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PERFORMANCE ANALYSIS OF ARTIFICIAL INTELLIGENCE TOOLS IN DIGITIZATION OF LOST CULTURAL HERITAGE: SARAY-I AMIRE

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ABSTRACT: The digitization of cultural heritage plays a critical role in the preservation of historical artifacts and their transmission to future generations. This study focuses on the digital reconstruction of the *Saray-ı Amire* in Manisa, a lost architectural structure from the Ottoman period, and evaluates the performance of artificial intelligence (AI) tools throughout this process. Traditional modeling techniques are compared with AI-based algorithms in terms of accuracy, speed, and level of detail. Data derived from archival documents, historical maps, engravings, and analogous structures were utilized to assess the accuracy of AI-generated models using metrics such as the Structural Similarity Index (SSIM) and Root Mean Square Error (RMSE). The findings reveal that while AI tools enable rapid modeling workflows, they present certain limitations in accurately capturing architectural details. The study advocates for the adoption of hybrid methodologies in the digitization of cultural heritage and discusses both ethical and technical issues involved in digital restitution processes. Ultimately, while Prome AI was effective in generating visual textures, Fabrie AI produced more precise and analytical results, yielding geometrically detailed reconstructions. However, both tools demonstrated limitations in preserving historical accuracy and faithfully reflecting architectural intricacies. Thus, alongside the efficiency and speed offered by AI technologies, the study emphasizes the continued importance of human intervention through hybrid approaches.

Keywords: Lost Cultural Heritage, Artificial Intelligence, Architectural Visualization, Saray-ı Amire

KAYIP KÜLTÜREL MİRASIN DİJİTALLEŞTİRİLMESİNDE YAPAY ZEKÂ ARAÇLARININ PERFORMANS ANALİZİ: SARAY-I AMİRE

ÖZET: Kültürel mirasın dijitalleştirilmesi, tarihî eserlerin korunması ve gelecek nesillere aktarılması açısından kritik öneme sahiptir. Bu çalışma, Osmanlı dönemine ait ve günümüze ulaşmamış bir yapı olan Manisa'daki Saray-ı Amire'nin dijital rekonstrüksiyonunu ele almakta ve bu süreçte yapay zeka (YZ) araçlarının performansını değerlendirmektedir. Geleneksel modelleme teknikleri ile YZ tabanlı algoritmalar karşılaştırılmakta; doğruluk, hız ve detay seviyesi açısından incelenmektedir. Arşiv belgeleri, tarihî haritalar, gravürler ve benzer yapılar gibi kaynaklardan elde edilen veriler kullanılarak, YZ araçlarıyla oluşturulan modellerin doğruluğu, Yapısal Benzerlik İndeksi (SSIM) ve Kök Ortalama Kare Hatası (RMSE) gibi metriklerle analiz edilmiştir. Bulgular, YZ araçlarının hızlı modelleme süreçleri sunduğunu ancak mimari detayları doğru yakalama konusunda bazı sınırlamalar taşıdığını ortaya koymuştur. Çalışma, kültürel mirasın dijitalleştirilmesinde hibrit metodolojilerin benimsenmesini önermekte ve dijital restitüsyon süreçlerindeki etik ve teknik meseleleri tartışmaktadır. Sonuç olarak, Prome AI görsel dokuları başarılı bir şekilde oluştururken, Fabrie AI ise daha hassas ve analitik sonuçlar sunarak geometrik detaylara yakın sonuçlar elde etmiştir. Ancak her iki araç da, tarihî doğruluğun korunması ve mimari detayların doğru yansıtılması konusunda sınırlamalar taşımaktadır. Bu nedenle, YZ araçlarının sağladığı hız ve verimliliğin yanı sıra, hibrit yöntemlerle insan müdahalesinin de önemli olduğu vurgulanmaktadır.

