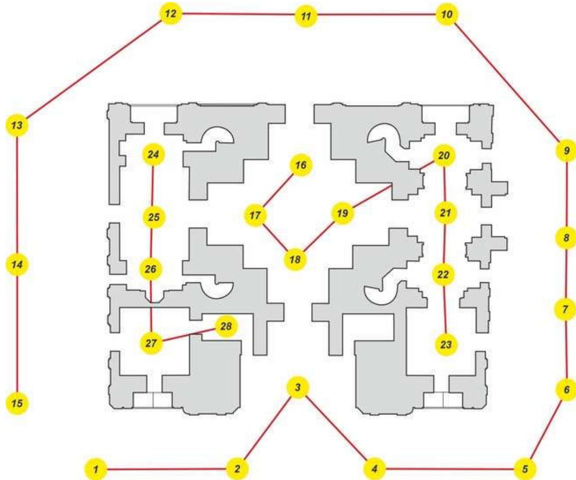
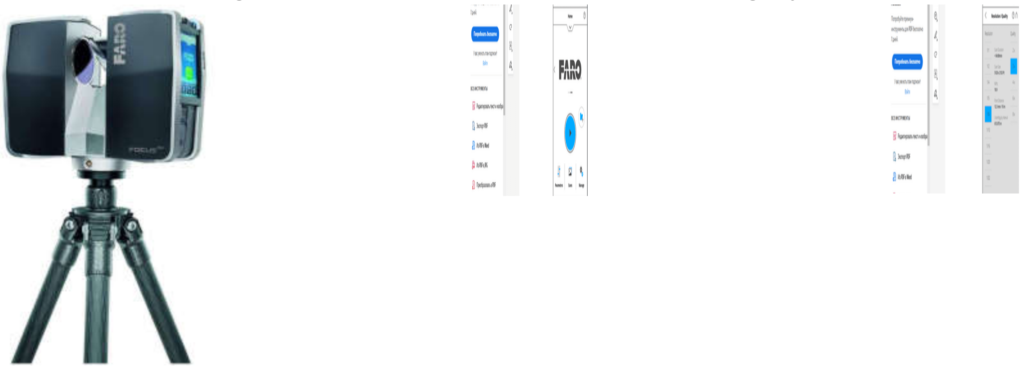


Fig. 5. Position of Faro Focus 3D S120 while scanning objects.



a. b. c.

Fig. 6. a) Faro Focus 3D S120 b) Home Screen of the controller software
c) Change Scan Resolution and Quality.

One operator is enough to manage the scanner [9]. When setting up the Faro Focus 3D S120 scanner, we set the resolution to 1/4 and the quality to 4x, then the scanner is activated by pressing the Start Scan button. In about 6-7 minutes, 1 scanner will take measurements of our object from the installed position, and we will continue to take measurements of the remaining parts of our object in the same way (Fig. 6).

We scanned the exterior and interior of our object by changing the position of the Faro Focus 3D S120 in the sequence shown in Fig. 5. When obtaining the point cloud from the measurements of the 3D laser scanner, you need be sure that no element has been missed. This is the main advantage of 3D scanning over manual measurements [10,11].

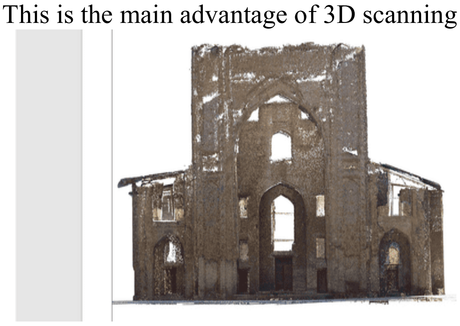


Fig. 7. The Facade of the Mausoleum Ishratkhana. Point cloud captured by Faro Focus 3D S120 laser scanner.

Once the measurements were completed, the 3D model of Ishratkhana was reconstructed on the computer using Faro Scene software and based on the 3D point cloud (Fig. 7).

