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Modern technologies in archaeology and their application in architectural object

Abstract. The study of modern technologies in archaeology and the restoration of architectural objects is extremely important because of the possibility of using them to preserve cultural heritage, discover new artefacts and improve scientific research methods. The aim of this study was to analyse the possibilities of using modern technologies for the rehabilitation and visualization of cultural heritage. The methods used in the course of the study included photogrammetry, comparative method, and analysis. The results of the study showed the significant potential of modern photogrammetry technologies in the preservation and visualization of cultural heritage. In particular, the use of aerial photogrammetry using a drone and ground photogrammetry using a digital camera made it possible to create three-dimensional models of architectural objects with high accuracy and detail. For example, 267 images were collected and processed using a drone for the Marinid Madrasa, Al-Mariniya Madrasa, and the Roma settlement. This data allowed for the creation of detailed three-dimensional models that were used to generate orthophotomaps and a visual inspection of the site. In addition, the export of 2D data and models proved to be effective for further modelling and analysis. This allowed for the development of a three-dimensional digital model that can be visualized, modified, and adapted at any time, which has become a valuable tool for architectural research and documentation. The results of the study confirmed the practical effectiveness of photogrammetric methods in the preservation and documentation of historical heritage. The use of digital models and orthophotomaps can facilitate visual analysis of objects, further research and archiving of cultural property. This approach has the potential for educational and tourism initiatives, engaging a wide audience in the study and appreciation of historical heritage

Keywords: photogrammetry; cultural heritage; 3D visualization; restoration of historical values; model detailing

INTRODUCTION

Modern technologies in archaeology and the restoration of architectural objects are important tools for preserving and understanding world history. The discovery and study of archaeological and architectural sites not only provides

an opportunity to better understand the past, but also helps to identify and shed light on the development of human civilization and the cultural and technological achievements of past eras. However, the problem associated

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with the research and restoration of archaeological and architectural sites is the complexity and limited access to materials and resources. Many sites are located in inaccessible places or are under threat of destruction due to a variety of factors, including natural disasters, climate change, and human activity. It is also important to keep in mind that even with financial resources, a lack of qualified personnel and equipment can complicate the research and restoration process.

That is why modern technologies can solve these problems, providing new opportunities for research and preservation of cultural heritage. For example, new technologies make it possible to survey large areas, discover new archaeological sites and study changes in the landscape over time. They also allow scanning and obtaining detailed topographic data, creating accurate 3D models of archaeological structures. These technologies help to increase the speed and accuracy of research, and reduce the risk of damage to artefacts and structures during restoration work. The use of computer modelling and virtual reality can allow archaeologists and conservators to effectively plan and restore architectural sites, reducing the risk of errors and increasing the efficiency of work. Such technologies can also be used to recreate ancient landscapes and environments, allowing researchers to better understand the context and cultural practices of past civilizations (Prychepii, 2022). Importantly, modern technologies are opening up new horizons for archaeological and architectural research, making it more accessible, accurate and efficient.

According to A. Cilek *et al.* (2020), 3D restoration technology is an extremely important tool for preserving and recreating cultural heritage. This technology allows creating virtual models of architectural objects with high detail, which can be used for the restoration and reconstruction of damaged or destroyed structures. Through the use of 3D scanning and modelling, this technology allows for the accurate reproduction of architectural details, dimensions, and shapes of objects, which is important for preserving their historical identity.

In a study by E. Mustafaraj *et al.* (2021), the authors proved that virtual 3D models open up many opportunities for analysing and studying the architectural features of objects. By examining these models, restorers can examine each element of the structure in detail, from the smallest details to the overall composition, which helps to develop effective strategies for the preservation and restoration of cultural monuments. Moreover, the paper argues that virtual reality allows researchers to study objects from different angles and recreate different historical contexts, which contributes to a deeper understanding of their structure and meaning. This opens up new possibilities for restoration, as it allows for more accurate and informed interventions aimed at preserving and restoring valuable historical objects.

In conformity with E. Petërçi (2022), virtual 3D models not only provide the ability to create videos and animations for visualizing objects, but also open up a wide range of other possibilities. For example, they can be used

to create measuring supports that allow obtaining accurate measurements of the size and proportions of objects directly from the virtual model. It is also argued that virtual models can be used to generate 2D plans and sections that allow for a detailed study of the architectural features of objects from different angles. This data can be used for further analysis and research, as well as for creating detailed profiles of objects that help to identify changes in their structure and reveal their history and evolution over time.

According to A. Pagliano (2022), the use of such a 3D model allows not only creating realistic 3D models of architectural objects, but also introducing innovative methods of analysis and interaction with these models. For example, this technology can include augmented reality, which allows users to interact with virtual objects in real time using special devices such as virtual reality headsets or mobile applications. This interactive capability allows users to explore and learn about architectural objects in a new format, opening up a wide range of opportunities for them to learn about history, culture, and architecture. The use of augmented reality can also contribute to a deeper understanding of objects and their importance in the context of cultural heritage, as well as to attracting a wider audience to the study and appreciation of these objects (Gryglewski *et al.*, 2020).

