# Preserving Built Heritage in Sri Lanka through Digital Twin Technology: Opportunities and Implications

**KSKNJ Kudasinghe[1,a*], WDBJ Jeewananda[2,b] and Malthi Padmaja[3,c]**

[1] Department of Town and Country Planning, University of Moratuwa, Sri Lanka

[2] Department of Civil Engineering, University of Moratuwa, Sri Lanka

[3]School of Architecture, Sri Lanka Institute of Information Technology, Sri Lanka

[a]kudasinghekskn j.22@uom.lk, [b] jeewanandawdbj.24@uom.lk, [c]malthi.p@sliit.lk

**KEYWORDS:** *Digital Twins, Historical Cultural Heritage, Conservation*.

## ABSTRACT

The "digital twin" concept has gained prominence in architecture and construction for maintaining accurate digital representations of physical structures. There is no generalized digital twin system which can be applicable for all purposes; thus, the digital twin development is context and site specific. Building Information Modeling proves invaluable for performance modeling, behavior analysis, and preventive maintenance of historic sites, yet its implementation complexities demand customized approaches. In Sri Lanka, digital twin adoption lags due to uncertainties in construction, operation, utility, and limited research on their cultural heritage impacts. Modernization threatens colonial street architecture, intensifying conservation urgencies. Digital twins offer detailed virtual models capturing architectural nuances and historical contexts, crucial for UNESCO World Heritage sites facing modernization and climate change threats. The UN's 2030 Sustainable Development Goals prioritize cultural and environmental sustainability, underscoring the need for effective conservation strategies. This study integrates a literature review, two case studies with a detailed algorithm for the creation of a digital twin, and professional interviews for identifying challenges and strategies for digital twin implementation. Case studies of the De Soysa building and Rangiri Dambulla Caves illustrate their potential respectively: the former preserving legacy amid urban development, the latter optimizing preservation through microclimatic analysis. Project-specific digital twins are pivotal for safeguarding cultural identity and managing heritage properties. Challenges in digital twin use for heritage preservation include data capture, costs, integration, and ethical considerations. Solutions entail advanced technologies, funding strategies, standard data formats, cloud storage, and ethical data handling to enhance management and preservation.

## INTRODUCTION

The concept of the "digital twin" has become increasingly prominent in various industries, including manufacturing, healthcare, aerospace, and the architecture, engineering, and construction sector [1]. Initially introduced by Grieves in the early 2000s within the context of industrial design, a digital twin is defined as a digital representation of a physical system, existing independently [1][2]. This model replicates the information found within the physical system and remains interconnected with it throughout its entire lifecycle [3]. In simpler words a digital twin is a virtual model of a physical object, system, or process.

In the past decade, interdisciplinary research has propelled Building Information Modeling into the spotlight within historic and cultural landscapes. This proven as an effective tool for performance modeling, behavior analysis, deterioration modeling, and preventive maintenance of historic cultural heritage sites [4]. One aspect of this is the digital twin, which offers a convenient way to maintain an accurate and up-to-date digital representation of physical structures [5]. This digital twin allows structural engineers to conduct Multiphysics and multiscale simulations, aiding decision-makers in understanding the current condition of a structure, identifying defects, and proposing remedial measures. The digital twin integrates various survey techniques [6] and BIM-based semantics [7].

Digital twin implementation is a complicated system and time-consuming procedure that involves numerous technologies and tools working together. Therefore, it is of vital importance to select the most appropriate algorithm/flow of inputs to create a project specific digital twin [8]. There is no generalized digital twin system which can be applicable for all purposes [9][10]. Thus, the development process of the digital twin needs to be specific and will vary from site to site

The adoption of digital twins in the Sri Lankan construction industry has been relatively limited compared to more technologically advanced countries [11]. However, research has indicated that there has been a growing awareness and interest in the potential of digital twins to transform the construction sector in Sri Lanka [12]. Despite numerous studies and research papers linking architecture with digital twins, there is still no consensus on the construction of these twins, the responsible parties for building and operating them, or the extent of their utility [13][14][15]. Furthermore, there is limited research on the aspects of the use of digital twins and its usage on the maintenance of cultural heritage within the built environment remains at the infancy stages [4].

