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Methods for building, rebuilding, and preserving historical structures

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Abstract: The article is devoted to analyzing construction, reconstruction, and restoration technologies for historical objects in the context of architecture and building. It examines various techniques and methodologies, encompassing historical and contemporary approaches. The article discusses concepts and types and the importance of preserving cultural heritage and using cutting-edge technologies to restore historical sites. This study aims to examine and analyze the construction, reconstruction, and restoration technologies employed for historical objects in architecture and buildings. The research methodology analyzes literary sources, historical documents, and scientific articles covering historical objects' construction, reconstruction, and restoration. It also utilizes data from practical experience in restoration and construction projects. The methodology includes the analysis and comparison of different approaches, the study of historical contexts, and the evaluation of the impact of technologies on the preservation of cultural heritage. Throughout the research, various technologies for the construction, reconstruction, and restoration of historical objects were examined. It was found that these processes are complex and multifaceted, requiring a careful approach and the use of diverse methods and tools. The research demonstrated that modern technologies effectively restore and preserve historical objects, ensuring their long-term operation and protection from wear. However, addressing budget constraints, data loss, and other challenges requires a comprehensive approach and collaboration among various stakeholders. In light of the considerations above, further research in the construction and restoration field can contribute to the further development and improvement of these processes to preserve and restore cultural heritage for future generations.

Keywords: *Adaptive architecture, Construction technologies, Reconstruction, Restoration of buildings, Revitalization of historical heritage sites.*

1. Introduction

Historical objects are vital in shaping each country's national identity and cultural face. However, due to the passage of time, the occurrence of natural disasters, the ravages of war, and the impact of human activity, many of these objects have suffered damage or deterioration to the extent that they require reconstruction and restoration. This process necessitates advancing technologies and methodologies to guarantee the most accurate replication of the historical appearance of the objects while safeguarding their authenticity and value. In this context, investigating and analysing various methodologies and techniques employed in constructing, reconstructing, and restoring historical objects become highly pertinent.

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Restoring historical objects is crucial in preserving cultural heritage and transmitting it to future generations [1, 2]. Construction, reconstruction, and restoration technologies are pivotal in integrating contemporary innovations with traditional methodologies. This article aims to examine international experiences and practices in Ukraine regarding using technologies to preserve and restore historical objects. Additionally, the article will analyse current trends and challenges in this field.

2. Literature Review

Between 2020 and 2024, several studies were conducted on cultural heritage conservation and restoration. One key topic was the application of three-dimensional technologies for the conservation and restoration of objects. Acke, et al. [3] conducted a study on the use of 3D technologies in the conservation and restoration of cultural heritage. Some studies focused on the digital reconstruction of objects, such as fragmented artefacts [4].

Individual studies have explored several issues related to the restoration of ancient architectural structures, including arch bridges [5] as well as the consequences of cultural disasters and ways to overcome them [6]. Additionally, utilising contemporary technologies, such as virtual reality and the Internet of Things, was a significant focus in restoring and conserving historical artefacts [7].

Some studies have examined risk management in construction and the preservation of cultural heritage in occupied territories [8, 9]. Consequently, research in the conservation and restoration of cultural heritage demonstrates the importance of applying modern technologies and approaches to preserving historical objects for future generations.

Furthermore, scientific research encompasses the field of construction technology management. Galinskyi, et al. [8] researched risk management issues during the construction process and the implementation of construction projects. Bushuyev and Trach [10] concentrated on managing the development of construction technologies based on knowledge.

The concept of virtual and augmented realities is also actively being explored. Zhu and Li [11] revealed the potential of virtual and augmented realities for emergency management in urban environments. In a recent study, Van Nguyen, et al. [12] proposed methods for reconstructing three-dimensional digital objects for application in virtual and augmented realities.

The review also encompasses studies on the restoration of historical artefacts. For instance, Fioretti, et al. [13] investigated the potential of employing archaeometric techniques to reconstruct wall frescoes at the Sanctuary of Santa Maria La Veterana in Italy. Moyano, et al. [14] proposed a systematic methodology for creating information models of historical buildings during architectural restoration.

3. Materials and Methods

The aim of the study is to explore the technologies of construction, reconstruction and restoration of historical objects.

