

# A NEW APPROACH TO PRESERVING HISTORICAL STRUCTURES FOR THE FUTURE: AI-SUPPORTED RESTORATION OF UNESCO-PROTECTED BUILDINGS

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**Abstract:** This study examines the theoretical and practical contributions of artificial intelligence (AI) technologies to the restoration processes of historic structures within the framework of preservation and sustainability principles. Preserving cultural heritage requires precise structural degradation analyses, the maintenance of aesthetic and historical integrity, and the effective use of scientific methods in restoration processes. Adopting an interdisciplinary approach to restoring historical buildings, especially when integrated with digital data processing, machine learning, and AI-supported analytical techniques, ensures the process becomes objective and replicable. While traditional restoration practices are often limited to qualitative data, observations, and expert opinions, AI-based methods leverage large-scale spatial data to enable highly accurate modeling and analysis, thus promoting a scientific, evidence-based approach to preserving cultural heritage.

*In this context, the article addresses the intersection of AI with architecture, conservation sciences, and engineering on a theoretical level, evaluating the contribution of spatial data collection methods, image processing techniques, and deep learning-based analyses used in digitizing historical structures to restoration projects. The study presents restoration scenarios for UNESCO-protected historical buildings, developed directly through AI-supported algorithms, thereby supporting the practical applicability of the technology with empirical data. AI-based methods that allow restoration processes to be approached objectively and verifiable are scientifically discussed in terms of the future role they may play in preserving historical heritage..*

**Keywords:** Artificial Intelligence, Historical Building Restoration, Cultural Heritage, Conservation

## 1. INTRODUCTION

As tangible carriers of human heritage, historical structures play a crucial role in preserving collective memory and ensuring cultural continuity. These buildings, which bear the marks of the past through their architectural identity, aesthetic qualities, and historical context, serve as physical entities and as important documents reflecting a society's cultural identity and values. However, the destructive effects of time and environmental conditions have made preserving and restoring historical structures imperative. This need is recognized as a local or national responsibility and an international priority for preserving humanity's shared heritage. International organizations such as UNESCO's World Heritage List and ICOMOS emphasize global responsibility for preserving historical structures and supporting implementing policies developed in this field.

In recent years, advancements in artificial intelligence (AI) technologies have introduced new application opportunities in architecture and restoration. AI transcends the limitations of traditional methods and holds the potential to redefine the theoretical and practical framework of the field by supporting the modeling and visualization of possible future restoration scenarios for historical structures. AI-based approaches, considering historical buildings' aesthetic and historical integrity, can provide visual predictions of a building's

past or future conditions. Thus, the innovative methods offered by AI enable restoration practices to be seen not just as an act of preservation but also as a creative process.

This study explores the potential contributions of AI-supported methods to restoring historical structures, focusing on how future restoration scenarios can be visualized through AI. The study aims to evaluate, within a theoretical framework, how AI technologies can be integrated into future restoration processes of historical structures, considering both aesthetic and historical contexts. In this regard, the visual and analytical potential of AI technologies in restoring historical structures is discussed, emphasizing their capacity to offer a new perspective on restoration practice.

The study aims to reveal the methodological and conceptual frameworks that allow for redefinition restoration processes using AI-based simulations and visualization tools, facilitating an interdisciplinary approach to restoration.

## **2. THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE RESTORATION OF HISTORICAL STRUCTURES**

Artificial intelligence (AI) is a technology developed to mimic human thought processes, which has evolved into the ability to design knowledge-based, analytical, and intelligent systems (Yeşil, 2024). This capacity offers new methodological possibilities in complex processes requiring an interdisciplinary approach, such as restoring historic buildings. AI-based approaches systematically analyze the current state of historical structures, providing the ability to evaluate future restoration scenarios in aesthetic and historical contexts.

Restoration is not only concerned with physical improvements but also aims to preserve a structure's historical identity and aesthetic integrity. In this context, AI predicts alternative restoration scenarios through its data analysis and modeling capabilities, enabling comparative evaluations via digital visualization. This approach elevates restoration processes to a more scientific, predictable, and aesthetically aligned framework.

### **2.1. The Relationship Between Artificial Intelligence and Architecture**

Artificial intelligence is a technology aimed at modeling human intelligence, simulating cognitive abilities such as reasoning, inference, generalization, and learning from past experiences through machines (Yılmaz, 2019). AI has become a concept integrated into almost all disciplines, professional fields, and daily life. This has created a significant area of interaction with the discipline of architecture. Yıldız (2014) emphasizes that AI interacts with architecture by integrating artistic and technological elements.

The interaction between AI and architecture allows for the development of various applications within the field of architecture due to the vast possibilities that technology offers. In this context, AI technologies in architecture optimize furniture placements through algorithmic approaches, collect data on user behaviors in physical spaces via sensor technologies, quickly generate survey models of spaces using digital tools, and produce spaces that suit different design styles. These applications enable architectural processes to be addressed with a more efficient, analytical, and user-oriented approach.

The expansion of AI's usage in architecture has sparked various predictions and debates about its future role. These discussions generally take place using two main approaches. The first approach offers a positive perspective, suggesting that AI will support architects' creative decision-making mechanisms when integrated into design processes. The second approach, however, expresses concerns that AI may

eventually take over the designer's role, transforming the profession's traditional nature. In this context, the potential impacts of AI technologies are examined in depth through theoretical and practical studies.

Öztürk (2018) highlights that it remains uncertain whether algorithms can evaluate multidimensional parameters like an architect and manage design processes, though the potential for technology to bring about profound changes in architectural production methods is undeniable. The integration of AI-based systems into architectural design processes thus signals a technical transformation and a paradigm shift regarding the creative dimensions of the architecture discipline.

In the architectural profession, viewing AI as a competitor to architects is seen as counterproductive both professionally and humanistically—such an approach risks overlooking the opportunities that technology offers. Wodzicki (2019) argues that AI should not be viewed as a threat to the architectural profession but rather as a tool that accelerates specific processes and increases efficiency.

In this regard, AI technologies are emphasized as being particularly useful in supporting architects in tasks such as automating repetitive tasks and analyzing large amounts of data. Thus, AI should be positioned not as a replacement for human creativity but as a technology that supports creative processes. This approach allows for both the improvement of design processes and the ability of architects to focus on more strategic and creative tasks by integrating technology into professional practices.