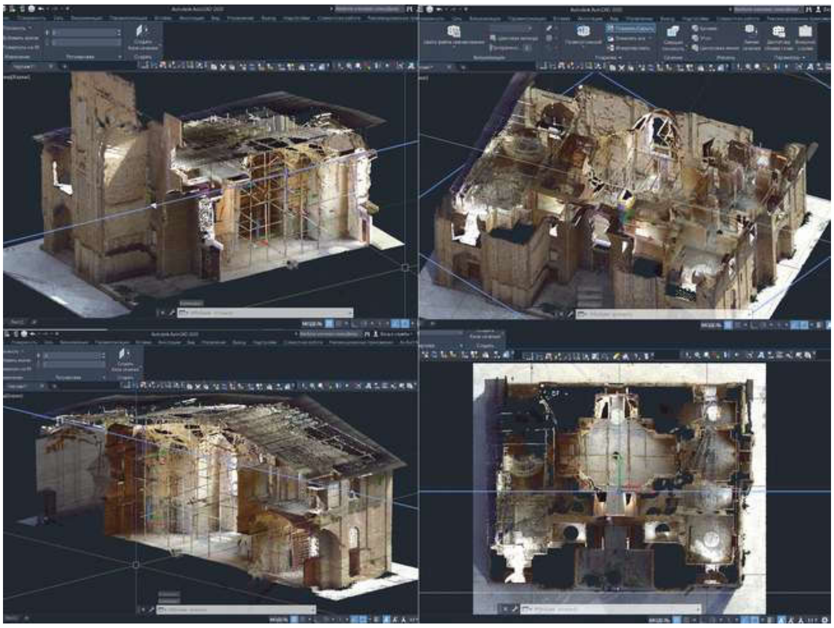


Fig. 8. Section Views of the Mausoleum Ishratkhana (AutoCAD).

Faro Scene is a software specifically designed by a company for processing point clouds from laser scanners. After the 3D laser scanning is completed, the Faro Scene software combines the point clouds from all the scans, which in this case are 23 scanned point clouds. Faro Scene automatically combines the point cloud, but errors may occur in some places. In such cases, you will have to combine individual point clouds manually.

We have also encountered similar situations and managed correct them manually. The 3D model created in this software can be exported to any of the programs we need (AutoCAD, Revit, Cloud Compare).

We converted the file to the. rcp* extension from Faro Scene (the FARO As Built software is installed as an additional module in the AutoCAD program) in order to continue working in AutoCAD (Fig. 8).

As-Built software is compatible with the AutoCAD program, and the command panel of As-Built software is added to AutoCAD. As a result, working with point clouds in AutoCAD becomes more convenient. AutoCAD program allows easily create cross-sectional and longitudinal surfaces, plan surfaces, and enables drawing facades and sections (Fig. 8). By continuing the work in AutoCAD, we were able to draw the facade, plan, sections, and side facades of Ishratkhana based on the measurements. When using a 3D scanner, specialists do not need to visit the object repeatedly and engage additional personnel. Sometimes, it is advisable to use drones to measure high parts of the object.

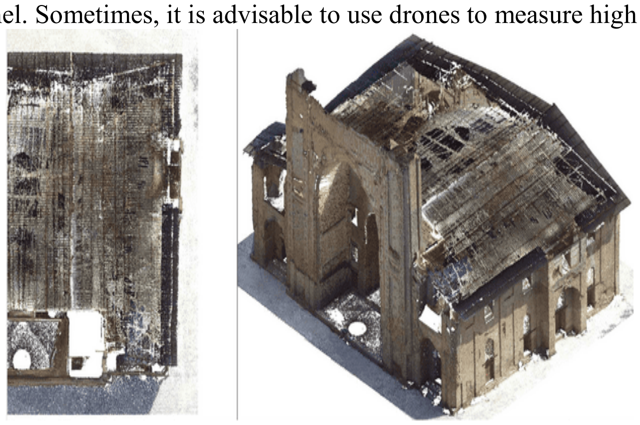


Fig. 9. General view of the Mausoleum Ishratkhana. Point cloud captured by Faro Focus 3D S120 laser scanner.

The drawings were reconstructed using a point cloud in AutoCAD. The point cloud was represented as a facade plane, and the modeling process took approximately several days.