The scientific work contains such methods as literature analysis, comparison, expert assessments, documentary analysis.

4. Results

Historical objects constitute an integral component of every nation's cultural heritage. They reflect the historical and architectural achievements of past eras, contribute to the formation of national identity, and facilitate society's cultural development. However, due to time, natural disasters, wars, and other negative factors, many historical structures and monuments require reconstruction and restoration to ensure their preservation for future generations.

Construction, reconstruction, and restoration of historical objects can be traced back to ancient times when people began building monumental structures such as palaces, temples, and cities. Nevertheless, the first genuine technologies for these activities emerged in antiquity, when people utilised rudimentary tools and materials such as stone, wood, and clay [15].

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This field's first significant technological advances can be traced back to antiquity. In ancient Greece, impressive construction technologies were developed, which are reflected in the monumental structures of that time. Consequently, the Greeks devised various engineering solutions to address complex architectural challenges. They employed optical and geometric methods to achieve precision in the correction of building structures. For instance, they employed sundials to ascertain the precise moment of sunlight, thereby enabling the optimal angle of tilt for columns and other structures to be determined [5].

Furthermore, it is essential to note that Greek architecture profoundly influenced the subsequent evolution of construction and art in Europe. Their ideas and technologies were acknowledged and developed over centuries. For example, the Greeks were the first to apply mathematical proportions and harmony to their architectural designs, creating aesthetically pleasing and balanced structures. In their architectural designs, the Greeks employed a system of columns with capitals and architraves, which became a defining feature of their architectural style. This system provided structural support for the building and visually added height and elegance.

Although many structures of Ancient Greece were destroyed over time, archaeological research and restoration projects have allowed us to understand their architecture and construction technologies better. Several temples and theatres have undergone partial restoration, allowing contemporary researchers and visitors to engage with the world of ancient Greek culture and art [16].

Preserving and restoring ancient Egyptian structures represents a significant endeavour in conserving global cultural heritage. Egyptian scholars and archaeologists employ contemporary technologies, such as laser scanning and computer modelling, to assess the condition of architectural structures and identify any damage [17]. Furthermore, they are developing conservation methods and protection from wear to preserve these valuable historical objects for future generations.

In medieval Europe, stone remained the principal material used to construct cathedrals, castles, and city walls. However, the development of stone processing technologies and large-scale construction operations that facilitated work with this material led to increased labour intensity and construction costs. In the Middle Ages, stone architecture was frequently combined with wooden structures to support roofs. It allowed for the construction of more complex and refined structures [6].

Several distinctive architectural styles emerged during the Middle Ages, including Romanesque, Gothic, and Renaissance. A distinct set of features and construction techniques characterised each style. For instance, Gothic architecture was characterised by its tall lancet windows, intricate facades, and grand stone patterns, which necessitated the development of sophisticated construction techniques to realise such examples of architectural excellence.

In the Middle Ages, as in other historical periods, the reconstruction and restoration of historical buildings played an essential role in preserving cultural heritage. Using novel technologies and methodologies to elevate substantial stone blocks permitted the execution of intricate repair and restoration operations. Furthermore, artisans and masters of the Middle Ages developed their skills in restoring sculptural and architectural details to preserve the original appearance of buildings [13].

During the Renaissance, there was a renewed interest in architectural styles and ideas from antiquity. The resurgence of architectural classicism was evident in numerous facets of construction and reconstruction. Architects of this period sought to reinstate stylistic elements of ancient Greek and Roman architecture, including Doric, Ionic, and Corinthian porticoes, columns, arches, and domes. The Renaissance period saw the active introduction of new building materials and technologies. For example, the use of stone, brick, and marble was developed during this period. Moreover, the methods for brick production and the creation of stone structures were also refined, allowing for the construction of more complex and larger-scale structures [13].

Furthermore, the Renaissance saw many historical objects undergoing active reconstruction and restoration. Several ancient temples, churches, and palaces were restored and renovated using new technologies and materials, facilitating the preservation of these significant cultural landmarks for future generations. In summary, the Renaissance was a significant development in architecture and

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construction, with active reconstruction of historical objects and experimentation with new technologies and styles [8].