Preserving historical buildings and historic landscapes is essential due to the rapid pace of modernization taking over Sri Lanka, which often results in their neglect and loss of cultural significance [16][17]. From example the rapid



https://doi.org/10.54389/EUAP8600

disappearance of Sri Lankan Street architecture rooted in colonial times poses a significant challenge to cultural preservation efforts. Effective conservation efforts, such as meticulous restoration, play a crucial role in maintaining architectural integrity and safeguarding cultural heritage [18]. These measures ensure that historical buildings continue to serve as invaluable artefacts, preserving our collective history and identity for future generations. Thus, Digital twins allow for the creation of highly detailed virtual models of historical buildings, capturing their architectural features, materials, and historical context digitally [19].

In terms of heritage sites, the impacts on UNESCO World Heritage sites are clear, and this trend poses a significant future threat to heritage properties worldwide [20]. Sri Lanka is home to several UNESCO World Heritage Sites. The United Nations' 2030 agenda for Sustainable Development Goals underscores the importance of cultural and environmental sustainability for human well-being. The Outstanding Universal Value (OUV) is crucial for preserving and managing World Heritage properties. It is assessed through 10 criteria covering cultural and natural values [21]. To qualify, a property must show integrity and authenticity. Effective protection and management systems are essential for its preservation [22]. This can be aided through digital twins as real-time data from sensors embedded in the physical building or historical site can be fed into the digital twin. Digital twins enable simulation of various scenarios, such as environmental changes or structural modifications, without risking damage to the actual building [23]. This capability helps in predicting the impact of interventions and optimizing conservation strategies.

This broader aim of this research is to explore the application of digital twins in the preservation of cultural heritage of the Sri Lankan built environment. Specific objectives include-

- Objective 01 focuses on identifying key facilitator areas through a literature synthesis, where digital twins can facilitate the preservation of cultural heritage within the built environment.
- Objective 02 includes developing algorithms tailored for site-specific digital twins within a given historical landscape. This approach aims to replicate conditions to mitigate long-term deterioration.
- Objective 03 is to identify and address challenges associated with implementing digital twins to safeguard cultural heritage in the built environment.

## LITERATURE REVIEW

**Digital Twins in Architecture.** Digital twins enable architects to visualize and simulate building designs in a virtual environment, facilitating better design decisions and improved communication with stakeholders [24]. Digital twins can also support design optimization by integrating real-time data from sensors to analyze building performance and optimize energy efficiency and occupant comfort [25]. Digital twins are used to track, analyze, and enhance physical prototypes and their roles can be broken down into three stages [26][1].

- See: a variety of sensors and devices gather data in order to visualize the situation.
- Think: intelligent software evaluates the collected data and, if a problem exists, identifies multiple possible remedies for each one.
- Do: select smart algorithms and implement the most appropriate solution.

A digital twin is a connected, virtual counterpart of a physical product, asset, or system that has both the elements and dynamics of the way the complex system runs and evolves over time. Hence, the digital twin architecture consists of three main components [27][1][2]:

- physical objects,
- virtual model,
- their connection.

Physical objects are essential components of the digital twin because they produce a large quantity of heterogeneous datasets from the real world [28]. A huge quantity of multi-source, diverse datasets are created from physical objects. Popular methods for capturing data include laser scanning and photogrammetry, which are both highly effective for creating digital replicas of buildings [29].

Technologies for virtual modelling include the process of converting a physical item into digital representations that computers can process, analyze, and manage [30]. Modeling is likely the most important aspect of a digital twin. A complete digital twin model includes its geometry (shape, size, position, and assembly relationship), physical characteristics (tolerances, material properties, and assembly information), behavior (how the virtual model reacts to external stimuli), and its rules (associations and constraints that can be used to analyze, judge, evaluate, optimize, and predict object performance) [30].

Connection and data transmission technologies - For the digital twin to provide near-real time control and virtual-real state mapping, high-fidelity connection mechanisms are required [1][2]. There are numerous connection protocols for data flow between the physical space and the digital twin, as well as within the cyber space among various software. Wire transmission and wireless transmission are the two current data transmission methods. The adoption of 5G contributes to meeting high accuracy and low latency demands [31].

