Applications of Digital Twins in Cultural Heritage: a Systematic Literature Review

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Abstract—This systematic literature review explores the current landscape of Digital Twins in the context of Cultural Heritage, focusing on their applications. By examining 57 papers, this review addresses how DTs enhance visitor experiences and preserve artifacts. The results are categorized into interactivity and visualization, preservation and restoration, and remote access, providing insights into the current state and future directions of Digital Twins in Cultural Heritage.

Index Terms—Digital Twin, Cultural Heritage, Systematic Literature Review

I. INTRODUCTION

Digital Twins (DT) presents a promising solution by providing a digital counterpart to physical artifacts and sites. This digital replica can be used for various purposes, such as monitoring the condition of artifacts, simulating restoration techniques, and creating immersive virtual experiences for education and tourism. Leveraging DT technology allows Cultural Heritage (CH) institutions to preserve artifacts more effectively and disseminate cultural knowledge more broadly [1].

Despite its potential, there is a lack of comprehensive studies systematically analyzing how DTs are utilized in this context. This review aims to fill this gap by providing a detailed analysis of the current applications of DTs in CH, highlighting successful implementations, and identifying areas for future research and development. Thus, this systematic literature review addresses the following main research question: *How have digital twins been used in the context of cultural heritage?*

This systematic literature review followed a structured approach [2] to identify, select, and analyze relevant studies on applying DTs in CH. A comprehensive search was conducted across several academic databases, including IEEE Xplore, ACM Digital Library, and ScienceDirect, using keywords such as "digital twin," "cultural heritage," "virtual modeling," and "heritage preservation." A total of 57 papers were selected for detailed analysis based on their relevance, quality, and contribution to the topic. The selected studies were then categorized and analyzed to address the research question. Figure 1 summarizes the details of the employed process, while the entire list of accepted papers can be found in our replication package[1].

II. DISCUSSION OF THE RESULTS

Digital Twins (DT) have been widely adopted in Cultural Heritage (CH) to enhance visitor experiences and preserve artifacts. The applications of DTs in CH can be broadly categorized into three areas: interactivity and visualization, preservation and restoration, and remote access.

A. Interactivity and Visualization

A significant majority of the studies (37 out of 57, 65%) highlight using DTs to create interactive and immersive experiences for visitors. These applications often involve *virtual tours*, *augmented reality (AR)*, and detailed *3D models* to provide engaging educational experiences.

- *Virtual Tours*: DTs enable virtual tours of CH sites, allowing users to explore historical locations remotely. These tours are enhanced with interactive elements, such as clickable information points and guided narratives, providing an in-depth understanding of the sites.
- *Augmented Reality (AR)*: AR applications overlay digital information onto the physical world, enhancing the visitor experience. For instance, visitors can use AR devices to see reconstructions of ruins in their original state.
- *3D Models*: Detailed 3D models of artifacts and historical sites provide an accurate and immersive way to study and appreciate CH. These models can be manipulated and examined from different angles, offering a deeper insight into the artifacts' features and significance.

The use of virtual tours and AR significantly enhances visitor engagement and education. These technologies provide a way to experience CH in a more interactive and immersive manner than traditional methods [3]. For example, virtual models of archaeological sites allow users to explore and interact with historical environments in a way that was previously impossible. This interactive approach helps maintain the authenticity and integrity of cultural artifacts while providing an innovative way to engage with history.

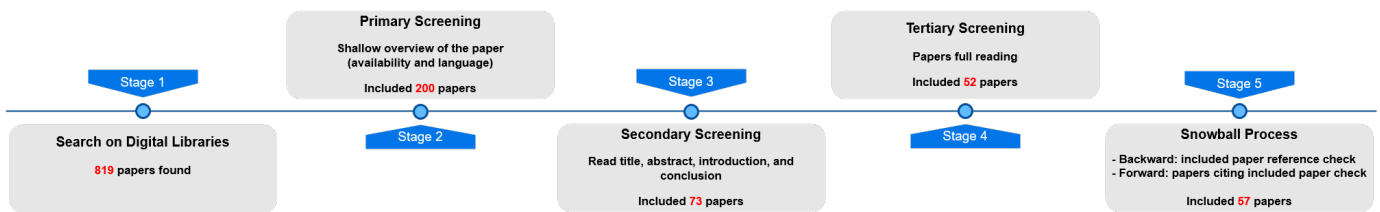[1]https://anonymous.4open.science/r/Digital- Twins-for-Cultural-Heritage-3CDC/README.md

Fig. 1. Process to conduct the Systematic Literature Review on Digital Twin in Cultural Heritage.

B. Preservation and Restoration

Half of the studies (28 out of 57 - 50%) focus on using DTs for the preservation and restoration of artifacts. By creating detailed digital replicas, conservators can plan and execute restoration projects with greater precision and minimal physical intervention.

- **Detailed Digital Replicas**: DTs enable the creation of highly detailed digital replicas of artifacts, which can be used for analysis and restoration planning. These replicas help conservators understand the artifacts' condition and identify areas that need restoration.
- **Simulation of Restoration Techniques**: DTs allow the simulation of various restoration techniques in a virtual environment before applying them to the physical artifact. This minimizes the risk of damage and ensures the most effective methods are used.
- **Condition Monitoring**: Continuous monitoring of artifacts through their digital twins helps detect any deterioration early. This proactive approach allows for timely interventions, ensuring the longevity of the artifacts.

DTs play a crucial role in the preservation and restoration of cultural artifacts. Creating detailed digital replicas allows conservators to plan and simulate restoration techniques, minimizing the risk of damage, [4]. Continuous condition monitoring through DTs ensures that any signs of deterioration are detected early, allowing for timely interventions. This proactive approach helps in preserving artifacts for future generations.

C. Remote Access

Approximately 20 (35%) of the studies emphasize the role of DTs in enabling remote access to CH sites. This is particularly beneficial for making CH accessible to a global audience, including those who cannot visit the physical sites.

- **Global Accessibility**: DTs make CH accessible to people worldwide, including those who may not be able to visit the sites in person. Virtual tours and online exhibitions allow a broader audience to experience and learn about CH.
- **Educational Outreach**: Remote access facilitated by DTs supports educational outreach programs. Schools and universities can use digital twins to teach students about CH, history, and preservation techniques.
- **Inclusivity**: DTs ensure that CH is inclusive and accessible to people with disabilities who might face challenges

visiting physical sites. Virtual experiences can be tailored to meet various accessibility needs, providing an equal opportunity for everyone to engage with CH.

One of the most significant benefits of DTs is their ability to provide remote access to CH. This democratizes access to cultural sites and artifacts, making them available to a global audience. Educational institutions can use DTs to enhance their teaching methods, providing students with immersive learning experiences [5]. Additionally, DTs ensure that CH is inclusive and accessible to people with disabilities, offering tailored virtual experiences.

III. CONCLUSION

The applications of Digital Twins in Cultural Heritage (CH) are diverse and impactful. By enhancing interactivity and visualization, supporting preservation and restoration, and providing remote access, DTs offer innovative solutions to some of the challenges faced by CH institutions. Integrating DTs into CH not only preserves physical artifacts but also enriches the educational and engagement experiences for a global audience. Future research should focus on advancing the capabilities of DTs, particularly in terms of interactivity, data management, and scalability, to fully realize their potential in the CH sector. By leveraging the strengths of DTs and addressing the current limitations, CH institutions can create more immersive, engaging, and sustainable ways to preserve and share our cultural legacy.

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