During the Baroque period, engineering technologies flourished, facilitating the realisation of ambitious construction projects. The utilisation of novel construction techniques, such as the incorporation of reinforced concrete structures and drainage systems, facilitated the realisation of architectural concepts in tangible form. Additionally, the Baroque period witnessed a heightened interest in restoring and conserving historical artefacts. Many churches and palaces were restored and renovated to preserve their historical and cultural value. Restorers employed novel technologies and methodologies to restore ancient edifices and ensure their preservation for future generations.

From the mid-18th century onwards, the Industrial Revolution profoundly impacted the construction industry. Novel materials, including cast iron, steel, and glass, became prevalent in the industry. The advent of steam engines also prompted a shift in the methods employed for transporting and lifting heavy materials, greatly facilitating the construction of large structures.

The architectural movement known as Modernism sought to achieve functionality and simplicity of form. In this period, architects employed novel materials and technologies to construct edifices that met the demands of contemporary life. Steel structures, glass facades, and open plans became characteristic features of Modernism. During this period, concrete and reinforced concrete became popular building materials. Their technical characteristics and properties permitted the construction of large and robust structures, such as skyscrapers and bridges. These materials also permitted architects to explore the potential of forms and devise novel architectural models.

The advent of industrial technologies and novel construction methodologies has facilitated the active reconstruction and restoration of historical edifices. Many ancient edifices were restored and modernised, ensuring their historical value while meeting contemporary requirements [18].

Contemporary technologies have facilitated the incorporation of novel materials that exhibit enhanced characteristics in terms of strength, environmental sustainability, and energy efficiency. For instance, using fibreglass composites, carbon fibres, and unique concrete mixes has enhanced the resistance and durability of building structures.

The advent of digital technologies, such as Building Information Modeling (BIM), has facilitated the creation of highly detailed designs and the effective management of construction projects at all stages. Virtual models allow effective communication between architects, engineers, and builders, enabling the resolution of issues before construction commences [4].

In the present era, robotic systems automate routine tasks on construction sites, thereby enhancing productivity and worker safety. Drones are employed for monitoring and inspecting construction sites from an aerial perspective, facilitating the rapid identification of issues and the tracking of progress [7].

One of the most crucial aspects of contemporary construction is the creation of structures that are resilient to the effects of climate change and extreme natural events. It uses energy-efficient and environmentally friendly technologies, including solar panels, drainage systems, and insulation [10].

A historical object is any item, structure, place, or landmark with historical, cultural, architectural, or archaeological value and is considered an object of historical heritage. It can be anything from archaeological remains and ancient cities to monuments, castles, churches, palaces, parks, and museums. Historical objects reflect the history, culture, and traditions of a particular locality or country and are of great importance for the preservation and study of the past. The state or local authorities can protect them as cultural heritage objects [19].

Construction technologies represent a set of methods, processes, materials, and tools used for planning, designing, constructing, and managing projects to create functional, durable, and aesthetic structures [20].

The main differences in construction technologies around the world lie in the following aspects:

1. Each country's culture, history and traditions can determine construction technologies. In countries with many historical monuments, unique methods of restoration and reconstruction can be developed.

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2. Each country has its own regulations and construction standards that govern the construction process, the quality of materials and the safety of buildings.

3. Construction technologies may differ depending on the region's climatic conditions and geographical features. In regions with extreme climatic conditions, unique building materials and methods can be developed to protect structures from weather conditions [3].

4. Developed countries may have access to more technological and economic resources for use in construction, including modern building materials and technologies. In less developed countries, traditional methods and materials may be used [21].

Here are some types of construction technologies that can be noted:

1. Conventional or traditional construction technologies have been used for centuries and are based on traditional building materials such as stone, brick, wood, and metal. These technologies encompass various methods and approaches to constructing buildings and structures. They can be adapted to different climatic and geographical conditions and consider local construction traditions and cultural features [22]. Such technologies are used for constructing various types of buildings, from residential houses to commercial facilities.

2. Modular construction technologies use pre-manufactured modular blocks or elements assembled to create a building. This approach reduces construction time and costs and improves quality. Modular blocks can be produced in factories using modern equipment and technologies, which allows for quality control of individual elements. These technologies enable the creation of buildings of various sizes and configurations, from residential homes to office buildings and hotels.