Implementing a digital twin is a complex and time-intensive process that integrates various technologies and tools. Hence, selecting the right algorithms and input flows tailored to the project is crucial [32]. There is no universal digital twin system applicable across all contexts, highlighting the need for specific development processes that vary from site to site

**Digital Twins in cultural heritage of built environment.** Digital twin is a promising technology used in cultural heritage preservation that allows for a complex interaction between actual physical objects (be it monuments, historical buildings, or archaeological sites) and their virtual representations [33]. The research framework presented in [34] consists of integrating historical building models in the digital twin environment with focus on supporting preservation of cultural heritage. The encompassing method recognizes the importance of model integration beyond the project stage, automatization of data analytics and simulation processes in the digital twin and consequently increased understanding of the effects preservation would have on cultural heritage sites and their patrons [35].

Historical buildings are subject to environmental factors that could interfere with their preservation. In the past, there have been numerous cases of different kinds of proposals and analysis aimed at assessing micro-climatic performances of historical buildings and monuments [36]. In addition, there are strategies for energy efficiency improvements of historic buildings in Europe in accordance with UN initiatives for sustainable development. [37] employ an integrated informative system together with digital twin technology aiming at maintenance and preservation of cultural heritage assets. They specifically focus on natural and human induced disasters and their effects on tangible cultural heritage, namely art objects [38], housed in an archaeological museum in South Italy.

Research by [39] details a case study of Rankoth Wehera/Stupa in Sri Lanka, where 3-D photogrammetric model creation for the application of Digital twin principles. Drone photogrammetry was discovered to be an extremely capable and convenient tool for the Digital twin process to extract 3-D Geometric, topological, textural and morphological information of the defects of the Stupa over a period of time [39].

Similarly [23], employ digital twin technology aiming at inspecting structural systems of historic buildings, namely Milan’s Cathedral, as well as providing predictive analysis predictive analysis of the maintenance of the cathedral in terms of damage restoration processes.

[40] and [41], presented a live-guided VR tour of an underground oil-mill in the town of Gallipoli, Italy for a content that is not accessible for people with disabilities and inspired by the pandemic situation in 2019 that limited public access to enclosed places.

Brazilian architect Fábio Rakauskas preserves architectural works and brings them into the modern world with digital replicas. He's done this for 14 historical buildings in his hometown of São Bernardo do Campo, a city close to São Paulo in Brazil. This work preserves the history of the 1960s Modernist Architecture Movement, connects people with their heritage, and tracks the buildings' continual evolution.

Through the synthesis of literature, key facilitator areas for employing digital twins in cultural heritage maintenance can be identified as follows:

- Generating precise digital replicas of artifacts, monuments, or entire historical sites to facilitate documentation.
- Evaluating risks such as climate change effects on cultural heritage

## METHODOLOGY

Firstly, a comprehensive literature review was conducted to establish the foundation for the research. This review identified two key facilitator areas where digital twins are essential for preserving cultural identity in the built environment:

1. Generating precise digital replicas of buildings.
2. Evaluating risks such as the effects of climate change on cultural heritage.

Secondly, two relevant case studies were selected to provide practical insights into the research.

Thirdly, the study identified the most appropriate algorithms and input flows needed to create a project-specific digital twin for the selected case studies.

Finally, semi-structured interviews were conducted with 10 professional practitioners in the construction industry. These interviews aimed to uncover the challenges associated with implementing digital twins and to explore strategies for mitigating these challenges.

Fig. 1 below illustrates the framework adopted for this study. This methodology ensures a systematic approach to utilizing digital twins for cultural heritage conservation, from initial literature review and case study selection to the creation of digital replicas and addressing potential challenges

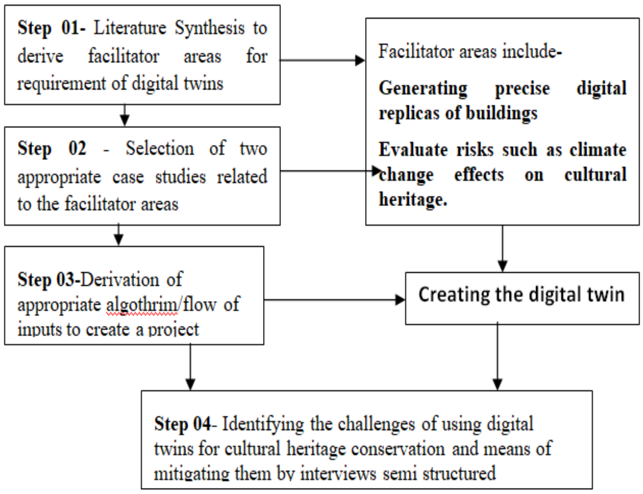


Fig. 1 Framework for developing the research

## RESULTS AND DISCUSSION

**Results from the Literature Synthesis.** As mentioned in the previous section, the literature synthesis identified two key facilitator areas where digital twins are essential for preserving cultural identity in the built environment:

1. Generating precise digital replicas of buildings.
2. Evaluating risks such as the effects of climate change on cultural heritage.

Therefore, under these facilitator areas the following two case studies were selected for the application of digital twins-

1. The disappearing urban streetscape of Salve Island, Colombo.
2. Rangiri Dambulla caves, Dambulla

**Results and discussion from the case studies.** The justification for the selection of these case studies and generated algorithms are detailed ahead.

The selection of case study 01:

The century old street houses/buildins alongside the streets express the old commercial interactions through their planning. However, they are fast disappearing with only a few of these buildings in existence in Sri Lanka at present. Increasing economic growth, which raised the standards of living, people are yet going for a modernized building style bringing down the traditional forms such as these traditional colonial buildings and with them a way of life.

The UDA in Sri Lanka has decided that the De Soysa building in Slave Island with a 150-year-old history will be brought down and new one with the same façade would be erected a distant over, this is done due to the road expansion. Architect Ismeth Raheem had stated, and this was published in the Sunday times that the building is a "remarkable gem of colonial street architecture and a century old building ". The building is demolished in order to offer the land to the Indian-owned Tata Housing Development Company. The Castle Hotel followed the same fate as the structure replaced this white structure that rose there- and which now houses the Tata project office is nothing like the Castle Hotel.

Fig. 2,3 Demolished state of the De Zoysa Building

The De Zoysa building was once the headquarters of the prestigious firm of H.W. Cave & Co., which from 1877 was the country's leading publishing and printing house. And it is said that during the 1920s and 1930s, the premises of H.W. Cave & Co. was considered one of the most fashionable addresses in Colombo.

The De Zoysa building holds cultural significance, and a digital twin helps in preserving and promoting this heritage. It provides a means for future generations to understand and appreciate the historical context of the building in terms of Sri Lankan Street architecture.

Digital twins allow for the creation of a highly accurate, three-dimensional, and interactive model of the building, ensuring that all architectural and historical details are preserved and can be faithfully recreated.

Even if physical reconstruction isn't feasible, a digital twin can serve as a virtual museum, allowing people to explore and experience the building as it once was.

Development of the algorithm for its Digital twin:

The following section details an algorithm and input flows needed to create a digital twin for the De Zoysa building.

- First need to collect historic information on the De Zoysa building. Common data capture methods include laser scanning and photogrammetry, which are excellent ways to recreate buildings digitally. However, have the availability of this type of technology is limited in Sri Lanka. Instead, we can use existing 2D documentation (old paper drawings or scanned plans, sections, and elevations), and previous visited site photographs to capture the details of subsequent building updates manually.
- Next, we create a proper database. For this we linked several external resources and embedded important information about the models within the components' characteristics, including:
    - Links to all available documentation about ramps, stairs, sheds, and structural elements
    - Data about the architects and other AEC professionals that worked on each project
    - Links to images and reports of important moments in the history of the building
- Next, we create a 3D printed model representing the current streetscape of Slave Island, including the remains of the De Soyza Building. This model provides a tangible, physical representation of the existing urban environment, capturing the intricate details of the contemporary streetscape. 3D printing technology ensures accuracy in replicating the physical attributes of the buildings and surrounding infrastructure.
- Then, to juxtapose the present with the past, a 3D model of the streetscape with the De Zoysa Building from the historic time is developed with the previously collected historical data. By using SketchUp's outlier tool, we can compare the original model alongside the updates, making it easy to compare the original and current states. By digitizing the collected information, a detailed and accurate 3D representation of the historical streetscape, including the De Soyza Building, is created. This model serves as a virtual reconstruction of the area as it once stood, providing valuable insights into the architectural and urban development over time.
- To facilitate an interactive and immersive comparison, the historical 3D model is integrated with QR code technology. A QR code is generated and associated with the digital model. When scanned using a smartphone or tablet, the QR code triggers an augmented reality (AR) experience. This AR feature allows users to visualize the historical 3D model superimposed onto the 3D printed structure of the existing streetscape.
- By overlaying the historical 3D model onto the current 3D printed streetscape, users can observe and analyze the changes that have occurred over time, thus a digital twin for the site is created.