Anahtar kelimeler: Kayıp Kültürel Miras, Yapay Zeka, Mimari Görselleştirme, Saray-ı Amire,

INTRODUCTION

Cultural heritage encompasses historical and artistic values that have been passed down from the past to the present and play a fundamental role in the preservation of social identity. The protection of cultural heritage not only ensures the continuity of historical knowledge, but also enables the transfer of the past to the future (Özkut, 2008). Especially buildings and artifacts that are in danger of extinction should be preserved not only for their physical but also for their social, aesthetic and symbolic meanings. The digitization of cultural heritage not only makes it accessible to a wider audience, but also contributes to academic research (Zhang et al., 2023). While digital preservation processes help to visualize and document cultural heritage, they also bring problems such as data gaps, misinterpretation and technological sustainability (Conway, 2010; Özkut, 2008).

Developing technologies in recent years offer new possibilities in the documentation and conservation of cultural heritage. Digital modeling, augmented reality (XR), virtual reality (VR) and 3D scanning techniques provide important solutions for cultural heritage conservation (Hutson et al., 2023). Thanks to these technologies, lost or damaged cultural heritage elements can be revived and analyzed in more detail (Melloni, 2018; Altay, 2023). For example, the virtual reconstruction of the Roman Theater of Palmyra was carried out using high-resolution panoramic photographs and global photogrammetry (Forte et al., 2024). However, in such digital reconstruction processes, historical accuracy must be ensured and scientific methodologies must be followed (Özkut, 2008; Poulopoulos & Wallace, 2022). Artificial intelligence (AI) based tools are increasingly used in the field of cultural heritage digitization. AI algorithms offer significant advantages to complete missing data, analyze damaged structures and perform restitution of lost structures (Duarte, 2024). Using metrics such as Structural Similarity Index (SSIM) and Root Mean Squared Error (RMSE), the historical accuracy of AI-assisted models is evaluated (Bakurov et al., 2022). However, limitations of AI models such as biases and speculative reconstructions in training datasets should also be considered (Liang & Huang, 2022). Although there are many studies in which AI technologies contribute to the documentation of cultural heritage, it is also noted that compared to traditional modeling methods, they may not accurately reflect detailed architectural features and interpretations may be detached from the historical context (Tiribelli et al., 2025; Zhang et al., 2022). Therefore, it is of great importance to use artificial intelligence in the digitization of cultural heritage, taking into account its ethical and technical limits (Özkut, 2008; Vuoto et al., 2023).

Research shows that traditional methods are being combined with modern technologies in the documentation, conservation and restitution of cultural heritage. Difficulties arising from incomplete historical records, physical deterioration and structural changes are being overcome with advanced digital tools (Karasakal, 2022; Otyakmaz, 2022). Various studies on religious, military, commercial and civil buildings have contributed to the restitution of historical buildings using techniques such as archival documents, photogrammetry and laser scanning (Boyacıoğlu, 2018; Özsavaşcı et al., 2018).

In recent years, digital reconstruction projects have come to the fore, and augmented reality (AR), virtual reality (VR) and artificial intelligence-supported modeling methods have enabled the revitalization of lost cultural heritage (Forte et al., 2024). For example, a virtual model of the Roman Theater of Palmyra was created with photogrammetry, and 3D digital reconstructions of historical settlements such as Gülbahçe were made (Tabur, 2024). However, existing studies have identified limitations such as data gaps, historical accuracy issues, and biases in AI models (Duarte, 2024). This thesis aims to develop a hybrid methodology for the restitution of lost cultural heritage by comparing manual modeling with AI-assisted techniques and considers the digital reconstruction of the Saray-ı Amire in this context.

This research aims to evaluate the reliability and accuracy of AI-based methods in the digital restitution process of lost cultural heritage. The study seeks answers to questions such as "To what extent can digital models preserve the historical, aesthetic and social values of cultural heritage?" and "How effective is AI-assisted restitution compared to manual modeling methods?". Using quantitative measures such as Structural Similarity Index (SSIM) and Root Mean Squared Error (RMSE), the historical accuracy of AI-assisted models will be evaluated and compared with traditional modeling techniques. In this context, the research aims to contribute to the literature both theoretically and methodologically. By comparing traditional modeling methods with artificial intelligence-based approaches, a comprehensive evaluation to determine the most appropriate methods in digital restitution processes is presented in the case of Manisa Saray-ı Amire.