## **2.2. Contributions of Artificial Intelligence to Architecture and Restoration**

The preservation and restoration of historical structures play a critical role in ensuring the sustainable transfer of cultural heritage to future generations. These processes involve repairing physical deterioration and preserving aesthetic, architectural, and historical values. The limitations of traditional methods have necessitated integrating artificial intelligence (AI) technologies into restoration processes today. AI's analytical capacity allows this field to be approached more systematically and scientifically, transforming traditional methods and making restoration practices more efficient and sustainable.

One of AI's most significant contributions to restoration is its ability to provide detailed analyses of structures' current condition. Traditionally, lengthy and error-prone processes can be carried out more quickly and accurately through AI-based data analytics. Ararat and Karadayı Yenice (2020) state that AI can identify the causes of physical deterioration in historical structures and determine appropriate intervention methods. In this context, AI enhances the efficiency of restoration processes by analyzing data, providing suggestions, and running simulations.

The importance of AI's data processing power in restoration projects is especially evident in digitalization and precision measurement techniques. In a study on the defense structures of Çatalca, Turkey, the conversion of digitized archival documents into CAD-based technical drawings highlighted AI's contributions in terms of speed and accuracy (Zağra, 2022). Such innovations enable the application of historical documents to restoration projects while preserving their historical context.

AI-supported techniques used in historical research offer new methods to support restoration processes. Tanrısever and Eravcı (2024) emphasize the importance of AI in speeding up and improving the accuracy of data collection, classification, and analysis, particularly when processing and interpreting historical documents. In documenting historical structures, AI algorithms' pattern recognition and

classification capabilities play a crucial role in preserving the buildings' original features.

Terrestrial laser scanning (TLS) further enhances AI's impact on restoration processes. In a study by Hamal and Ulvi (2024), the role of TLS in creating precise three-dimensional models of historical structures was examined, and the advantages of these methods over traditional documentation techniques were highlighted. The study points out the contributions of this technology, particularly in terms of accuracy, speed, and cost-effectiveness.

The integration of AI into restoration processes not only provides technical advantages but also promotes the preservation of cultural heritage through interdisciplinary collaboration. AI-supported innovative approaches in architecture and restoration ensure the preservation of historical structures' aesthetic and historical integrity while producing lasting and sustainable solutions for future generations.

### **2.3. Digital Reconstruction for Historical Buildings**

Digitization, regarded as a critical process in information and document management, is a comprehensive transformation mechanism that enables the transfer of physical materials into electronic formats and their secure preservation over the long term. In today's information society, it is necessary to approach digitization processes systematically and scientifically to manage data and documents effectively. Converting paper-based documents, photographs, and other graphic materials into digital formats facilitates data access. It offers significant advantages regarding information security, sustainability, and long-term preservation. Compared to traditional archiving methods, digitization processes are widely applied in many fields due to their benefits, such as faster access, reduced physical space requirements, and excellent protection against deterioration.

This process enhances the effectiveness of document management systems and ensures that information remains accessible, processable, and shareable over the long term. Külçü (2010) states that digitization allows physical documents that cannot be adequately identified or processed in their traditional form to be transferred to electronic environments through advanced software systems, enabling more efficient data analysis. In large-scale archiving projects, digitization technologies provide revolutionary advancements in institutional and academic information management by allowing documents to be indexed, automatically classified, and accessed based on content.

With the advancement of artificial intelligence (AI) and machine learning technologies, digitization processes have reached an even more advanced stage today. Technologies such as optical character recognition (OCR) enable printed documents to be converted into text-based formats, while big data analytics aids in classifying documents within archives. Moreover, advanced search algorithms enhance the accessibility of information. These developments are utilized in various fields, from preserving cultural heritage and academic research to government archives and private-sector information management. Therefore, digitization should be seen as the transfer of physical documents to electronic formats and a strategic transformation process that makes information management systems more efficient, sustainable, and accessible.

In historical structures, digital reconstruction allows for the virtual recreation of buildings and monuments in their original or restored state. AI technologies, combined with high-resolution 3D scanning and modeling tools, enable the reconstruction of intricate architectural details. This facilitates the accurate

documentation of historical structures and offers new possibilities for virtual tourism, educational tools, and interactive exhibits. Furthermore, digital models serve as a vital reference during physical restoration, helping minimize errors and preserve the structure's integrity.

As historical structures undergo natural wear and damage over time, digital reconstruction provides a way to safeguard cultural heritage. Through 3D modeling, virtual simulations, and augmented reality applications, these structures can be visualized in their past or future states, allowing for predictive analysis of how restoration might alter their appearance.

### **3. AI APPROACHES IN THE RESTORATION OF HISTORICAL BUILDINGS**

The preservation and restoration of historical buildings is more than just a physical intervention process; it is an interdisciplinary approach that ensures the sustainable management of cultural heritage. While traditional restoration methods have relied on analyzing historical documents, on-site observation, and expert opinions, recent years have seen the emergence of AI-based technologies that make these applications more systematic and scientific. In particular, deep learning and machine learning algorithms allow for a comprehensive analysis of the current state of historical buildings, the detection of damages, and the determination of appropriate intervention methods. Terrestrial laser scanning (TLS) and image processing techniques enable the creation of three-dimensional (3D) point clouds, which allow structural deformations to be modeled with high precision, ensuring that restoration projects are conducted with a data-driven approach (Hamal & Ulvi, 2024). Additionally, AI-supported simulation systems are employed to predict interventions that preserve historical buildings' original materials and aesthetic characteristics, thus minimizing errors during the restoration process.

AI's data analytics and big data processing capabilities enable the evaluation of information from previous restoration projects, providing optimization for future applications (Tanrısever & Eravcı, 2024). By integrating AI technologies into the field of restoration, not only can the physical integrity of structures be maintained, but their artistic and cultural identities can also be preserved and revitalized. In this context, AI-based approaches place restoration processes on a more scientific foundation, offering more comprehensive and sustainable solutions for the protection of cultural heritage.

These AI-driven methods offer transformative tools for assessing structural damage, improving accuracy in material selection, and predicting the long-term impacts of various restoration techniques. Through historical data analysis, predictive modeling, and advanced imaging techniques, AI is contributing to restoration practices that are more precise, efficient, and aligned with the preservation of the building's historic essence. AI's role in restoration is evolving, making it an indispensable tool for future conservation efforts, allowing cultural heritage to be maintained in a way that respects its past and future significance.