In a nutshell, the above-mentioned process involves creating a 3D printed model of the current streetscape of Slave Island, including the De Soyza Building. Also, historical 3D model is then developed using past images and data with SketchUp. This historical model is linked to a QR code, which, when scanned, overlays the historical model onto the 3D printed structure. This allows users to compare and visualize changes between the existing and historical conditions.

This comparative visualization highlights the architectural transformations, urban planning decisions, and cultural shifts that have shaped Slave Island. The digital twin thus becomes a powerful tool for architects, historians, urban planners, and the general public, enabling a deeper understanding of the area's historical evolution and current state.

The selection of case study 02:

UNESCO has inscribed the Rangiri Dambulla Caves as a world heritage site. However, there is history of threats documented in the reports on state of conservation of Rangiri Dambulla Cave Temple archived in the World Heritage Center from 1997 to 2019. Outstanding Universal Value of a world heritage property is affected by threats encompassing multiple secondary threats. Studies by [42] explicitly prove a significant level of decays caused to paintings within the caves due to changes in the cave's microclimatic conditions such as temperature and humidity. Furthermore, [42], states that there is no proper means to implement a visitor management plan into caves. This is of vital importance as when the cave is congested with people, there are high levels of carbon dioxide, these $CO_2$ levels influence on the decay levels of the cave walls.

Fig. 4,5 Whitening of the Ceiling and wasp damage on the ceiling. Source- [42]

Moreover, if a property loses the characteristics which warranted its inscription on the World Heritage list, it can be deleted from the list [43]. Thus, the Rangiri Dambulla Caves are on the verge of being removed from the UNESCO world heritage list, if a proper mechanism to combat these problems are created.

Therefore, creating a digital twin for the preservation of heritage properties like the Rangri Dambulla caves, focusing on microclimatic conditions is of paramount importance.

Development of the algorithm for its Digital twin:
The following section details an algorithm and input flows needed to create a digital twin for the Rangiri Dambulla Caves

- First gather information about the caves' history and current conditions (temperature, humidity, light, air quality). Use sensors to monitor these conditions continuously.
- Next Make a detailed 3D model of the caves using laser scanning or photogrammetry. Include all architectural details and materials.
- Then merge environmental data with the 3D model to create a dynamic digital twin. Use software like Building Information Modeling (BIM) to manage this integration.
- Then connect real-time data from sensors to the digital twin for continuous updates.
- Next use predictive modelling to foresee potential problems within the caves.
- Finally, based on the simulations, we can propose solutions for controlling the microclimate within the caves. For example, the real time sensors can quickly identify when the $CO_2$ concentrations are high, i.e.- when the visitor count is high. These ultrafine particles can affect the deteriorating state of the paintings within the cave.

The algorithm mentioned in the above section proves that a digital twin of the Rangiri Dambulla caves, focusing on microclimatic conditions, offers a powerful tool for preservation. By integrating detailed 3D models with real-time environmental data, you can simulate and predict the impact of various conditions on the caves, leading to more informed and effective preservation strategies.

**Challenges in using digital twins for cultural heritage preservation in the built environment.** The final part of this study identified the challenges and potential mitigation strategies for implementing digital twins in the preservation of cultural heritage within the built environment through semi-structured interviews with 10 industry specialists. These industry specialists included-

- 05 Architects with experience in heritage architecture
- 02 Archaeologists
- 02 Technical Managers - Engineering Software Development Organization
- 01 Machine Learning Engineer

Additionally, the survey identifies strategies for mitigating these challenges.

01. High-Resolution Data Collection: Capturing detailed and accurate data of heritage sites can be difficult, especially for intricate or hard-to-reach areas. Incomplete or unavailable historical data can hinder the creation of accurate digital twins.