METHODOLOGY

According to Figure 1 the methodological framework begins with comprehensive documentation, which serves as the foundational stage for subsequent processes. This documentation informs the development of a sustainable and flexible spatial database, enabling the systematic organization and management of spatial data relevant to cultural heritage.

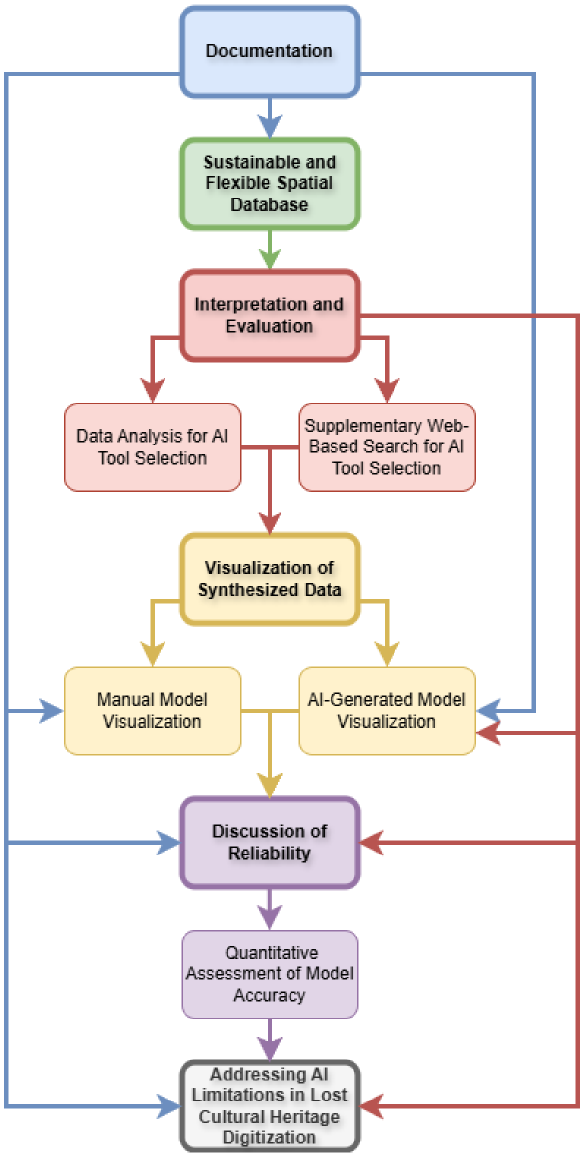

Figure 1 Method Flowchart

Following this, the process advances to the interpretation and evaluation phase, which bifurcates into two key sub-processes: data analysis for AI tool selection and supplementary web-based searches aimed at identifying the most appropriate AI tools for modeling tasks. These inputs converge at the visualization of synthesized data, where the integrated data is used to produce two distinct outputs: manual model visualization and AI-generated model visualization. Both visualization methods feed into a critical discussion of reliability, which examines the trustworthiness and potential discrepancies between manual and AI-generated outcomes. This discussion is further substantiated by a quantitative assessment of model accuracy, providing empirical validation of the models' precision. Finally, the process culminates in addressing AI limitations in the digitization of lost cultural heritage, reflecting on the broader implications and challenges of utilizing AI technologies in heritage preservation. Notably, feedback loops within the flowchart suggest a dynamic and iterative process, emphasizing the importance of continuous evaluation and refinement across each stage. (Figure 1)