The study by M. Bercigli *et al.* (2022), which focused on the use of such technology in the restoration of architectural objects, notes that it can open up new perspectives for the reconstruction and analysis of historical buildings. This technology, distinguished by its innovative approach, uses a combination of artificial intelligence and deep learning to automate the analysis of structural details of objects. This approach has made it possible to detect the smallest changes and damages that might otherwise go unnoticed under normal circumstances. In addition, it is particularly emphasized that this technology allows for more efficient planning and execution of restoration processes, providing a more detailed and objective analysis of the condition of architectural objects (Shumka, 2022).

Since the above-mentioned studies were aimed at a more general study of the use of modern technologies in the restoration of architectural objects, the purpose of this work was to investigate specific methods and technologies that can be used for the effective restoration of archaeological sites, using the practical example of the Marinid Madrasa, Al-Mariniya Madrasa, and the Roma settlement in Morocco.

MATERIALS AND METHODS

This study used the photogrammetry method to obtain three-dimensional models of objects, a comparative method to analyse different approaches to documenting historical buildings, and an analysis to assess the effectiveness of the applied methods. These methods made it possible to obtain a detailed three-dimensional reconstruction of the objects, compare different approaches to digitizing heritage, and draw conclusions about their effectiveness. During the practical part of the study, several prominent



archaeological sites in Morocco in the cities of Salé and Rabat, which are key centres of Moroccan cultural heritage, were examined. The sites include the Madrasa of Marinid Abu Al-Hassan, the Madrasa of Al-Mariniya, and the Roma settlement. These sites are important because they play a significant role in preserving and understanding the cultural heritage of the region.

A Nikon D5600 digital camera (China) was used to collect data and document the sites, which ensured high accuracy and allowed capturing images of numerous points. By collecting a series of overlapping images, detailed data was obtained, which was used to create accurate and realistic digital models of the objects. More detailed characteristics of the camera are shown in Table 1.

Table 1. Characteristics of a digital camera

Matrix resolution	24.2 megapixels
Image processor	EXPEED 4
ISO range	100-25600
Auto focus	39 AF points with phase detection support

Source: compiled by the authors

A DJI Mavic Pro unmanned aerial vehicle (China) equipped with a 1-inch sensor camera was also used to obtain images. This camera has a multi-format sensor that provides a resolution of up to 12 megapixels. This

resolution makes it possible to obtain detailed images necessary for accurate mapping and modelling of objects. More detailed characteristics of the camera on the unmanned aerial vehicle are shown in Table 2.

Table 2. Characteristics of the camera on the unmanned aerial vehicle

Resolution	up to 12 megapixels
Diaphragm	f/2.2
Focal length	28 mm (equivalent to 35 mm)
Viewing angle	78.8°
Sensor	1/2.3" CMOS

Source: compiled by the authors

For the documentation, 267 images were taken using an unmanned aerial vehicle. The height from which the images were taken ranged from 5 to 25 m, which allowed obtaining images of objects from different angles and in different detail. The overlap provided along the lateral circle and the track was 85%, which ensured that there was sufficient overlap between images for accurate reconstruction of the objects.

Agisoft Metashape, a software program based on the Structure from Motion (SfM) method, was used to process the digital images, and create three-dimensional spatial data. Agisoft Metashape uses the Scale-Invariant Feature Transform (SIFT) algorithm, which has several processing stages. The first stage is to detect scale-spatial extremes, where a Gaussian difference function (1) is applied to identify potential points of interest (Karwel & Markiewicz, 2022):

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y), \quad (1)$$

where: * – collapsing operator; $G(x, y, \sigma)$ – a Gaussian scale variable; $I(x, y)$ – the input image.

To determine the localization of key points in the scale space, the principle of difference of Gaussian numbers was used. It made it possible to find the extremes of the scale space, which is a three-dimensional function $D(x, y, \sigma)$, where x and y are spatial coordinates and σ is a scale parameter. The difference of Gaussian numbers was calculated as the difference between two images, one of which has a scale k times larger than the other. The function $D(x, y, \sigma)$ (2) is described by an expression that depends on the

spatial coordinates and the scale parameter (Rodríguez-Martín & Rodríguez-González, 2020):

$$D(x, y, \sigma) = L(x, y, k\sigma) - L(x, y, \sigma). \quad (2)$$

The key point descriptor is a tool for describing the features that define each key point in an image. One of the key aspects of the descriptor is its rotation invariance, which means that it remains robust to changes due to image rotation. The approach used to determine the orientation of a key point is as follows (3, 4):

$$M(x, y) = \frac{L(x, y+1) - L(x, y-1)}{\sqrt{(L(x+1, y) - L(x-1, y))^2 + (L(x, y+1) - L(x, y-1))^2}}, \quad (3)$$

$$\varphi(x, y) = \tan\left(\frac{L(x, y+1) - L(x, y-1)}{L(x+1, y) - L(x-1, y)}\right). \quad (4)$$

First, the local luminance gradient in the vicinity of the key point was calculated. Then, a histogram of the gradient directions was determined, which shows the distribution of the gradient in different directions. The direction with the highest gradient strength is considered to be the main direction of orientation of the key point. The resulting three-dimensional models were further used to analyse architectural details, recreate the structure of objects, and perform virtual visual inspections. The photogrammetry method resulted in detailed and realistic three-dimensional models of objects, which greatly simplified their study, preservation, and documentation.



The comparative method was used to conduct a detailed assessment of different approaches to documenting and digitizing historical heritage sites. Based on this analysis, the most appropriate method was selected for further application in the study. The selected methods were used to obtain detailed three-dimensional models of the heritage objects, considering their geometric complexity and features. The results were analysed in detail and used to formulate conclusions and recommendations for the further use of digitization techniques in heritage research.