#### **3.1. 3D Scanning, Digital Twin Technologies, and Historic Buildings**

The concept of a digital twin refers to the dynamic software model of a physical object or system, essentially a digital equivalent of a real-world entity. The concept gained widespread recognition with NASA's 2010 technology roadmap. Digital twin technology allows for the analysis of real-world conditions, simulation of different scenarios, and dynamic adaptation to environmental changes through virtual models of physical systems. This technology increases operational efficiency by monitoring and evaluating processes, enabling more effective decision-making mechanisms (Erturan & Ergin, 2018).

In this context, the development of digital twin technology is directly linked to three-dimensional (3D) scanning methods. 3D scanning technology is critical in creating accurate and detailed digital representations of physical objects or structures, serving as a key component in developing digital twins. Techniques such as laser scanning, photogrammetry, and structured light scanning facilitate the creation of high-precision digital models, allowing for realistic and detailed representations of digital twins. This process is critical in industrial design, manufacturing, healthcare, construction, and energy sectors, where understanding and managing complex systems are crucial. 3D scanning technologies ensure that physical entities are accurately and fully represented in the digital realm, serving as an essential tool for creating digital twins.

Creating digital twins allows for comparisons between pre- and post-restoration phases for historical buildings, enabling structural analysis and helping identify the most appropriate intervention methods. Digital twins document the current state of structures, track changes over time, and analyze the long-term impacts of restoration interventions. Documenting a building's current condition provides a critical data source for identifying damage and planning restoration processes. In cases where historical buildings are worn or partially destroyed over time, 3D scanning data becomes a key reference for reconstructing their original forms.

Using 3D scanning and digital twin technologies offers invaluable insights into historical buildings' structural integrity, material composition, and aesthetic elements. Digital twins allow for predictive maintenance strategies and more informed restoration decisions by simulating various environmental factors and deterioration processes. This results in more precise and data-driven restoration projects that can preserve the buildings' cultural and historical significance for future generations.

### **3.2. Artificial Intelligence in Damage Detection and Reconstruction Processes**

In the preservation and restoration of historical buildings, both destructive and non-destructive testing methods are employed to detect structural damage. Destructive examination methods, which require direct intervention in the building materials, risk damaging the structure's original integrity. On the other hand, non-destructive examination methods allow for identifying deterioration in the surface and inner structure of the material without altering its physical or chemical properties. These methods provide a more precise analysis of the current state of the structure, enabling conservation decisions to be based on scientific grounds (Dwivedi et al., 2018). With technological advancements, non-destructive examination methods have become increasingly common and are integrated with AI-supported analyses, offering innovative approaches to preserving historic buildings.

Non-destructive examination methods, which have evolved alongside technological advancements, are widely used in various sectors, including aviation, energy production, industry, automotive, petrochemical, and engineering (Kubba, 2008). These methods enable a detailed analysis of structures, allowing for the rapid and accurate identification of damage that might be difficult to detect using traditional evaluation techniques. In the context of historical buildings, non-destructive methods play a critical role in identifying early-stage deterioration, helping to prevent progressive damage. Additionally, these techniques allow for detailed analysis of the surface and internal structure of materials, providing a scientific foundation for preservation and restoration processes. In assessing historical buildings, the initial step in detecting damage typically involves visually inspecting the material surface (Tavukçuoğlu, 2009).

In recent years, various non-destructive examination methods have been developed based on different working principles to assess the current state of structures. These methods are categorized by their application techniques, including visual inspection, electromagnetic

testing, moisture measurement, thermal analysis, acoustic and ultrasonic testing, and radiographic imaging (Evans, 2015). Additionally, technological advances have enabled techniques such as photogrammetry, digital image processing, and laser scanning to document and analyze historical buildings. These technological approaches allow for faster and more accurate assessments of structures. Research highlights the importance of visual inspection, electromagnetic testing, infrared thermography, sonic and ultrasonic testing, radiographic analysis, photogrammetry, and terrestrial laser scanning as key non-destructive examination methods.

Artificial intelligence (AI)--based technologies are becoming increasingly important tools in historical buildings' preservation, restoration, and reconstruction processes. Traditional restoration and reconstruction methods often involve long-term fieldwork, expert evaluations, and detailed analyses, which can be time-consuming, costly, and prone to human error. However, AI-supported approaches offer the ability to manage the process more quickly, systematically, and based on scientific data, providing more sustainable solutions for protecting cultural heritage. In this context, machine learning, deep learning algorithms, big data analytics, and digital twin technologies are among the innovative tools used to reconstruct historical buildings.

AI-supported reconstruction processes typically begin with collecting and digitally modeling existing data on historical buildings. In this process, archival documents, historical photographs, architectural drawings, maps, and geophysical analyses are integrated into AI-based systems to create digital replicas of the buildings. AI-supported digital twin and 3D modeling techniques allow for creating digital replicas of historical structures, enabling the testing of different intervention scenarios before restoration. This approach enables scientific evaluations of material selection, structural durability, and aesthetic compatibility, leading to the development of optimal restoration strategies.

One of the most significant contributions of AI to reconstruction processes is the ability to offer predictive modeling techniques for completing missing or damaged building components. Machine learning algorithms use data from the analysis of structures from similar periods to enable the redesign of damaged or lost sections in a way that is consistent with the architectural style. This ensures that historical buildings are reconstructed as close as possible to their original form, while also considering factors such as sustainability and structural compatibility in material selection.

Generative adversarial networks (GANs) allow for the digital reconstruction of severely damaged or lost sections of buildings by analyzing their temporal changes. These AI-based models offer significant advantages, especially for reconstructing buildings with undocumented or incomplete data sets, ensuring that cultural heritage is recreated as accurately as possible. Supported by deep learning algorithms, these techniques minimize errors in reconstruction processes and contribute to applying restoration methods that are most faithful to the original form.

### **3.3. Artificial Intelligence Support in Material Selection and Conservation Techniques**

Material science plays a fundamental role in restoring historical structures, ensuring that the original texture of the building is preserved and that the renewal process is durable. Artificial intelligence (AI) technologies provide innovative solutions for optimizing material selection and conservation techniques in restoration processes. AI applications, such as computer vision and machine learning, enhance the effectiveness of restoration and preservation efforts by accurately identifying and documenting the characteristics of cultural artifacts. These technologies are used to detect damaged parts, complete missing sections, and restore deteriorated texts. AI-supported image processing and deep learning algorithms can detect cracks, color changes, and other signs of deterioration on building

surfaces with high precision. This allows for a detailed analysis of the current state of structures, enabling a comprehensive assessment before restoration begins.