The methodology of this study is based on a comprehensive analysis of primary sources (Ottoman archival documents, old maps) and secondary sources (academic studies, historical research) during the data collection process. The existing ruins of Saray-ı Amire were examined and comparative analyses were made with structures from similar periods. The collected data was digitized and integrated into a spatial database. The digital modeling process followed two main approaches: manual modeling and AI-assisted modeling

In this phase, the accuracy of architectural models of Saray-ı Amire—both manually created and AI-generated—was evaluated using quantitative methods. The analysis aimed to objectively assess the adherence of the models to documented historical and architectural features in terms of visual and structural similarity. Two primary metrics were employed: Structural Similarity Index (SSIM) and Root Mean Square Error (RMSE). SSIM is a perceptual metric that measures structural similarity between two images by considering components such as luminance, contrast, and structure. It yields a value between -1 and 1, with 1 indicating perfect similarity. In this study, grayscale versions of the rendered images were compared using Python and the skimage.metrics library, and SSIM values were computed for each pair. Higher SSIM scores indicated a stronger resemblance of the AI-generated model to the manually produced reference (Bakurov et al., 2022). On the other hand, RMSE measures the pixel-wise differences between two images, reflecting the average magnitude of error. Lower RMSE values imply closer visual similarity. The numpy library in Python was used to calculate RMSE, and all images were resized to identical dimensions prior to comparison. RMSE is widely utilized in fields such as digital watermarking, remote sensing, and medical imaging to assess image quality (Bindu et al., 2018; Kumar & Srinivasan, 2012; Liang & Huang, 2022). By using SSIM and RMSE together, this study provided a robust and systematic evaluation of the fidelity of AI-generated models compared to manually constructed ones.

Data Collection and Documentation Process

Data collection was conducted through a comprehensive analysis of primary and secondary sources:

1. Primary sources: Ottoman archival documents, old maps, architectural drawings and Ottoman chronicles
2. Secondary sources: Academic studies on Ottoman palace architecture, historical research and cultural heritage conservation projects were reviewed

In addition, the surviving ruins of the Saray-ı Amire were examined, but since it is largely destroyed, comparative analyses were made with similar structures such as the Edirne Palace. All collected data was digitized and integrated into a sustainable and flexible spatial database.

Digital Reconstruction Process

The digital modeling process was carried out with two main methods:

1. Manual 3D Modeling:
    - Created using SketchUp and Lumion.

  - Measurements and data from historical documents are integrated into the model.
  - Accuracy was assessed by structural similarity analysis (SSIM) and error measures (RMSE).
2. Artificial Intelligence Assisted Modeling:
  - Automatic modeling was done with tools such as Prome AI, Fabrie AI, DesignerSense AI.
  - The obtained images were compared with manual models and the margin of error was analyzed.
  - The success of artificial intelligence tools in capturing architectural details is examined.

Evaluation Criteria

In the research, two main measurement methods were used to evaluate the differences between AI-supported modeling and manual modeling:

1. Structural Similarity Index (SSIM): Used to measure the similarity between manual and AI-generated models.
2. Root Mean Squared Error (RMSE): It was applied to calculate the margin of error of the models created with artificial intelligence.
   In addition, ethical considerations were made during the modeling process, analyzing how faithful speculative reconstructions are to historical accuracy.

MATERIAL

Area And Scope Of The Study

This study focuses on the digital reconstruction of one of the Ottoman-era palaces, the Saray-ı Amire in Manisa, which is now completely lost. The aim of the study is to examine the effectiveness and accuracy of artificial intelligence-based modeling tools in the preservation of cultural heritage. The research focuses on archival documents, engravings, old maps, architectural plans and common features of Ottoman palaces, aiming to create the most realistic model in terms of historical accuracy.