Detailed analysis also proved to be an important method in the study, allowing us to identify and analyse the key differences in the condition of architectural objects before and after the application of various restoration methods. A detailed comparison allowed determining the effectiveness of each method and defining their advantages and limitations. The analysis of the results proved to be an important step in determining the best approaches to the preservation and restoration of architectural heritage, contributing to the development of strategies that consider the unique characteristics of each object.

RESULTS

The restoration and conservation of archaeological sites is a complex and demanding process that requires great attention to detail and authenticity. However, with the advent of new technologies such as 3D modelling and digital documentation, this process is becoming more efficient and accessible, as 3D modelling allows archaeologists to create accurate and detailed virtual copies of objects, which facilitates their research and analysis.

The use of 3D modelling in archaeology has great potential not only for research, but also for the preservation and presentation of cultural heritage. It allows archaeologists to create realistic virtual exhibitions that can be accessed by a wide audience via the Internet or special applications. Such digital reconstructions can be used for teaching, visiting virtual museums, or simply for excursions into the past. The new possibilities offered by digital

documentation and 3D modelling contribute to the integration of technology into the process of cultural heritage preservation and research. Thanks to the development of computer technology and digital photography, it is now possible to conduct more accurate and detailed research of archaeological sites. This allows for the preservation of significant artefacts and structures for future generations and a deeper understanding of history and cultural development (Ferdani *et al.*, 2020).

Virtual restorations are an important step in the recreation and preservation of cultural heritage based on scientific data and existing documentation. This process includes a number of methods that allow recreating the previous state of an object, taking into account its lost polychrome, identifying individual architectural elements and reconstructing the entire object. Virtual restorations can be displayed in the form of 3D models for distribution, or used to create physical copies using technologies such as 3D printing. However, it is important to keep in mind that virtual restoration is not an end in itself, but only the first step in the physical restoration process.

To achieve successful virtual restoration, it is necessary to have access to detailed archaeological and historical information about the site. This may include archaeological finds, historical documents, photographs, and other sources that allow reconstructing the appearance of the object in the past. After collecting this data, it is analysed and processed in detail to create an accurate virtual model of the object. Another important aspect of virtual restoration is its scientific validity. The process of virtual reconstruction should be based on reliable data and scientific principles to ensure the accuracy and authenticity of the object's reconstruction. In this regard, expert assessment, and consultation with specialists in the field of archaeology, conservation, and history play an important role. Only scientifically based virtual reconstruction can serve as an effective basis for further actions in the restoration and preservation of cultural heritage. Figure 1 represents more details on the possibilities of using 3D models for the restoration of objects.

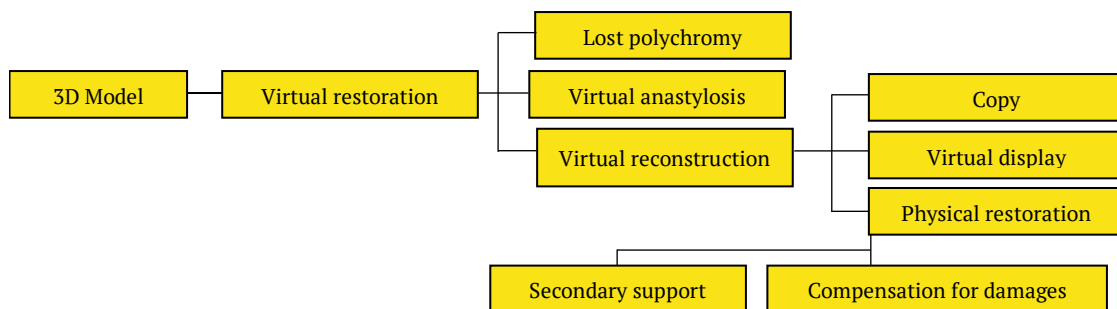


Figure 1. Possibilities of using 3D models for object restoration

Source: compiled by the authors based on L. Acke *et al.* (2021)

Virtual reconstruction of architectural objects is the recreation of their appearance, structure, and functionality in a virtual environment. This process begins with the analysis of archaeological data, including archival

materials, photographs, drawings, plans, and any other available information about the object. Based on this data, a digital model of the object is created that reflects its appearance in the past.



During the virtual reconstruction, it is necessary to consider the architectural styles and techniques that were typical for a particular era or region. This allows recreating an object with maximum accuracy and authenticity. In addition, the virtual reconstruction process can use specialized software tools and technologies, such as computer graphics and modelling, to create detailed and realistic virtual models. One of the key aspects of virtual reconstruction is the ability to recreate lost or damaged elements of an object. This allows restoring the original appearance and structure of an object that may have been lost as a result of natural or anthropogenic impacts. This approach allows researchers and conservators to get an idea of how the object looked in the past and what architectural details were typical for it (Pietroni & Ferdani, 2021).

Virtual reconstruction can be used to study and analyse various aspects of an object, such as its functionality, structure, and relationship with other architectural objects or the environment. This allows revealing various aspects of history and culture associated with the object and studying it in the context of the socio-cultural environment.