To mitigate this challenge, we can use advanced techniques like laser scanning (LiDAR) and photogrammetry to capture high-resolution 3D models. Also, we can use artificial intelligence to fill gaps in historical data by predicting and reconstructing missing information.

02. High costs and complex software tools: The technology and expertise required for creating and maintaining digital twins can be expensive. The software and tools needed for digital twin creation and management can be complex and require specialized training.

For mitigating these we can seek funding and grants from governmental and non-governmental organizations dedicated to heritage preservation. Develop and implement training programs for staff and stakeholders to build the necessary skills. Utilize open-source software where possible to reduce costs.

03. Data integration and management: Integrating various data types (e.g., 3D models, environmental data) from different sources can be challenging. Managing large volumes of data efficiently while ensuring its integrity and accessibility over time.

To mitigate these aspects, we can adopt industry standards for data formats and protocols to ensure compatibility and use cloud-based storage and processing solutions to manage data more effectively.

04. Ethical and legal concerns: Ensuring the privacy and security of data, especially when it involves culturally sensitive information. There is the need to navigate legal regulations related to data collection, storage, and sharing.

To mitigate the above we can develop transparent data management policies that respect cultural sensitivities and privacy concerns. Ensure compliance with relevant legal and ethical guidelines, including obtaining necessary permissions for data collection.

By addressing these challenges through strategic planning and collaboration, the use of digital twins can significantly enhance the preservation and management of cultural heritage sites.

## CONCLUSION

In conclusion, the concept of the "digital twin" has gained significant traction across various industries, including architecture and construction, as a tool for maintaining accurate and up-to-date digital representations of physical structures. The interdisciplinary research over the past decade has spotlighted historic building information modeling for its efficacy in performance modeling, behavior analysis, deterioration modeling, and preventive maintenance of historic heritage sites. However, the implementation of digital twins is complex and requires a tailored approach for each project.

In Sri Lanka, the adoption of digital twins in the construction industry lags behind more technologically advanced countries. This is compounded by the lack of consensus on their construction, operation, and utility, and limited research on their impact on maintaining cultural heritage. The preservation of historical buildings is critical as modernization threatens to erase cultural significance, as seen with the rapid disappearance of colonial street architecture.

Digital twins offer a solution by creating detailed virtual models that capture architectural features and historical context. They are particularly vital for UNESCO World Heritage sites, which face threats from modernization and climate change. The United Nations' 2030 agenda for Sustainable Development Goals emphasizes the importance of cultural and environmental sustainability, underscoring the need for effective conservation strategies.

This study involved a comprehensive literature review, two case studies, identification of appropriate algorithms for creating digital twins, and interviews with construction industry professionals. These methods highlighted the challenges and potential strategies for implementing digital twins.

The De Soysa building on Slave Island and the Rangiri Dambulla Caves are prime examples where digital twins can play a crucial role. For the De Soysa building, a digital twin can aid in preserving its legacy amid urban development. For the Rangiri Dambulla Caves, a digital twin focusing on microclimatic conditions can enhance preservation efforts by predicting and mitigating environmental impacts.

Overall, the development of project-specific digital twins is essential for preserving cultural identity and managing heritage properties, ensuring they remain integral parts of our collective history and identity for future generations.

The final part of this study explores the challenges encountered when using digital twins for preserving cultural heritage. Challenges include capturing detailed data, high costs, data integration issues, and ethical concerns. Solutions involve advanced technologies like laser scanning, seeking funding, using standard data formats and cloud storage, and ensuring ethical data handling. These strategies aim to improve how cultural heritage sites are managed and preserved with digital twins.

## REFERENCES


[1] Michael Grieves. (2014) Digital twin: manufacturing excellence through virtual factory replication. White paper,

[2] Michael Grieves. (2016). Origins of the digital twin concept. Florida Institute ofTechnology, 8, 2016.