Saray-ı Amire was built in Manisa during the Ottoman period as a center where princes were educated and important administrative decisions were made. Started in the mid-15th century during the reign of Murad II, the palace was expanded during the reign of Mehmed II (Mehmed the Conqueror) and played an important role in the social and political structure of Manisa (Uluçay, 1941). In addition to being an administrative center where princes were educated, the palace is also noteworthy as a part of the sancak system implemented by the Ottomans in the provincial administration. However, with the abolition of the sanjak system in 1595, it fell out of use and was largely destroyed by fire during the War of Independence (Isa et al., 2018). Today, a large part of the palace has been destroyed and the physical presence of the building has largely disappeared, except for the Fatih Tower and the remains of a few baths (Figure 2). Today, the area where the palace was located is located within the Şehzadeler District of Manisa and includes Fatih Park, Cumhuriyet Square, and other monumental structures that reflect the past location of Saray-ı Amire (Gevorgyan etl al.; 2023).

Figure 2 Fatih Tower and bath remains

Other Materials

In the study, firstly, the architectural features of Saray-ı Amire were determined by scanning various written and visual sources. In the digital modeling process, artificial intelligence based tools such as Prome AI, mnml AI, Fabrie AI, DesignerSense AI, ArchiVinci AI, ReRender AI, Maket AI and Visoid AI were used. These tools were preferred to increase structural accuracy and ensure contextual relevance. SketchUp and Lumion software were used for modeling and rendering, and visual outputs were obtained. In addition, Python programming language was used as a supportive tool for data processing and analysis.

In the creating process, initially, a set of manually created images and corresponding descriptive prompts is prepared to establish a foundational dataset. This curated data serves as a reference for the model to begin learning meaningful associations between visual elements and textual descriptions. Subsequently, the dataset is expanded through the collection of large-scale image-text pairs, which are utilized to train the underlying generative model effectively.

FINDINGS

Comparison of Artificial Intelligence and Traditional Modeling Results

Figure 3 provides a detailed representation of the architectural and spatial characteristics of the Saray-ı Amire, presenting renderings generated by various AI tools. The design reflects the basic principles of Islamic architecture, including axial symmetry, a paved central courtyard and several functional buildings surrounded by colonnaded galleries. Stone and stucco are used on the façade, with curved openings, rectangular windows and detailed workmanship, especially at the entrances.