Lost polychromy and virtual analogues are important aspects of virtual reconstruction of architectural objects that help to recreate their original appearance and atmosphere. Polychromy in architecture refers to the use of different colours and patterns on the surface of a building to give it an artistic expression. However, sometimes these colours can fade or lose their brightness due to natural factors or human activity. Virtual reconstruction of lost polychromy allows restoring the colour scheme and ornaments of an object by analysing archaeological data, archival sources, and specialized software tools. This helps to give the object a realistic and authentic look that matches its historical context and style (Fazio *et al.*, 2022).

Virtual analogues play an important role in the process of virtual reconstruction, especially for objects that have been damaged or destroyed in the past. Analogue is a method of restoring an architectural object when the restored parts are combined with the original ones using modern materials to restore its original appearance and functionality. In virtual analogues, archaeologists and conservators can use 3D models to accurately recreate damaged parts of an object and integrate them with original elements. This allows them to restore the object in its original form and preserve its cultural and historical value for future generations.

The use of photogrammetry for documenting and analysing archaeological sites is also of great importance for preserving and enhancing access to cultural heritage. This method provides accurate and detailed information about objects, including their geometry, size, and structure. It is important to note that photogrammetry allows obtaining this information directly from photographs, which makes the documentation process more efficient and affordable.

The creation of 3D models of archaeological sites is an important step in the preservation and recreation of these monuments. These models provide not only a visual

representation of the object, but also the ability to use geometric data to develop restoration and virtual recovery plans. In addition, 3D models can be used to create virtual tours and exhibitions, allowing a wide audience to learn about cultural heritage. The successful implementation of digital technologies in the documentation and restoration of archaeological sites can greatly facilitate the work of archaeologists and conservators. They get the opportunity to work with high-precision data and access new methods of analysis and visualization. This, in turn, helps to improve the level of cultural heritage preservation and increase its accessibility for further research and study.

Choosing the right method for 3D modelling plays a key role in the process of documenting architectural objects, as it affects the quality and accuracy of the resulting model. In order to achieve the desired level of detail and accuracy, combined approaches are often used that combine the use of digital cameras, unmanned aerial vehicles and image data analysis. This approach aims to create models of architectural objects using a variety of data sources, such as photographs and images captured by digital cameras and unmanned aerial vehicles. This process allows obtaining a complete and detailed model of the object that reflects its real appearance and structure.

In the case of the Abu Al-Hassan Madrasa, the Roman remains, and the Al-Mariniya Madrasa, which will be discussed further below, the combined approach allows for the collection of sufficient and comprehensive data to document and assess the condition of these historic sites. The analysis of the data allows for the identification of physical damage and the identification of necessary interventions and conservation methods aimed at preserving these valuable cultural monuments for future generations. This method of documenting and archiving historical data helps to preserve and study cultural heritage with maximum accuracy and detail.

The sites selected for the study are located in the cities of Salé and Rabat, which are prominent cultural heritage sites in Morocco. In 2012, these sites were inscribed on the UNESCO World Heritage List, recognized as world treasures of history and culture. The first site is the Madrasa Marinid Abu Al-Hassan, which served as a Quranic school, college, and hostel. This architectural masterpiece serves not only as an educational institution but also as an important symbol of religious and cultural heritage (Škrabić Perić *et al.*, 2021).

The second object is the Al Mariniya Madrasa, which occupies an important place in the history of Morocco. Built in the first half of the 14th century during the reign of the Marinid Sultan Abu Al-Hassan bin Uthman, it is a symbol of the glorious dynasty that ruled the country for almost two centuries. The Al Mariniya Madrasa is not only an architectural masterpiece, but also a witness to a great era in Moroccan history, marking the cultural and religious development of the country.

The third object of the study is a Roma settlement that dates to 25 BC. Based on the results of archaeological excavations and research, there is a great opportunity to



restore the life of the city of Sala during the reign of Juba II. This city was distinguished by its architecture, which was organized on the principle of terraces, which was typical for many large centres of the Hellenistic East. Numerous buildings from the pre-Roman period were found on the territory of these narrow terraces, some of which were later incorporated into buildings from the Roman era. This shows that some structures have survived subsequent eras, retaining traces of past eras and cultural influences.

Archaeological findings allow researchers to create a portrait of the city's inhabitants' lives, customs, economic

activity, and social organization. This provides a unique opportunity to better understand and reconstruct the history and culture of the ancient cities of Sala and Rabat (Fig. 2), which is an important step in the uncovering and interpretation of archaeological data. These sites are important witnesses to the past, demonstrating the richness and diversity of Morocco's cultural heritage. They are not only architectural monuments, but also symbols of history, reflecting the greatness of ancient civilizations and cultural traditions that continue to live in the heart of this country (Mandor & Mostafa, 2022).



Figure 2. Place of practical research

Notes: 1 – Al-Mariniya Madrasa; 2 – Roma settlement; 3 – Marinid Abu Al-Hassan Madrasa
 Source: compiled by the authors

It should be noted that photogrammetry is an important and powerful measurement technique that allows creating high-quality 2D or 3D digital models of objects. This process is not limited to the use of photographs; it can use any type of image, such as radar data or scanning devices. The main idea is to obtain the maximum number of points on the monitored object using the available technical means (Fiz *et al.*, 2022). In the process of measuring various architectural

structures using a camera and unmanned aerial vehicles, it is necessary to take into account their complexity and shape, which determines the need for measurements from different angles. To ensure the required quality and accuracy of measurements, it is important to achieve a minimum image recovery rate of 75% (Fig. 3). This means that when a surface is digitized, a certain fragment of the image is shifted parallel to the digitized surface to obtain the next image.