AI-supported systems can assist in analyzing the properties and behaviors of different materials, helping to identify the most suitable materials for restoration. These systems evaluate materials based on durability, compatibility, and aesthetic criteria. AI can also be used in material science to analyze large data sets, determining the chemical and physical properties of the original materials used in historic buildings. As a result of these analyses, modern materials selected for restoration can closely match the original materials, ensuring that the historical and aesthetic integrity of the structure is maintained.

AI can predict future deterioration processes that buildings may face. These predictions allow conservation experts to shape restoration strategies proactively according to long-term preservation goals. AI-supported material selection and conservation techniques contribute significantly to preserving historical structures based on scientific data and developing sustainable restoration processes. These methods offer time and cost savings in restoration processes while minimizing human errors, ensuring the sustainable preservation of cultural heritage.

## 4. METHOD

### **Artificial Intelligence in Cultural Heritage Preservation: Case Studies of Restoration and Application Scenarios**

The preservation of cultural heritage requires a multidisciplinary and dynamic process that ensures the sustainable maintenance of historical structures' physical, aesthetic, and identity integrity. Traditional restoration methods' limitations necessitate the integration of contemporary technologies, and in this context, artificial intelligence (AI)-based approaches present an innovative paradigm in restoration practices.

In this study, three historical structures, each representing different countries and continents, have been selected from the UNESCO World Heritage List: the Colosseum (Rome), Independence Hall (Philadelphia), and Hagia Sophia (Istanbul). These selected structures are examined using two different AI models, focusing on how AI can assist in their restoration, which materials it could recommend, and how the outcomes of the restoration processes would be visualized.

#### **Model 1: GPT-4o (OpenAI)**

The first AI model used in this study is GPT-4o, developed by OpenAI. This model employs advanced natural language processing and deep learning techniques, offering a wide-ranging information processing capability that significantly contributes to various aspects of the restoration process. GPT-4o performs detailed analyses of historical structures, detecting damage, identifying suitable materials for restoration, and creating restoration simulations. The model supports real-time visual inspection, analyzing the current state of structures, conducting real-time damage assessments, and predicting future deterioration processes. By leveraging its data-driven approach, GPT-4o aids in optimizing restoration strategies based on scientific and historical accuracy.

#### **Model 2: Gemini (Google DeepMind)**

The second AI model, Gemini, developed by Google DeepMind, contributes significantly to restoration processes with its real-time visual inspection capabilities, deep analytical capacity, and extensive data processing abilities. Gemini analyzes real-time visual data from historical structures, detecting surface wear and structural deformations and performing damage assessments. By integrating textual and visual data, Gemini contextualizes the structures' historical significance and suggests the most appropriate restoration methods. It also helps evaluate structural endurance and materials, thus guiding restoration teams to ensure long-term conservation.



Both AI models are compared based on their ability to analyze the current conditions of the selected historical structures, suggest appropriate restoration materials, and simulate potential restoration outcomes. This approach highlights the critical role of AI technologies in facilitating sustainable and accurate preservation of cultural heritage, particularly in addressing the challenges conventional restoration methods face.

The following sections will discuss in detail the restoration workflows of each AI model, their comparative strengths, and practical application results on the Colosseum, Independence Hall, and Hagia Sophia.

5. RESULTS

This section evaluates the current state of three UNESCO World Heritage-listed historical structures using two different artificial intelligence (AI) models. It includes the restoration needs, areas requiring restoration, material selection, structural compatibility, expected outcomes of restoration, and visualizations of these processes.

5.1. Rome, Colosseum

Located in the capital of Italy, Rome, the Colosseum is a remarkable architectural feat dating back to Ancient Rome. It holds the title of the world's largest amphitheater. Construction of the structure began in AD 70 and was completed in AD 80.

Architectural Features and Structural Dimensions:

- **Architectural Style:** Built in the classical Roman architectural style.
- **Dimensions:** The Colosseum is 189 meters long, 156 meters wide, and approximately 50 meters tall.
- **Capacity:** It could hold an estimated 50,000 to 80,000 spectators.
- **Construction Material:** It was constructed using travertine stone, tuff, concrete, and brick (Kavraz, 2018).

Although it has suffered significant damage over time due to earthquakes and the removal of building materials for other construction projects, parts of the Colosseum still stand as one of Rome's most significant cultural heritage landmarks.

The current state of the Colosseum was analyzed using AI models, and the question of whether restoration is needed was posed to the models. The analysis used two AI models, each assessing the structure's current condition. The AI models were asked, "If you were to restore this structure, which parts would you restore and why?" The models generated various responses. Both AI models were then queried about the materials that should be used to restore the Colosseum, yielding different answers based on distinct methods and data (Table 5.1).



Figure 5.1. Colosseum Day and Night Photo (Yeşil, 2022)