3. Monolithic concrete construction creates solid and stable structures by pouring concrete into specially prepared formwork. This method allows for the creation of complex architectural forms and structures and provides high strength and stability. The use of monolithic concrete enables the realisation of a wide range of construction projects, from tiny residential houses to extensive commercial and industrial facilities [23].

4. Ecological construction technologies aim to reduce environmental impact using environmentally friendly materials, energy-efficient technologies, and alternative energy sources. These technologies include using renewable materials, energy-efficient heating and air conditioning systems, and water recovery and purification systems. The main goal of such technologies is to reduce CO2 emissions and other harmful substances into the atmosphere and reduce energy and resource consumption [24].

5. "Smart Construction" technologies represent an innovative approach that uses modern technologies to optimise construction processes. These technologies include the use of the Internet of Things (IoT), Artificial Intelligence (AI), Virtual Reality (VR), and automated management systems to improve the management of construction projects, monitor production processes, and reduce resource expenses. For example, sensors can be installed at construction sites to monitor noise levels, temperature, and humidity. At the same time, analytical systems can predict project completion times and identify potential issues. Such technologies enhance the efficiency and accuracy of construction processes and reduce risks and costs [14].

6. 3D printing technologies are rapidly gaining popularity in the construction industry as they allow for faster and more efficient creation of building structures. With 3D printers, construction elements can be created by applying layer layer by layer, enabling the realisation of complex architectural forms and structures. These technologies are beneficial for building prototypes and experimental structures and producing unique architectural elements that would be difficult to manufacture using traditional methods. Additionally, 3D printing helps save time and materials, reduce costs, and minimise waste [25].

7. Industrialised construction technologies are used to produce building elements in factories, which ensures high quality and uniformity of products and reduces construction time and costs. These technologies include modern production processes and technologies, such as automated quality control systems, robotic production lines, and computerised management systems. Manufacturing building elements in factories ensures high speed and accuracy of production, reducing risks and costs [11].

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8. "Green Construction" technologies aim to create environmentally friendly and energy-efficient construction projects. It includes using renewable materials, energy-efficient heating and air conditioning technologies, and green technologies for air and water purification. Green buildings may also incorporate solar panels, wind turbines, and other alternative energy sources to meet their needs. These technologies allow for reducing the environmental footprint of construction and enhancing its resilience to climate change.

9. Technologies such as the use of renewable materials, reduction of CO2 emissions, and energy efficiency contribute to reducing the negative impact of construction on the environment and making buildings more resilient to climate change. Moreover, these technologies can help reduce heating and air conditioning costs, ultimately lowering the building's operational expenses. Green buildings also improve the quality of life for people who work or live in them by improving air and water quality and reducing the impact of harmful substances on health Table 1.

Table 1.
Some of the well-known construction technologies and historic sites.

Country	Construction technology	Historical sites
Germany	Monolithic construction	Cologne Cathedral, Brandenburg Gate in Berlin, Parliamentary Complex in Berlin
Italy	Using stone and marble (Renaissance style)	Duomo di Milano Palazzo Vecchio in Florence Palazzo Medici-Riccardi in Florence
France	Using stone and glass, mosaics (Gothic style)	Notre-Dame de Paris Cathedral, Chartres Cathedral, Amiens Cathedral
Egypt	Using limestone and stone	Pyramids of Cheops, Chephren, Menkaure
USA	Using steel	The Statue of Liberty, the Washington Monument, the Main Building of the Capitol
Ukraine	Traditional technologies use brick and stone. Using stone and wood	St. George's Church in Lviv, St. Sophia Church in Kyiv, State House in Kyiv, Pochayiv Lavra, Kyiv-Pechersk Lavra, Lviv City Hall

Source: Fioretti, et al. [13].