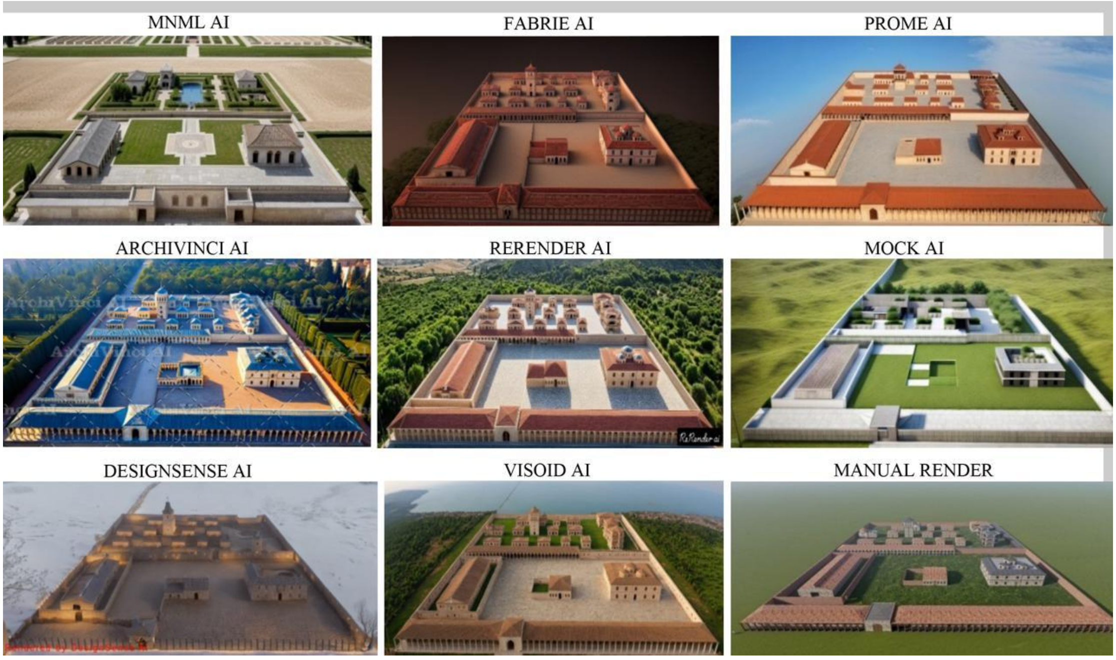

Figure 3 Renders produced by AI Tools

Roof structures vary from sloping tiled designs to flat surfaces and domes, providing both aesthetic and functional harmony. High perimeter walls provide privacy, while the landscape features geometric patterns and vegetation, creating a harmonious balance between building and nature.

The AI-generated renderings focus on green spaces and open spaces in some, while others emphasize the stone surfaces of the courtyard and minimal vegetation. Each AI tool emphasizes different features: MNML AI emphasizes symmetrical design and geometric landscaping; ARCHIVINCI AI highlights blue tiled roofs and large green spaces; FABRIE AI focuses on structural organization with red tiled roofs and minimal landscaping; Re RENDER AI depicts the paved courtyard and green spaces with a balance of open and enclosed spaces; PROME AI emphasizes spatial zoning with central courtyard and tower; MOCKET AI presents a simplified layout with central green space and single-storey units; DESIGN SENSE AI emphasizes material textures and spatial depth; VISOID AI shows a structural geometric layout with multi-domed structures.

Each rendering reflects the unique visual output of the respective AI tools, offering different perspectives on the design of the complex.

According to Table 1 evaluations using Structural Similarity Index (SSIM) and Root Mean Square Error (RMSE) revealed the success of the AI tools in architectural visualization. The highest SSIM score belongs to Prome AI with 0.656, indicating strong structural alignment. The lowest SSIM was seen in ReRender AI with 0.118, indicating significant structural differences. The lowest result in RMSE values was obtained by DesignSense AI with 9.55, indicating a more consistent density of pixels.

Prome AI and DesignSense AI excelled in terms of structural cohesion and pixel-level consistency, while ReRender AI and VISOID AI underperformed. Overall, while AI tools have potential in architectural visualization, there are challenges in photorealistic detail.

Table 1: SSIM and RMSE Analysis Results

AI Tool	**Orginal Model**	**AI Generated Model**	**Orginal Render**	**AI Generated Render**
	SSIM	RMSE	SSIM	RMSE
ArchiVinci AI	0.225	10.27	0.217	10.21
DesignSense AI	0.581	9.55	0.326	9.92
Fabrie AI	0.330	10.41	0.339	10.31
Model AI	0.387	10.38	0.272	10.33
MNML AI	0.347	10.03	0.252	10.27
Prome AI	0.656	10.62	0.332	10.30
ReRender AI	0.118	10.15	0.151	10.21
Visoid AI	0.390	10.08	0.300	10.25

Evaluation Of Artificial Intelligence Tools In Terms Of Time Efficiency And Acurracy

Artificial Intelligence tools provide a huge advantage in terms of time over manual modeling. For example, while Prome AI produced a model in only 9 seconds, Mnml AI was able to model in 151 seconds. However, it was emphasized that fast modeling processes often lead to loss of detail and therefore a hybrid approach is required.

DISCUSSION

The integration of artificial intelligence (AI) technologies in the field of architectural visualization and cultural heritage digitization shows significant potential by increasing efficiency and creativity in architectural practices (Ashraf et al., 2024; Hakimshafaei, 2023). Systems such as "Sketch-to-Architecture" demonstrate that AI tools transform the design process by enabling rapid iterations in the design process (Li et al., 2024). However, the use of AI in cultural heritage conservation for lost buildings often neglects fundamental architectural principles such as cultural context and sustainability while emphasizing aesthetic elements (Rashid, 2024).