Table 5.1. Analysis of the Current State of the Colosseum through AI Models

1. Does the Colosseum need restoration?
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<b>Model 1 (OpenAI-GPT-4o):</b>
"Whether the Colosseum needs restoration requires a detailed analysis of the structure's current state. However, in general, it can be said that the building requires some restoration and maintenance efforts to preserve and strengthen certain sections. The Colosseum has been standing for nearly 2,000 years and has been affected by many factors such as earthquakes, air pollution, natural erosion, tourist crowds, and past incorrect interventions."
<b>Model 2 (Google DeepMind-Gemini):</b>
"Yes, the Colosseum requires restoration. The 2,000-year-old structure has deteriorated due to natural disasters, weather conditions, and tourism pressure. Restoration will preserve the building's historical fabric while strengthening it with modern techniques for future generations. This is crucial for both structural integrity and cultural heritage."
<b>2. If you were to restore the Colosseum, which parts would you restore and why?</b>
<b>Model 1 (OpenAI-GPT-4o):</b>
<p>"If I were restoring the Colosseum, my primary goal would be to preserve its historical fabric while minimizing damage and ensuring it remains structurally sound for future generations. During the restoration process, I would focus on areas that threaten structural stability, and ensure safety for visitors by reinforcing critical parts. I would first intervene in the load-bearing systems that require strengthening. Although better preserved than other sections, the walls and arches on the northern side need reinforcement due to erosion and cracks. I would maintain the original travertine stones, replacing missing sections with compatible materials. Earthquakes have heavily damaged extensive sections on the southern side. Rather than rebuilding these sections from scratch, I would preserve the existing ruins to support the structure's integrity. Additionally, worn-out stairs and stone pavings at the entrance and exit points would be reinforced to ensure visitor safety. The Hypogeum (underground tunnels and chambers), which is of significant historical importance, has collapsed. I would focus on strengthening the parts of the structure at risk of further collapse. Moreover, due to the environmental factors that have caused chemical damage to the stone surfaces, I would use protective coatings and bioremediation techniques to reduce further erosion and preserve the material integrity.</p> <p>Lastly, I would incorporate digital technologies like augmented reality (AR) or virtual reality (VR) to allow visitors to experience the Colosseum as it was in the past, without physically altering the structure."</p>
<b>Model 2 (Google DeepMind-Gemini):</b>
<p>"If I were to restore the Colosseum, I would begin by reinforcing weakened arches, walls, and vaults for structural safety, as these areas have been damaged by earthquakes and natural erosion over time. I would then restore the main arena, where gladiator fights took place, to its original state to give visitors a chance to experience the ancient atmosphere. The Hypogeum, which served as a preparation area for gladiators and animals, would also be revitalized. Additionally, I would restore missing travertine stones on the façade to bring back the grandeur of the structure while preserving the historical fabric. I would also consider redesigning some of the tribunes as seating areas for modern use, which could also accommodate concerts or performances.</p> <p>Using digital reconstruction technologies, I would visualize lost details, allowing visitors to "travel through time" in an interactive experience. This would help preserve the building while making it more accessible to the public."</p>

<b>3. Which materials would you use for the restoration?</b>
<b>Model 1 (OpenAI-GPT-4o):</b>
"If I were to restore the Colosseum, I would select materials that both preserve its historical authenticity and enhance its durability. The primary material I would use is travertine stone, as it was the original building material. Missing or damaged stones would be replaced with travertine of similar physical and chemical properties. I would use hydraulic lime mortar, mimicking the characteristics of the opus caementicium (Roman concrete), to strengthen the materials and minimize potential cracking over time. For metals, since iron fasteners in the original structure have deteriorated, I would use stainless steel or titanium alloy anchors, which are corrosion-resistant and will help preserve the structural integrity long-term. To protect stone surfaces from further damage due to air pollution and acid rain, I would apply nanotechnology-based protective coatings. These materials protect the stone without altering its natural appearance. Alternatively, I would consider using bioremediation to promote self-healing of the stone using calcite-based protectors, which offer sustainable long-term solutions. I would also consider using composite stone materials for the restoration of missing details, which would mimic the natural stone while providing enhanced durability through modern production techniques."
<b>Model 2 (Google DeepMind-Gemini):</b>
<p>"If I were tasked with restoring the Colosseum today, I would combine traditional materials with modern techniques to balance durability and aesthetics. The original materials used in the Colosseum—travertine, tuff, brick, and concrete—would still be central to the restoration. However, I would also incorporate modern engineering materials such as high-performance concrete, steel reinforcements, and composite materials to enhance resistance to earthquakes, erosion, and other environmental factors. Travertine would remain essential for preserving the original appearance of the structure. However, to increase resilience, I would also use lightweight composite materials to reduce the structure's weight and improve earthquake resistance. In place of the original mortar, I would use modern chemical-enhanced mortar that is more resistant to water and moisture.</p> <p>During restoration, I would utilize 3D scanning and modeling technologies to restore missing parts and ensure the structural integrity is maintained without compromising the historical appearance. This would help preserve the Colosseum's ancient grandeur while ensuring it is safe and durable for future generations."</p>





5.1.1. Expected Outcomes and Visualization of the Restoration

In this study, which aims to create visualizations related to the restoration process of the Colosseum, specific focal points have been identified based on the responses provided by two different artificial intelligence models. In this regard, the data presented by both models have been analyzed with the goal of generating visual representations of the restoration process (Table 5.2).

Table 5.2. Analysis of the Restoration Process of the Colosseum in Rome Through Artificial Intelligence Models (Yeşil, 2025)

<b>Model 1 (OpenAI-GPT-4o):</b>
"During the reinforcement of the arches and walls located on the northern facade of the Colosseum, efforts were made to preserve the original travertine stones, with missing sections being completed using materials compatible with the structure. On the southern facade, without undertaking a holistic reconstruction of the building, the existing remains were supported with appropriate protective interventions. Additionally, the hypogeum

(underground tunnels) was restored using controlled structural reinforcement techniques designed to minimize the risk of collapse, while prioritizing the preservation of historical details. Finally, to protect the stone surfaces from degradation caused by air pollution and acid rain, surface protection applications were carried out using biomineralization techniques."

<b>Restoration of the Colosseum with Model 1:</b>	
	
<b>Model 2 (Google DeepMind-Gemini):</b>	
<p>"The restored Colosseum in its magnificent and completed form. In this scene, reflecting the grandeur of Ancient Rome, all structural elements have been carefully reinforced and repaired. The arches, vaults, and walls have been restored in adherence to the original stone craftsmanship, with missing travertine stones replaced, and the structure has regained its former splendor."</p>	
<b>Restoration of the Colosseum with Model 2:</b>	
	

5.2. Philadelphia, Independence Hall

Independence Hall is a monument located in the city of Philadelphia, Pennsylvania, in the United States, and is considered one of the most significant structures in American history. The construction process began in 1732 and was completed in 1753. During the 18th century, the building served as the central hub of the American independence movement, hosting political and legal developments, thus playing a critical role in the country’s founding process. Notably, the adoption of the Declaration of Independence on July 4, 1776, and the preparation and ratification of the United States Constitution here in 1787 are key elements that cement the historical importance of the structure.

Architectural Features and Structural Dimensions

**Dimensions:** The building measures 41 meters in length, 14 meters in width, and approximately 13 meters in height.

**Architectural Style:** It was designed in the Georgian architectural style.

**Construction Materials:** It was built using red brick, wood, and stone materials. (Education & Sites, 2000).



Figure 5.2.. United States, Independence Hall (Yeşil, 2025)

Independence Hall is considered one of the most meticulously preserved structures in the United States due to its historical and cultural significance. To ensure the preservation and sustainability of the building, the National Park Service (NPS) conducts regular maintenance and conservation efforts. In this context, periodic assessments are carried out to maintain the original architectural features of the building and to prevent structural deterioration that may occur over time. The most recent large-scale restoration of Independence Hall was completed in the 1950s, and today, conservation processes continue within the framework of modern techniques and conservation principles.