Figure 3. Recovery process using sequential images as an example

Source: compiled by the authors



So, for example, in Figure 4, which represents a length of 1 m, the digitized surface is shifted by 25% of this length, which is 0.25 m, to digitize the next part of the surface.

This approach ensures high quality and accuracy of measurements for further analysis and research of architectural structures (Putch, 2017).



Figure 4. Photos used in the process of digitizing the surface

Source: compiled by the authors

Figure 5 shows a grey triangle indicating the position of the camera during capture. It is important to ensure that the edges of the object are visible in multiple images, as this allows covering not only the central elements, but also the corners and edges. To achieve this, images of the object were taken outside its boundaries to capture extreme points and corners. This is necessary for effective object reconstruction. It is also important that a point of the object is visible in at least two images to ensure that it can be

reconstructed. The surface that needs to be digitized may have a corner, so to connect the two surfaces, it is required to move around the corner. This motion should provide a minimum overlap of 75% and typically include at least six photos at the corner. For example, to scan a column 360° around the object, 36 steps of 10° each were taken.

Figure 6 demonstrates pre-processing of the point region, where unwanted points in the image are removed for further analysis and object reconstruction.

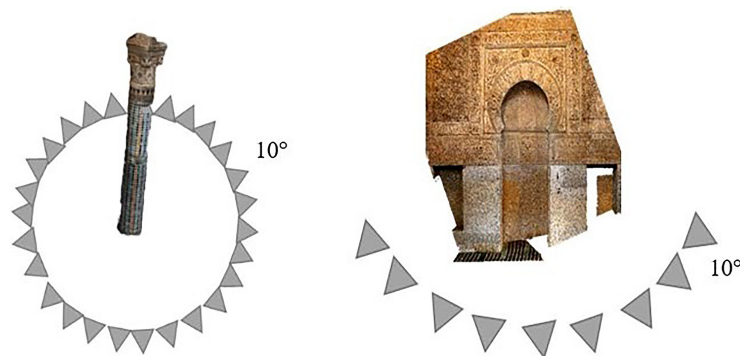


Figure 5. Camera position during angular scanning

Source: compiled by the authors

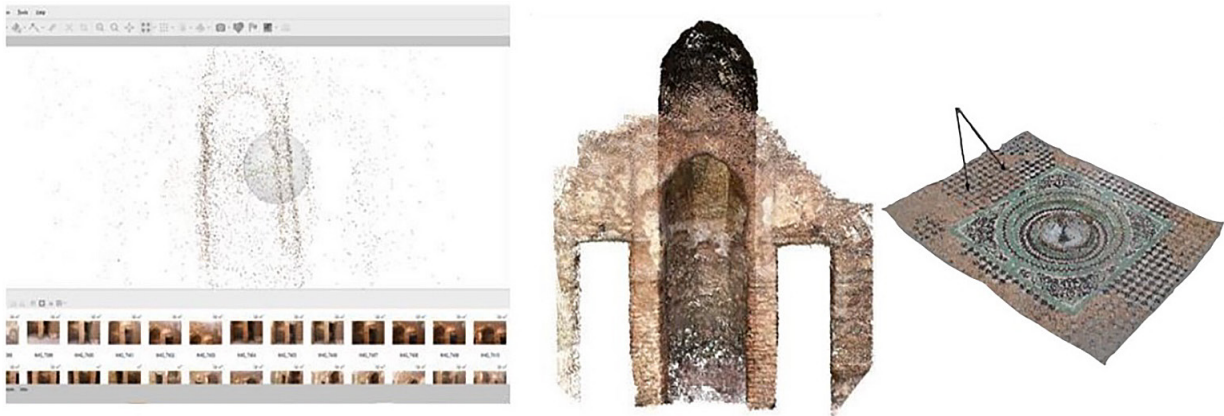


Figure 6. Process pre-processing

Source: compiled by the authors

At the end of the SIFT process, unique descriptors are calculated for each key point. This step is important so that each key point can be uniquely identified in the image. The local environment of each key point is used to calculate the descriptors. This environment includes the pixels surrounding the key point and allows extracting the unique features of this point. Each descriptor is a vector of numerical values that characterize the features of the corresponding key point. These descriptors can be used to compare key points between different images, which

allows searching for objects in images, identifying relationships between objects, and performing other image processing tasks (Zhong & Li, 2019).

At the stage of obtaining consistent data (Fig. 7), it is necessary to perform pre-processing to help reduce unwanted effects and noise in the point cluster. This phase is important for keeping only those points that are interesting and important for modelling. After that, it is possible to start creating digital models based on these point clusters.



Figure 7. Examples 3D modelling of some objects

Source: compiled by the authors

The resulting digital models are quite simple, as they are created from field data. However, these models have several applications, including video and animation. Furthermore, they can be used to create measurement supports (Fig. 8), generate 2D plans and sections (Fig. 9), and create profiles. These data processing products allow not only visualizing objects and terrain, but also analysing their geometry and properties in detail. They can become important tools for archaeologists, geologists and other specialists to study and investigate natural and cultural sites.