The role of AI in cultural heritage conservation has also been explored with frameworks such as X-NR. This framework digitally reconstructs heritage sites using augmented reality and neural rendering techniques (Stacchio et al., 2024). However, despite the capacity of AI to capture spatial and visual elements, issues such as prompt engineering, biases in training datasets, and regional linguistic biases limit the accurate representation of cultural architectural styles (Sukkar et al., 2024).

AI tools such as PlantoGraphy incorporate iterative design principles, addressing shortcomings in traditional AI workflows (Huang et al., 2024). However, challenges remain in terms of proportional accuracy, multi-perspective consistency, and integration of these tools with existing architectural workflows (Li et al., 2024). AI appears to offer a wide range of applications, from reinterpretation of traditional motifs to future projects such as Mars habitats (Gür et al., 2024). Nevertheless, limitations in terms of data set diversity and controllability of the AI model suggest the need for continuous improvement and domain-specific training.

The example of Saray-ı Amire emphasizes the importance of basing AI applications on cultural, historical and architectural values (Özkut, 2008). An interdisciplinary collaboration of architects, historians, computer scientists and ethicists is required to overcome the limitations of AI and align it with cultural preservation goals. Furthermore, transparent documentation of AI workflows is crucial for maintaining trust with stakeholders such as local communities and heritage professionals.

RESULTS AND EVALUATION

The research revealed that AI-based tools offer speed and automation advantages in digital modeling processes, but have limitations in accurately capturing architectural details. In comparisons of AI models with traditional models, SSIM analyses showed a similarity of around 85%, while RMSE analyses indicated significant deviations in architectural elements. These results show that AI tools offer a time-saving solution for large-scale projects, but that human elaboration is still necessary.

Significant differences were also observed between the different AI tools used in the modeling process. While Prome AI was successful in creating realistic textures but had a high margin of error in geometric details, Fabrie AI provided more analytical and precise results and achieved results closer to architectural drawings. This emphasizes the need for caution in the selection of AI tools.

The success of the AI-supported models varies in terms of historical context, material choices and preservation of architectural details. Some models were able to preserve the spatial layout appropriate to Ottoman palace architecture, but there were deficiencies in material and ornamental details. In particular, aesthetic elements such as stone textures, arch details and woodwork could not be fully reflected. In addition, the tendency of some AI tools to integrate modern design elements into the historic building poses a risk to the accurate representation of cultural heritage.

When analyzing how data deficiencies affect artificial intelligence algorithms, the limited availability of historical documents directly affected the accuracy of the models. Due to the lack of full-scale plans of the Saray-ı Amire, comparative examples were used in the modeling process, but this compromised historical accuracy. Speculative reconstructions can lead to inaccurate or incomplete representations of cultural heritage; some AI tools have deviated from historical reality by suggesting designs that are inappropriate for Ottoman architecture. To avoid such deviations, we propose a hybrid approach in which historians, architects and AI experts work together.

The success of **Prome AI** and **DesignSense AI** is evaluated based on **SSIM** (Structural Similarity Index) and **RMSE** (Root Mean Square Error), which assess the accuracy of visual quality and proportion. Higher **SSIM** values indicate that the AI-generated model is structurally more similar to the original, while lower **RMSE** values suggest fewer pixel-wise discrepancies. In this context, **Prome AI** and **DesignSense AI** achieved higher **SSIM** values and more favorable **RMSE** scores, resulting in models that are closer to the original compared to other tools.

Finally, the dependence of artificial intelligence tools on the datasets they are trained on can lead to the risk of misinterpreting cultural heritage. Models trained with datasets predominantly based on Western architecture may suggest details that are inappropriate for Ottoman palaces. For this reason, it is suggested that the datasets on which artificial intelligence models are trained should be more diversified. All these findings show that AI-supported digital reconstruction projects should be cautious and should be supported by manual modeling methods. It is recommended that hybrid methods should be adopted, especially for the preservation of historical and cultural context.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the article.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

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