To preserve the current state of Independence Hall, its structural and aesthetic integrity has been evaluated using various analytical methods. In this regard, artificial intelligence-based analytical techniques were employed to assess whether the building requires restoration. The study utilized two different artificial intelligence models to conduct independent evaluations, and through these models, the physical condition of the building was thoroughly analyzed. The models made inferences regarding the current state of the historic building and its potential conservation needs, providing assessments on whether restoration is necessary (Table 5.3).

Table 5.3. Analysis of the Current Condition of Independence Hall in the United States through Artificial Intelligence Models

Question 1: Does Independence Hall require restoration?
Model 1 (OpenAI-GPT-4o):
"No, Independence Hall does not currently require extensive restoration. Regular maintenance and improvement efforts are sufficient to preserve the historical fabric of the structure."
Model 2 (Google DeepMind-Gemini):
"No, Independence Hall does not currently have an urgent need for restoration."

5.3. Istanbul, Hagia Sophia

Hagia Sophia is a monumental structure located in Istanbul’s Historic Peninsula, with significant architectural and cultural importance. Used for different functions throughout the Byzantine, Ottoman, and modern periods, it holds great historical value. Originally built by Byzantine Emperor Justinian I between 532 and 537, Hagia Sophia served as the largest church in the Christian world for nearly 1,000 years. After the conquest of Istanbul

by the Ottoman Empire in 1453, it was converted into a mosque, then into a museum in 1935, and later reopened as a mosque in 2020 (Amjad-Ali, 2021).

Architectural Features and Structural Dimensions

- **Dimensions:** The building measures 100 meters in length, 70 meters in width, and 55.6 meters in height. The diameter of the dome is approximately 31 meters.
- **Architectural Style:** Designed in the Byzantine architectural style.
- **Construction Materials:** The building was constructed using marble, stone, brick, and special mortar. Lightweight bricks were imported from Rhodes for the dome, and columns were sourced from various ancient cities (Sqour, 2016).

Hagia Sophia stands as a bridge between Eastern and Western cultures and is recognized as a world heritage site in terms of its architectural, historical, and artistic value. Both during the Byzantine and Ottoman periods, it employed the most advanced engineering techniques of its time, making it a significant structure in the history of architecture.

To determine the restoration needs of Hagia Sophia’s 1,488-year-old historical structure, a comprehensive analysis was conducted using two different artificial intelligence models. In this process, the building’s current structural condition, material durability, and environmental influences were evaluated based on various parameters. The artificial intelligence models were asked, “Does Hagia Sophia require restoration?” Additionally, the models were presented with the question, “If you were restoring this structure, which sections would you restore and why?” The models provided various responses. To determine which materials should be used in Hagia Sophia’s restoration, both artificial intelligence models were asked the same question, but each developed recommendations using different data sets and analysis methods (Table 5.4).

Table 5.4: Analysis of the Current Condition of Hagia Sophia in Istanbul through Artificial Intelligence Models

Question 1: Does Hagia Sophia require restoration?
Model 1 (OpenAI-GPT-4o):
"Yes, Hagia Sophia requires restoration. Having hosted various civilizations over the centuries, this structure has undergone a natural process of wear due to the effects of time and environmental factors. Given its historical and cultural value, preserving the building and passing it on to future generations is a significant responsibility. Therefore, restoration work should be carried out using scientific methods without damaging its original architecture and artistic details. During the restoration process, preserving both the aesthetic and structural integrity of the building should be prioritized, with a meticulous approach carried out by expert teams. In this way, Hagia Sophia's historical identity can be preserved, ensuring it remains intact for many years and is passed down to future generations."
Model 2 (Google DeepMind-Gemini):
"The restoration of Hagia Sophia is an inevitable necessity to enhance the physical durability of the structure, preserve its historical fabric, and pass it on to future generations. Given the risks posed by earthquakes, material degradation, and human-induced damage, it is crucial that ongoing efforts continue with scientific rigor and precision. Although there may be public speculations due to the length and complexity of the process, the need for restoration is an essential requirement."



<b>Question 2: "If you were restoring this structure, which sections would you restore and why?"</b>
<b>Model 1 (OpenAI-GPT-4o):</b>
<p>"If I were restoring Hagia Sophia, my primary focus would be on strengthening the structural stability of the building and preserving its historical fabric. First and foremost, the main dome would be the area of greatest intervention. Having been repaired several times throughout history, the dome requires a detailed engineering analysis due to the cracks and disruptions in the load balance that have developed over time. To ensure it is unaffected by earthquakes and to provide long-term stability, I would reinforce it with lightweight but durable materials and conduct work to enhance the load-bearing capacity of the supporting arches. Additionally, I would assess the large buttresses added during the Ottoman period to ensure the structure maintains a balanced load distribution.</p> <p>Inside the building, mosaics, frescoes, and calligraphic works are among the most delicate elements that must be preserved. Due to damage caused by humidity, air pollution, and previous interventions, I would implement special conservation efforts and develop systems to balance the humidity. Specifically, I would aim to clean and stabilize the Byzantine mosaics found in the dome and side walls using non-invasive techniques to achieve the best result with minimal intervention. To prevent further deterioration of the mosaics, I would establish climate control systems to maintain the temperature and humidity balance inside the building.</p> <p>The floor has also been significantly worn, with subsidence occurring in some areas. The marble flooring of Hagia Sophia has been exposed to millions of visitors over the centuries, leading to considerable wear. I would ensure that the subsided or cracked marble is replaced with materials matching the original, and I would develop methods to preserve structurally damaged stones in place. With modern technologies, I would use laser scanning methods to create a digital map of the floor, ensuring the original positioning of each stone is maintained.</p> <p>When it comes to the exterior, Hagia Sophia's walls are highly vulnerable to environmental damage. Due to wind, rain, temperature fluctuations, and air pollution, significant erosion and biological contamination (such as moss, fungi, and mold) can be seen on the stone surfaces. I would use the most appropriate methods to clean and protect the exterior surfaces without causing further damage. Furthermore, I would conduct a detailed analysis of the existing supporting buttresses added during the Ottoman period and perform strengthening work to ensure structural integrity.</p> <p>The minarets are also significant sections in need of restoration. Over time, the stone blocks of the four minarets have suffered erosion and cracking, necessitating detailed inspection. First, the load-bearing systems of the minarets should be analyzed, necessary strengthening should be carried out, and the damaged stones should be replaced with the most suitable natural stones matching the original. Considering the critical role the minarets play in the building's overall aesthetic and static balance, I would ensure they are restored in a way that preserves both their structural and visual integrity.</p> <p>Lastly, I would focus on water insulation, one of the most significant problems. Over time, water seepage has occurred in the foundations and walls of Hagia Sophia, damaging both the structural system and the artistic works inside. To prevent moisture-related deterioration, I would strengthen the foundation's insulation and reconfigure the water drainage systems. Throughout this process, my priority would be to use modern engineering techniques to ensure maximum protection with minimal intervention, without damaging the historical and cultural identity of the structure."</p>