Figure 8. Example point area for measurements
Source: compiled by the authors

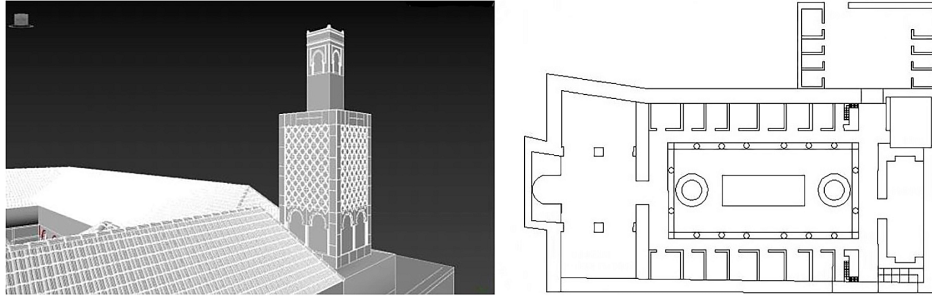


Figure 9. 3D model and 2D plan of the object

Source: compiled by the authors

Drone images play an important role in various aspects of geospatial analysis and visual documentation. First and foremost, they are used to generating 3D models that provide a detailed three-dimensional image of the area or object under study. These 3D models become an important tool for analysing the geometric characteristics of objects, displaying their structure and shape. The resulting images are also used to create high-precision orthophotomaps. Orthophotomaps are orthogonal images of the earth's surface that are used to measure and analyse geographical objects such as buildings, roads, terrain. These orthophotomaps are an important source of geospatial data for a variety of industries, including geodesy, geographic information systems, and urban planning. The

resulting images provide a visual inspection of the site in its current state, which allows analysing changes over time, identifying possible problems or potential threats to the environment, and determining the need for additional research or interventions. This visual approach allows for effective management and monitoring of sites using the latest data collection technologies.

Once the photogrammetric process is complete, the resulting 2D data and models can be transferred to the 3Ds Max platform for further processing and modelling (Kaimaris *et al.*, 2022). This process allows for the creation of realistic three-dimensional models, as well as provides flexibility and efficiency in work and accuracy in the result (Fig. 10).

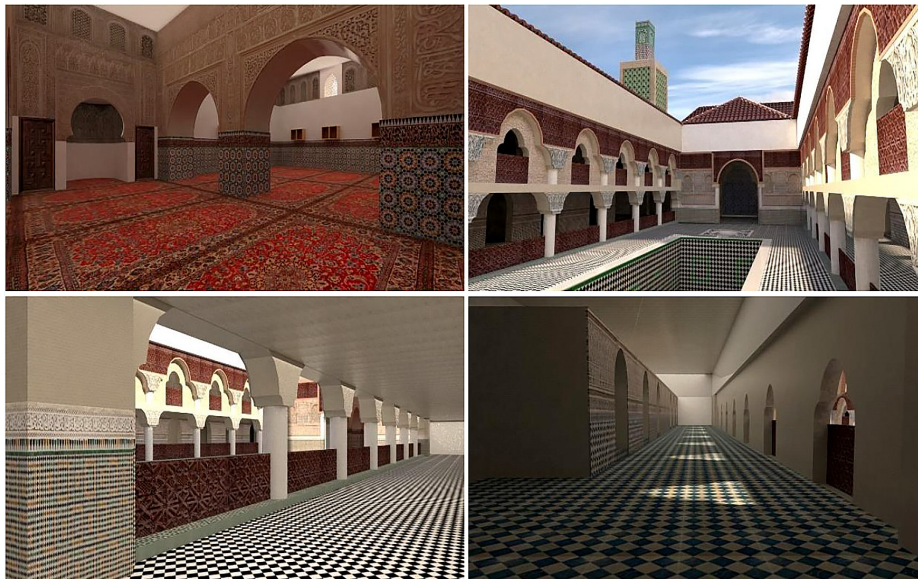


Figure 10. Photorealistic 3D object model

Source: compiled by the authors

Thus, the use of photogrammetry and modern technologies in restoration techniques proves to be extremely useful and promising. This approach not only allows for detailed documentation and analysis of archaeological sites, but also provides the possibility of virtual reconstruction, restoration of lost polychromy, and solving numerous problems related to the conservation and restoration of cultural heritage.

Thanks to digital models obtained through photogrammetry, experts can thoroughly examine the condition of objects, identify damage and losses, and develop effective conservation and restoration strategies. In addition, the ability to create virtual analogues allows viewers to travel back in time and see objects in their original glory, making cultural heritage accessible and fascinating to a





wide audience. However, it should be borne in mind that the use of digital technologies in restoration requires a great deal of awareness and professionalism on the part of specialists, as well as consideration of ethical, cultural, and historical aspects. Nevertheless, with the right approach, these methods open up new opportunities for preserving and restoring cultural heritage, ensuring its accessibility and preservation for future generations.