Reconstruction of historical objects is integral to preserving cultural heritage and restoring their architectural value. This process involves restoring and refurbishing old buildings and structures to preserve their historical character and authenticity. Here are some aspects and methods of reconstructing historical objects: 1) The first step in reconstructing a historical object is a detailed study of archival materials, photographs, drawings, and other historical sources to restore its original appearance and structure. 2) Architectural experts conduct a detailed analysis of the structure and design of the historical object to understand its features and requirements for reconstruction. 3) During reconstruction, an effort is made to use the same materials used in constructing the original structure or their authentic equivalents. 4) An essential aspect of reconstruction is restoring architectural details, such as doors, windows, facades, and other elements that add character to the historical object. 5) Sometimes, modern technologies and construction methods are used during reconstruction to ensure the stability and safety of the building, mainly to increase its resistance to natural disasters and other adverse effects. 6) The reconstruction of historical objects must comply with the requirements for protecting and preserving cultural heritage, including international and national standards and legislation [12].

Several types of reconstruction of historical objects can be used depending on the condition of the object, its historical significance and the purpose of the restoration [26]. Here are some types of reconstruction:

1. Full reconstruction involves restoring a historical object to its original condition. It may include recreating destroyed parts and restoring the structure and design following historical sources.

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2. Partial reconstruction means that only certain parts of the historic property will be restored, while others may remain unchanged or modernised. It can preserve the object's authenticity, while certain elements can be adapted to new needs.

3. Adaptive rehabilitation includes modifying a historic property for a new functional purpose. For example, an old factory can be converted into a residential complex while maintaining the architectural features and style of the original building [26].

4. Conservation and restoration means that, in some cases, the main goal is to preserve the object's condition as it is now, with minimal interference with its structure or appearance. It may also include strengthening and protecting old materials from further deterioration.

The processes of reconstruction and restoration are two distinct approaches to the revitalisation of architectural and cultural heritage. Reconstruction entails the recreation or restoration of an object based on architectural or historical data, with some latitude for utilising novel technologies and materials. It may entail repairing damaged components of the object and even alterations to its structure or purpose to accommodate contemporary requirements. Conversely, restoration is focused on the preservation of the original appearance and materials of the object. This process entails repairing damaged components utilising original materials or their exact reproductions. Restoration is typically based on historical research and archival sources to ensure authenticity. Consequently, reconstruction may entail substantial alterations or adaptations, whereas restoration is designed to maintain the original appearance and structure of the object [27].

Thorough research and analysis of the historical object are essential in the initial stages of restoration. This entails collecting and analysing archival materials, taking photographs, measuring the object, and conducting an expert assessment of its condition and restoration needs.

It is also essential to consider the planning and design stages of restoration. Developing a restoration project requires meticulous attention to detail, as the objective is to preserve the object's authenticity. At this juncture, decisions are made regarding selecting materials and restoration methods.

One of the principal aspects of restoration is the execution of the restoration work itself. Restoration encompasses the restoration or reproduction of damaged components of the object using original materials or their equivalents. It may necessitate considerable skill and attention to detail.

The process is particularly labour-intensive, requiring accurate collation of comprehensive data about the object. To illustrate the complexity of the initial assessment, consider the example of bricks (Figure 1):

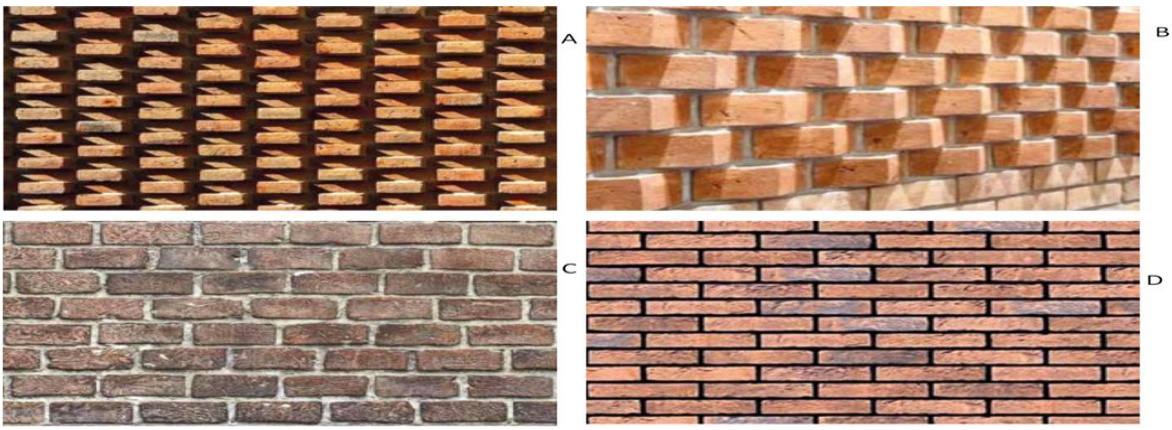

Figure 1.
Types of brickwork on facades.
Source: Kutsevych, et al. [28]