<b>Model 2 (Google DeepMind-Gemini):</b>
<p>"In the process of restoring Hagia Sophia in Istanbul, my primary goal would be to preserve the historical layers and original materials of the building. The first area I would focus on is the exterior restoration carried out in the 1950s using concrete. Over time, concrete has trapped moisture, leading to the deterioration of the Byzantine-era bricks and mortar. Therefore, I would ensure that concrete is replaced with traditional materials, such as hydraulic lime mortar, in line with the original structure. Additionally, cleaning and consolidation efforts would be important to preserve the stone and brick textures on the façade.</p> <p>In the second phase, I would examine the deformations in the main dome and pendentives. Considering the earthquake risk, it would be critical to strengthen the dome's load-bearing system and use techniques compatible with the light materials used in the Byzantine era. The mosaics and frescoes inside, which have suffered damage from humidity and human-induced factors, would require careful attention. In these areas, I would implement solutions to improve humidity insulation and prevent microorganism growth by ensuring a balanced climate. Additionally, the restoration of the calligraphy plaques and wooden panels from the Ottoman period would be important for preserving the building's multi-layered identity.</p> <p>Lastly, I would focus on improving the foundation and drainage systems surrounding the building to prevent water seepage. This would be a crucial step for long-term preservation. During this process, I would aim to balance both aesthetic and structural integrity based on scientific methods derived from archaeological and architectural findings."</p>
<b>Question 3: "If you were restoring Hagia Sophia, which materials would you choose?"</b>
<b>Model 1 (OpenAI-GPT-4o):</b>
<p>"If I were restoring Hagia Sophia, I would select materials based on principles of preserving the historical fabric, enhancing structural durability, and ensuring long-term protection. For strengthening the main dome and supporting arches, I would opt for lightweight, high-strength composite materials that are compatible with the original brick systems used during the Byzantine and Ottoman periods but produced using modern engineering techniques. To optimize the load distribution without increasing the building's weight, I would use carbon fiber-reinforced polymer (CFRP) systems to enhance the durability of the dome and arches. This would allow for structural reinforcement without damaging the building's historical fabric, while also ensuring long-term durability.</p> <p>In restoring the mosaics and frescoes in the interior, I would use non-invasive laser cleaning techniques to remove dirt and oxidation without harming the mosaics. For missing sections, I would use natural mineral paints that match the original pigments and reinforce them with micro-injection techniques using binding materials. Additionally, to prevent damage from humidity on the mosaics, I would apply hydrophobic yet breathable protective coatings to safeguard the surfaces.</p> <p>For the restoration of the marble flooring, I would use natural stone materials that are closest to the original ones, such as Proconnesos (Marmara Island) and Afyon marble. I would complete missing sections and restore the integrity of the floor. In areas with significant wear, I would use micro-sanding and low-pressure water abrasion techniques, free of chemicals, to clean the marble while preserving its natural texture. For voids under the floor, I would use injection methods with natural hydraulic lime-based mortars to maintain structural integrity.</p> <p>For the preservation of the exterior and stone walls, I would employ non-invasive cleaning</p>

methods (such as laser cleaning, dry ice blasting, and low-pressure sandblasting) to protect the building's original stone texture. To complete missing or eroded stones, I would use travertine, limestone, or granite-based natural stones that closely match the original texture. To ensure long-term preservation, I would apply breathable stone protective coatings that prevent biological growth and enhance surface durability while protecting it from atmospheric factors.

For strengthening the minarets, I would use high-strength lime-based mortars while adhering to traditional stoneworking techniques. To increase the static stability of the minarets, I would apply stainless steel anchoring systems where necessary, but these interventions would be designed to be invisible from the outside.

Regarding water insulation and drainage systems, to prevent moisture and water seepage—one of the most significant threats—I would develop the most suitable water drainage and drainage systems based on geotechnical analyses. To strengthen the foundation insulation, I would use special natural coatings that are breathable yet waterproof (such as natural lime-based waterproofing systems), which would protect the foundation while maintaining the building's breathability and ensuring proper moisture balance.

Throughout the selection of materials, I would prioritize those that are faithful to the historical fabric and reversible. During the restoration process, I would aim to integrate natural stones, lime-based mortars, and high-tech materials that can blend with the historical fabric of Hagia Sophia, ensuring its proper and durable transmission to future generations."

**Model 2 (Google DeepMind-Gemini):**

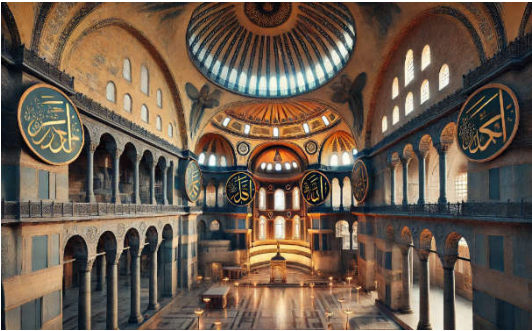

"While restoring Hagia Sophia, my primary aim would be to preserve the historical and architectural identity of the structure by staying as true as possible to the original materials. On the exterior, in order to address the moisture and crack issues caused by the concrete used in the 1950s, I would base my approach on Byzantine-era techniques. For instance, instead of concrete, I would use mortar made from lime, sand, and crushed brick (horasan mortar) to reinforce the walls. This material, with its breathable structure, would balance the moisture, prolong the lifespan of the stone and brick, and preserve the aesthetic integrity of the building. Additionally, to replace missing or damaged stones on the façade, I would prefer natural stones (such as Marmara marble) and handmade bricks that are consistent with the original materials. This would ensure the preservation of the historical fabric while preventing the harsh appearance of modern interventions.