DISCUSSION

Archaeological sites are not only witnesses of past eras, but also an inexhaustible source of knowledge about history, culture, and heritage. They reflect the secrets of past civilizations and reveal many layers of cultural heritage that define modern society. The excavation of archaeological sites arouses interest and fascination not only among scientists but also among the public, as they allow delving deeper into the world of the past and better understanding our roots. However, many archaeological sites are often exposed to natural factors and other negative influences, which can lead to their damage or destruction. Therefore, it is important to take measures to preserve and restore them. In this context, modern technologies are becoming very useful tools for archaeologists and restorers. Such technologies can allow scientists to obtain detailed information about the condition of archaeological sites, recreate their original forms and structures, and preserve this heritage in a virtual format for future research and generations. Technologies can also be used to identify and register archaeological sites over large areas, which contributes to more efficient organization and coordination of their preservation and research. One of the most important areas of application of modern technologies in archaeology is their use for the study and restoration of architectural objects. Photogrammetry, laser scanning, virtual reality and other digital tools help preserve the uniqueness and cultural heritage of architectural monuments for future generations (Karpov, 2023). They help to reconstruct and recreate destroyed parts of buildings, while preserving their original appearance and authenticity. Such technologies can also allow for the study of techniques and styles used in construction and reveal many other aspects of architectural heritage.

In their work, I.M.E. Zaragoza *et al.* (2021) provide examples of the use of digital technologies and virtual reality for the restoration of architectural objects. Specifically, the study described the use of laser scanning to create an accurate three-dimensional model. After that, the study also used computer programs to virtually reconstruct the model in its original form based on the data obtained. It is noted that this method allowed archaeologists to get a detailed picture of the condition of the object and identify its damage or changes in structure. Compared to the study by the researchers, the results of this study demonstrate similar and additional benefits of using advanced technologies in the restoration of architectural objects. Some similarities can be observed in the use of 3D modelling and analysis of architectural features of objects. However, the results

of this work emphasize the role of photogrammetry as a key tool in this process, in particular, the use of ground and aerial photogrammetry to create detailed 3D models. The combination of these methods has resulted in not only high-quality 3D models, but also enhanced orthophotos and 3D files that have become a valuable addition to the site documentation. In addition, the results obtained indicate the importance of photogrammetry technologies in the restoration and preservation of cultural heritage, providing an opportunity for effective analysis and rehabilitation of historical objects with a high level of accuracy and detail.

The study by M. Atik *et al.* (2023) also notes that virtual reality can be used to make an interactive virtual journey around an architectural object, recreating it in detail, and even allowing users to interact with it in a virtual environment. It is emphasized that this approach allows the audience to better understand the historical significance and architectural features of the object without the need to be physically present on site. In general, in the research of the researchers, it was concluded that digital technologies and virtual reality are truly effective tools for the restoration of architectural objects, allowing to preserve their historical value and authenticity. Compared to the study by the researchers, the results of this work add a new dimension to the understanding of the use of digital technologies in the restoration of architectural objects. Although the work of the researchers focuses on the use of virtual reality to create interactive virtual tours around objects, the results of this study extend this understanding by showing the variety of technologies that can be used for detailed restoration and preservation of architectural monuments. Thus, the findings complement and extend the conclusions, showing that photogrammetry, together with other digital technologies, can be an effective tool in the preservation and restoration of architectural heritage, providing a detailed and authentic approach to restoration projects.

As a result of a study by V. Barrile *et al.* (2022), which focused on the possibilities of using 3D models for the restoration of objects, emphasizes that they can be used to restore architectural objects in a virtual environment, and make it possible to study their structure and recreate their appearance in different historical eras. This is an important aspect, as it allows restorers to work effectively to restore details and elements of architecture, which can be important for preserving the historical value of objects. Comparing both studies, the results of this paper demonstrate a similar approach to the use of 3D models for the restoration of architectural objects. Both studies emphasize the importance of digital technologies in recreating architectural objects in a virtual environment and the possibility of using these models to study their structure and recreate their appearance in different historical eras. However, the results of this work may additionally highlight certain shortcomings or limitations of this approach. For example, although the virtual environment allows for the recreation of architectural objects in detail, it may not be able to recreate the sense of physical presence and comprehension



of the scale and proportions of objects (Dokolova, 2023). In addition, depending on the quality and accuracy of the modelling, some details, or features may be lost or distorted. Thus, although the use of 3D models for restoration has its advantages in the recreation and research of architectural heritage, it is important to consider their limitations and to carry out additional checks and corrections to ensure the accuracy and reliability of restoration projects.

According to C.A. Jones & R. Church (2020), photogrammetry is considered one of the most effective technologies in modern archaeology for creating accurate and detailed digital models of architectural objects. This method allows obtaining high-resolution three-dimensional images by analysing two-dimensional photographs. It is noted that the use of photogrammetry allows archaeologists to carry out non-invasive surveys of objects, which is especially important for preserving their integrity. In addition, this technology allows for the creation of digital copies of objects that can be used for detailed study, reproduction, and virtual travel, as well as for archiving and preservation of cultural heritage. The study argues that photogrammetry also opens up opportunities for visualizing and researching architectural objects from different angles and perspectives, helping to reveal their history and significance. The results of this study additionally confirm the high efficiency of photogrammetry in archaeological research, in particular, in the restoration of architectural objects. Similar to the study by the researchers, this study also identified photogrammetry as one of the most effective technologies for creating accurate and detailed digital models. The use of photogrammetry in the study made it possible to obtain high-resolution three-dimensional images, which was an important prerequisite for the reproduction of architectural objects in a virtual environment. Thus, the results of this work confirm and extend the findings of C.A. Jones & R. Church on the effectiveness of photogrammetry in the reproduction and study of architectural objects.