Due to the fact that the Mausoleum Ishratkhana is a historical monument, we cannot determine the dimensions of the object from photographs. The point cloud captured by Faro Focus3D S120 laser scanner is the best basis for obtaining accurate measurements (Fig. 9). At the same time, the point cloud (three-dimensional model) of the mausoleum is checked for anomalies.

1) If we pay attention to the facade and side facades shown in Figures 10 and 11, a red line is indicated for taking measurements (±0.000). From this, it can be seen that the mausoleum is not flat, meaning that the left side of the front view is - 0.46m lower. Additionally, it can be seen that the right side of the side view is - 0.43m lower. Assuming the foundation of the mausoleum is a rectangle, the four points on the foundation, A (±0.00), B (-0.46m), V (-0.43m), G (-0.43m), indicate different heights (Fig. 12b).

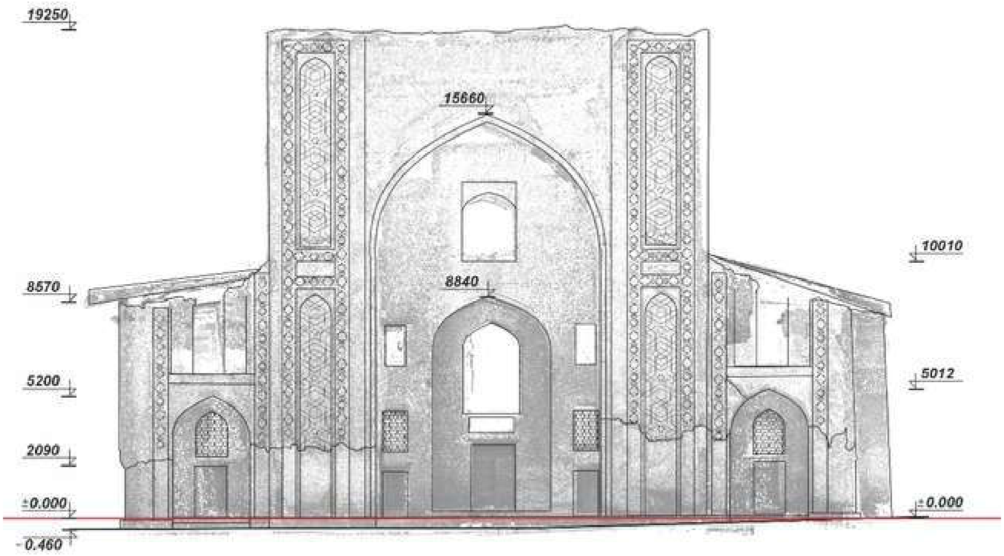


Fig. 10. Drawing of the facade of the Mausoleum Ishratkhana.