For the mosaics and frescoes in the interior, I would use lime-based plasters and natural pigments. Instead of chemical paints, I would restore the colors using pigments with organic binders such as egg whites or beeswax, in the same manner as during the Byzantine period. This method would enhance the brightness and durability of the mosaics while facilitating future restorations. Furthermore, for the calligraphy plates and wooden craftsmanship from the Ottoman period, I would select materials produced using traditional techniques, such as walnut wood and gold leaf. Particularly for the wooden elements, I would use natural resin-based preservatives to prevent moisture and insect damage, reflecting the multicultural heritage of the structure.

For structural reinforcement, I would employ modern yet discreet techniques, such as light steel wires or carbon fiber supports, for the dome and arches. However, these interventions would be concealed behind the original stone and brick to maintain the aesthetic integrity. In the foundation and drainage system, I would use geologically compatible drainage pipes and clay-based insulation materials to prevent subterranean water from damaging the structure. As a result, by blending both traditional and scientific methods, my goal would be to carry Hagia Sophia's thousand-year-old story into the future."

5.3.1. Expected Outcomes and Visualization of the Restoration

This study aims to create visualizations related to the restoration process of Hagia Sophia, by evaluating the data provided by two different artificial intelligence models and identifying specific focal points. In this context, the goal was to generate visuals reflecting the restoration process based on the analyses of both models (Table 5.5): Table 5.5: Analysis of the Restoration Process of Hagia Sophia in Istanbul through Artificial Intelligence Models (Yeşil, 2025)

<b>Model 1 (OpenAI-GPT-4o):</b>	
<p>"The visual should depict the completed restoration of Hagia Sophia. The main dome and supporting arches must be reinforced, all cracks repaired, and structural stability ensured. In the interior, Byzantine mosaics and Ottoman calligraphy should be restored, radiating with vibrant colors. The marble floor should have regained its former grandeur, with all cracks and wear removed. On the exterior, the stone surfaces should be cleaned, biological contamination eliminated, and original details preserved. The minarets should be reinforced and complement the aesthetic integrity. The lighting system should highlight the building's grandeur while preserving the historical atmosphere. The visual should reflect a successful restoration in which modern engineering harmonizes with traditional craftsmanship, and the historical fabric is preserved."</p>	
<b>Restoration of the Colosseum with Model 1:</b>	
	
<b>Model 2 (Google DeepMind-Gemini):</b>	
<p>"Create a realistic and detailed digital visualization. The visual should depict the completed restoration of Hagia Sophia. On the exterior, the concrete coatings should be removed, and the original stone and brick texture should be reinforced with horasan mortar. The surfaces should be cleaned, historical details preserved, and the façade should stand out with its natural texture. The main dome and pendentives should be reinforced against earthquake risk, ensuring structural stability, and should rise magnificently."</p>	
<b>Restoration of the Colosseum with Model 2:</b>	



## 6. CONCLUSION

The preservation and restoration of historic buildings is a complex process that requires interdisciplinary collaboration, aimed at ensuring the sustainable transmission of cultural heritage to future generations. While traditional restoration methods are largely based on expert opinions, physical examinations, and information derived from historical documents, the development of digital technologies today allows restoration processes to be approached in a more systematic, data-driven, and analytical framework. In this context, artificial intelligence-supported techniques, particularly through data analysis, image processing, and machine learning algorithms, enable restoration processes to be conducted with higher precision.

This study examined the integration of artificial intelligence technologies into restoration processes and assessed their contributions in detail. AI-based analyses can be effectively utilized in critical processes such as material identification, surface damage detection, modeling the decay rates of building components, and optimizing intervention methods. Especially through computer vision techniques, it has become possible to analyze the surface textures of historic buildings in detail and create damage detection maps, thus enabling the restoration process to be based on a more systematic and data-driven approach. Additionally, big data analyses and AI-supported optimization techniques allow for the determination of the most appropriate intervention methods based on data derived from the restoration of similar structures, enhancing the long-term sustainability of restoration practices.

To enhance the effectiveness of AI-supported restoration applications and ensure the production of sound results, it is crucial to meet some fundamental requirements. Firstly, comprehensive and reliable datasets must be established to improve the accuracy of AI models for historic building restoration. Moreover, it is essential to consider ethical principles and international conservation standards in the integration of AI into restoration processes. AI should not be viewed solely as a tool for ensuring technical accuracy but should also be supported by interdisciplinary collaborations that safeguard the historical and cultural context.

Furthermore, differences between AI-based systems must be taken into account. Two different AI models trained with the same dataset and parameters may offer similar but distinct recommendations for the restoration process. This difference arises from the inherent algorithmic structures of AI models, parameter optimizations during learning processes, and their interpretive capabilities in data analysis. For instance, a model using computer vision techniques might rely on a deep learning network to detect surface damage, while another model may analyze the same data using a different machine learning algorithm. As a result, both models may make similar predictions regarding the location and general size of the damage, but one model might more accurately identify material degradation, while the other might excel at detecting surface deformations. These differences highlight the critical importance of model selection and accuracy analysis in the integration of AI technologies into restoration processes.

In this context, for AI usage in restoration processes to be successful, it is necessary to compare the outputs of different models, analyze their accuracy rates in detail, and guide model selection processes based on scientific data. When advanced AI models are trained with larger and more diverse datasets, they will be able to analyze the physical and material properties of historic buildings in greater detail and significantly enhance the accuracy of restoration processes.

The integration of AI technologies into the field of restoration has the potential to provide more precise, scientific, and sustainable solutions compared to traditional methods. However, the adaptation of these technologies into restoration processes should be approached with a holistic perspective that includes technical, ethical, and interdisciplinary evaluations. The widespread adoption of AI in restoration processes will enable interventions aimed at preserving historic buildings to be conducted in a more systematic, data-supported, and long-term conservation-oriented manner. In this regard, the increased academic research in the development and application of AI-supported restoration approaches will create a qualified and sustainable transformation in the preservation of cultural heritage.

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