According to a study by L. Mantovan & L. Nanni (2020), artificial intelligence and machine learning are promising technologies for the restoration of architectural objects. It is emphasized that these methods can be used to analyse large amounts of data and recognize patterns in damaged or lost structural elements. This technology makes it possible to automate the process of recovery and restoration, reducing the time and effort required for restorers. In addition, the study found that machine learning can be used to improve recognition and restoration algorithms, which helps to improve the quality and accuracy of work. The findings indicate that this approach can become an effective tool in the restoration of even the most complex architectural structures, allowing them to preserve their historical and cultural value for future generations. The results of this study complement and extend the conclusions of the researchers regarding the potential use of artificial intelligence and machine learning in the restoration of architectural objects. As indicated in the conclusions of the researchers, such technology can be a promising tool for

analysing large amounts of data and recognizing patterns in damaged or lost structural elements. However, in contrast to this approach, this study focuses on the use of physical restoration methods, such as photogrammetry, which provides high accuracy and detail in creating digital models of architectural objects. While artificial intelligence and machine learning can automate the recovery and restoration process, they can require significant amounts of data to train and need to be updated regularly to maintain accuracy (Nesterov, 2023). Effective implementation of such technologies requires careful planning, including the collection and processing of large amounts of data and ongoing training of models to ensure accuracy and quality of results.

In general, the results of research conducted in this area indicate significant progress in the use of modern technologies in the restoration and preservation of architectural objects. The introduction of digital technologies can greatly facilitate the process of analysing, reconstructing, and preserving cultural heritage. Innovative methods, such as artificial intelligence and machine learning, open up new opportunities for automating and optimizing restoration processes, which helps preserve historical sites for future generations. However, it is important to bear in mind that the effective use of these technologies requires a deep understanding and expertise in archaeology and restoration, as well as continuous improvement and refinement of methods. The development and implementation of digital technologies in the field of archaeology is a key factor in preserving and promoting cultural heritage for future generations.

CONCLUSIONS

This study has shown that the reliance on the use of advanced technologies in everyday life leads to improved conservation and restoration of archaeological sites. The effective restoration of the damaged mihrab of the Marinid Madrasa, Al-Mariniya Madrasa, and the Roma settlement, in particular, is an example of such an improvement, where the immediate value of the site slowed down the loss of its individual value and the architectural complex as a whole. Overall, it is important to note that the demand for 3D technologies for heritage digitization is growing rapidly, offering a promising way forward for the future of cultural heritage development.

This study has shown that the use of photogrammetry allows historical remains to be digitally recorded at a high level of detail, facilitating the rehabilitation and effective analysis of cultural sites. The use of ground and airborne photogrammetry in this study allowed for the creation of high-quality three-dimensional models of architectural objects, including enhanced orthophotos and 3D models. Photogrammetry technologies also proved useful for modelling and analysing architectural structures with high accuracy and detail. Selected virtual 3D models have proven to be efficient and fast in analysing structural elements and associated data. These technologies open up new opportunities for the management and preservation of cultural heritage,





as well as for tourism and educational initiatives aimed at bringing this heritage closer to new generations. The results of this study confirm the significant potential of photogrammetry technologies for the preservation, restoration, and accessibility of cultural heritage for future generations.

Areas for further research in this area may include the development of new methods for analysing and interpreting the data obtained to better understand cultural sites and their history. It is also important to consider in detail the possibilities of using virtual reality and augmented reality for interactive study and promotion of cultural

heritage among the public. Conducting such research with the use of various modern technologies can help expand the knowledge base and improve the practical application of new methods in the preservation and research of archaeological sites.

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CONFLICT OF INTEREST

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Сучасні технології в археології та їх застосування у реставрації архітектурних об'єктів

Анотація. Вивчення сучасних технологій в археології та реставрації архітектурних об'єктів є надзвичайно важливим через можливість їх використання для збереження культурної спадщини, відкриття нових артефактів та вдосконалення методів наукових досліджень. Метою цього дослідження було проаналізувати можливості використання сучасних технологій для реабілітації та візуалізації об'єктів культурної спадщини. У ході дослідження були використані такі методи, як фотограмметрія, порівняльний метод та аналіз. Результати дослідження показали значний потенціал сучасних технологій фотограмметрії у збереженні та візуалізації культурної спадщини. Зокрема, використання повітряної фотограмметрії за допомогою дрона та наземної фотограмметрії за допомогою цифрової камери дозволило створити тривимірні моделі архітектурних об'єктів з високою точністю та деталізацією. Наприклад, за допомогою дрона було зібрано та оброблено 267 знімків медресе Маринід, медресе Аль-Маринія та ромського поселення. Ці дані дозволили створити детальні тривимірні моделі, які були використані для створення ортофотопланів і візуального огляду місця. Крім того, експорт 2D-даних і моделей виявився ефективним для подальшого моделювання та аналізу. Це дозволило розробити тривимірну цифрову модель, яку можна візуалізувати, модифікувати та адаптувати в будь-який час, що стало цінним інструментом для архітектурних досліджень та документації. Результати дослідження підтвердили практичну ефективність фотограмметричних методів у збереженні та документуванні історичної спадщини. Використання цифрових моделей та ортофотопланів може полегшити візуальний аналіз об'єктів, подальші дослідження та архівування культурних цінностей. Такий підхід має потенціал для освітніх та туристичних ініціатив, залучення широкої аудиторії до вивчення та поцінування історичної спадщини

Ключові слова: фотограмметрія; культурна спадщина; 3D-візуалізація; реставрація історичних цінностей; деталізація моделей