Alternatively, for instance, a variety of types of grouting for curly masonry (A, B), "industrial" poke masonry without jointing (C), and spoon masonry with jointing (D) (Table 2):

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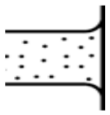
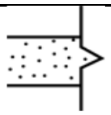
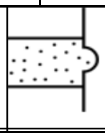
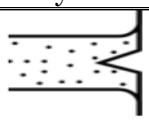
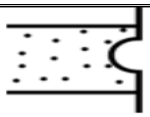
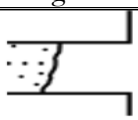
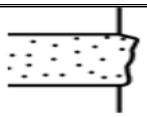
Table 2.
Types of grouting.

Grouting "scraping" embroidery	Corner	Stitching	"Twist"	Double trimming	Slotting
					
Embroidery	Roller		Trimming blank	Raw	
					

Source: Tsyrfa, et al. [9].

The final stage of the restoration process involves completing the finishing works and the transfer of the object to the client or relevant authorities. It is also essential to obtain the necessary permits and certificates that confirm the compliance of the works with the requirements for the preservation of cultural heritage.

5. Discussion

The loss of historical data, plans, and drawings represents a significant obstacle to restoring historical objects. In instances where a building or structure has been destroyed or damaged by natural disasters, war, or other unforeseen circumstances, the loss of documentation can significantly complicate the restoration process.

One of the most notable examples is the restoration of Notre Dame de Paris, the subject of considerable interest and debate. Following the extensive damage caused to the cathedral by a major fire in April 2019, there was a pressing need for its restoration. However, many historical documents, plans, and drawings were lost or damaged due to the fire. Consequently, the architects and restorers utilised data from the video game Assassin's Creed: Unity, which had meticulously recreated the cathedral in its virtual reality [29]. This approach permitted retaining the cathedral's essential details and architectural characteristics for subsequent restoration.

Furthermore, it is essential to acknowledge the absence of international standardisation in the field of construction, reconstruction, and restoration technologies for historical objects, which presents significant difficulties and challenges [17]. Nevertheless, each country has its regulations, standards, and methods to restore and preserve cultural heritage. It can result in discrepancies in the quality and efficiency of work and complicate collaboration between countries in solving everyday tasks. To illustrate, historical objects within a country may be included in the UNESCO World Heritage list, necessitating particular attention and adherence to international standards in restoration and preservation processes. However, different countries may adopt disparate approaches to these tasks, leading to variations in methodology and outcomes [30].

Such discrepancies can challenge ensuring uniform quality and standards in restoring historical objects. These discrepancies necessitate a meticulous examination and the implementation of potential measures to harmonise approaches and guarantee compliance with international norms in conserving cultural heritage.

6. Conclusion

The research revealed that the construction, reconstruction, and restoration technologies employed in preserving and restoring cultural heritage are of paramount importance. The application of various

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methods and innovative approaches in these fields allows for a practical impact on the condition and appearance of historical objects, thereby ensuring their longevity and value to society. Expert evaluation and analysis of historical objects are pivotal in determining optimal strategies for preserving and restoring such objects. An essential aspect of this process is developing and implementing innovative approaches that facilitate the preservation of cultural heritage for future generations.

In conclusion, the restoration of historical objects necessitates a comprehensive approach, which encompasses research, planning, the execution of restoration work, and the completion of the project following all the requirements for the preservation of cultural heritage.

One of the principal avenues of enquiry in this field is utilising digital technologies. Computer modelling, laser scanning, and virtual reality permit a comprehensive analysis of the object's condition before any work commences. It allows for the planning and execution of restoration measures with high precision and minimal impact on the object. Such technologies also permit the reproduction of missing parts of structures, thereby virtually restoring their former appearance.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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