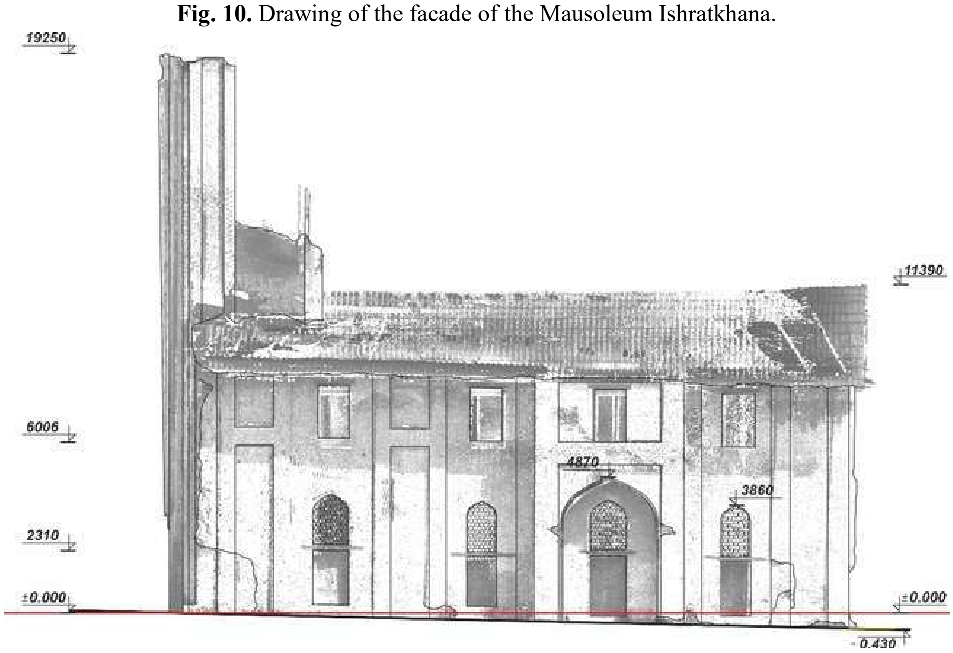


Fig. 11. Drawing of the side facade of the Mausoleum Ishratkhana.

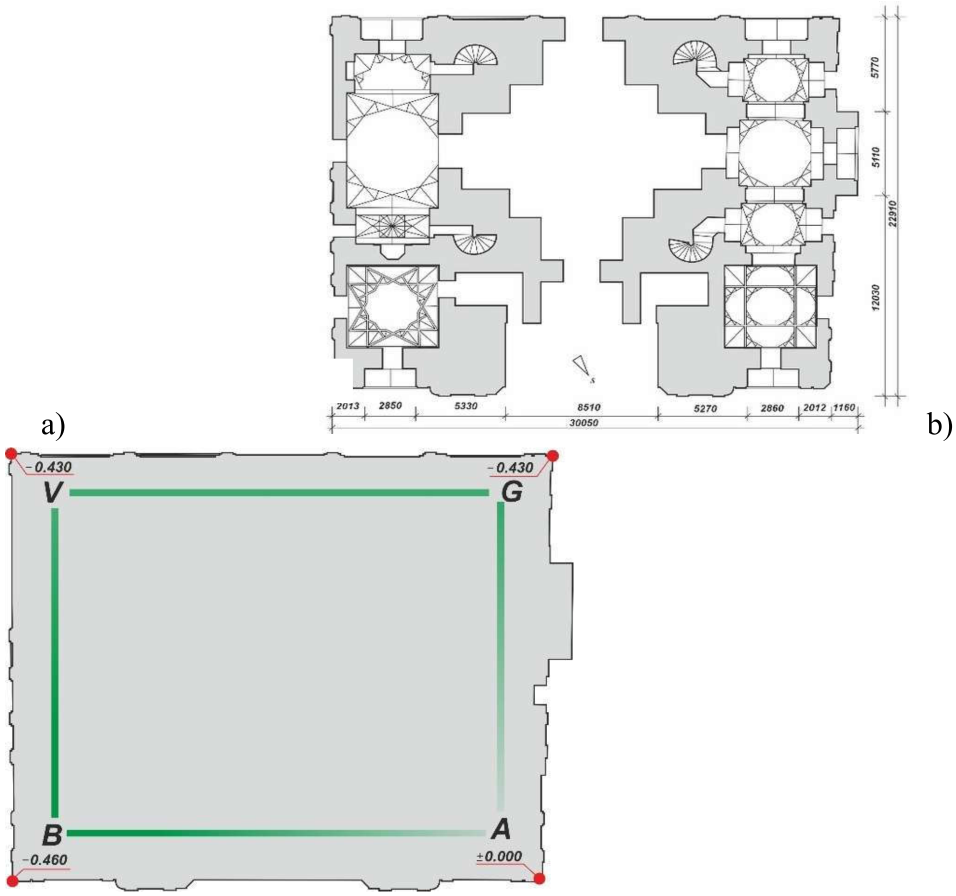


Fig. 12. a) Plan of the first floor of the mausoleum. b) The surface of the mausoleum at the ±0.000 elevation level.

2) The degree of deviation of the lower part of the main portal from the vertical plane was checked. The color map of the degree of deviation is shown in Fig. 13. The color map of the portal shows that the deviation increases from north to south with a maximum offset difference of 0.12 m at the upper southern corner. To ensure that this degree of portal deviation does not develop, periodic monitoring through laser scanning was recommended. Additionally, it was suggested to continue installing laser targets to improve the accuracy of the monitoring.

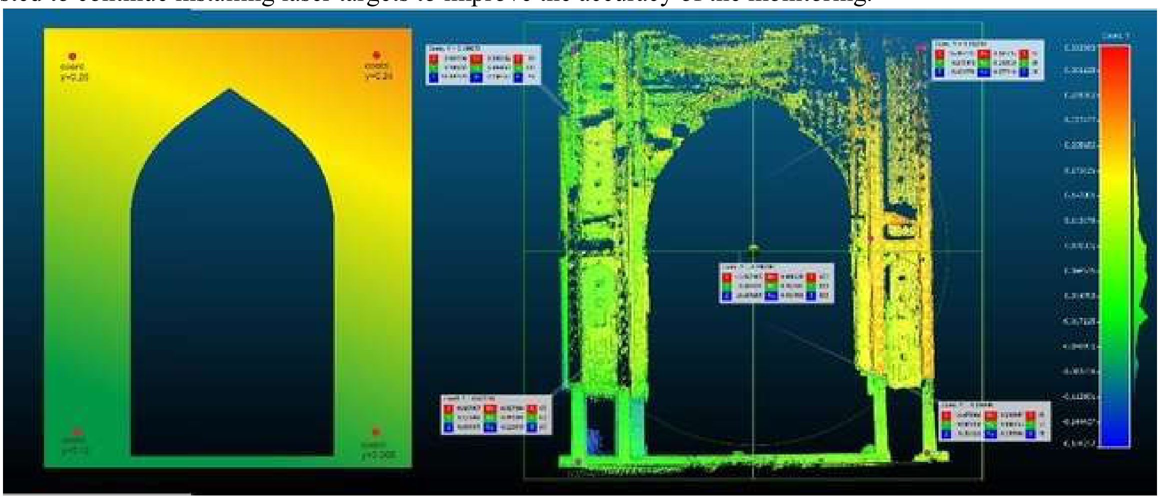


Fig. 13. Color map of the Portal.

In designing the drawings for the Mausoleum Ishrat Khana, laser scanning was a useful alternative to traditional measurement methods and provided a high-resolution point cloud of the facade, which would serve as the basis for further effective reconstruction.

Three-dimensional scanners are significantly superior to other equipment when measuring complex objects due to their capabilities. The highest accuracy (up to 1 mm) and measurement speed (almost 1 million points per second), as well as automation functions that minimize the impact of the human factor, all ensure reliable project implementation, reducing working hours and labor.

3. Conclusion.

Based on these results, the following conclusions can be drawn. The results of scientific research show the advantage of using laser scanning for accurate documentation of the geometry of an architectural monument. The current state of the monument and its structural anomalies were analyzed, and it was determined that they could be used in future observation expeditions.

A difference in the dimensions of the mausoleum's foundation, i.e., its surface, was noticed, and deformation in the portal was indicated. This should be monitored to ensure that it does not develop further. It was also recommended to continue installing laser targets to improve the accuracy of monitoring. The portal deviation increases from north to south, with a maximum differential displacement of 0.12 m at the upper southern corner. Periodic monitoring through laser scanning should be planned for future inspections. As a result of such periodic monitoring, it will be possible to conduct a comparative analysis of several digital models in the future, allowing the observation of deformations and changes in the mausoleum.

The obtained 3D models can be easily stored for future restoration, and files containing all necessary data, including details of defects and the condition of structures and constructions, can be created. These technologies require full 3D modeling of objects using various methods and for different projects. Computer technologies provide the opportunity to preserve what remains and, at the same time, restore what has been lost. The obtained results confirm the advantages and undeniable prospects of using computer technologies across the entire scope of museum activities.

Virtual restoration and reconstruction can be successfully implemented through a rational combination of intuitive artistic thinking and scientific technologies. It is the emergence of a new scientific discipline, which can be conditionally called artistic and computer reconstruction of works of art.

Preserving priceless architectural monuments with a rich history for future generations can only be achieved through the use of innovative technologies and materials in the restoration process, which harmoniously complements the unique experience of the creators of the Eastern Renaissance.

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