[3] Ivanov, S., Tarasyev, A., Rak, A., Averkin, A., & Izrailov, R. (2020). Digital Twin of City: Concept Overview. In 2020 Global Smart Industry Conference (GloSIC). IEEE. https://doi.org/10.1109/GloSIC50382.2020.9277755

[4] Jouan, P. and Hallot, P., 2019. Digital twin: A HBIM-based methodology to support preventive conservation of historic assets through heritage significance awareness. The international archives of the photogrammetry, remote sensing and spatial information sciences

[5] Fuller, A., Fan, Z., Day, C. and Barlow, C., 2020. Digital twin: Enabling technologies, challenges and open research. IEEE access, 8, pp.108952-108971

[6] Martínez-Carricondo, P., et al. (2019). UAV Photogrammetry and HBIM for the Virtual Reconstruction of Heritage. ISPRS Archives – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15

[7] Parisi, G. I., Kemker, R., Part, J. L., Kanan, C., & Wermter, S. (2019). Continual lifelong learning with neural networks: A review. Neural Networks, 113, 54–71. https://doi.org/10.1016/j.neunet.2019.01.012

[8] Farsi, M., Ariansyah, D., Erkoyuncu, J.A. and Harrison, A., 2021. A digital twin architecture for effective product lifecycle cost estimation. Procedia CIRP, 100, pp.506-511

[9] Kor, M., Yitmen, I. and Alizadehsalehi, S., 2023. An investigation for integration of deep learning and digital twins towards Construction 4.0. Smart and Sustainable Built Environment, 12(3), pp.461-487

[10] Liu, Y., Sun, Y., Yang, A. and Gao, J., 2021. [Retracted] Digital Twin-Based Ecogreen Building Design. Complexity, 2021(1), p.1391184

[11] Perera, W.S.D., Ranadewa, K.A.T.O., Parameswaran, A. and Weerasooriya, D., 2023. Status quo of digitalisation in the Sri Lankan construction industry

[12] Opoku, D.G.J., Perera, S., Osei-Kyei, R., Rashidi, M., Bamdad, K. and Famakinwa, T., 2023, January. Barriers to the adoption of digital twin in the construction industry: A literature review. In Informatics (Vol. 10, No. 1, p. 14). MDPI

[13] Ozturk, G.B., 2021. Digital twin research in the AECO-FM industry. Journal of Building Engineering, 40, p.102730

[14] Nguyen, H.X., Trestian, R., To, D. and Tatipamula, M., 2021. Digital twin for 5G and beyond. IEEE Communications Magazine, 59(2), pp.10-15

[15] Yin, X., Liu, H., Chen, Y. and Al-Hussein, M., 2019. Building information modelling for off-site construction: Review and future directions. Automation in construction, 101, pp.72-91

[16] Silva, K.D., Taylor, K. and Jones, D.S. eds., 2023. The Routledge handbook of cultural landscape heritage in the Asia-Pacific. Routledge, Taylor & Francis Group

[17] Wickramasinghe, N., 2014. Sri Lanka in the modern age: a history. Oxford University Press.

[18] Gutschow, N., 2017. Architectural heritage conservation in South and East Asia and in Europe: contemporary practices. Authenticity in architectural heritage conservation: Discourses, opinions, experiences in Europe, South and East Asia, pp.1-71

[19] Cosovic, M., Amelio, A. and Junuz, E., 2019. Classification methods in cultural heritage. In CEUR Workshop Proceedings (Vol. 2320, pp. 13-24). CEUR-WS

[20] Caust, J. and Vecco, M., 2017. Is UNESCO World Heritage recognition a blessing or burden? Evidence from developing Asian countries. Journal of Cultural Heritage, 27, pp.1-9

[21] UNESCO, 2012. Understanding world heritage in the Asia and Pacific, the second cycle of periodic reporting 2010 2012, UNESCO, Paris, France

[22] UNESCO, 2008. Policy document on the impact of climate change on world heritage properties, UNESCO-WHC, Paris. France

[23] G. Angjeliu, D. Coronelli, G. Cardani. (2020) Development of the simulation model for digital twin applications in historical masonry buildings: The integration between numerical and experimental reality, Computers Structures

[24] Gul, M., Ahmed, S., & Jo, J. (2020). Digital twins: A comprehensive survey from smart cities to Industry 4.0. IEEE Access

[25] Gupta, R., Bhattacharya, M., & Kalaga, D. V. (2021). Digital twin-based energy efficiency optimization in smart buildings: A comprehensive review. Renewable and Sustainable Energy Reviews

[26] Madni, A. M., Madni, C. C., & Lucero, S. D. (2019). Leveraging Digital Twin Technology in Model-Based Systems Engineering. Systems, 7(1), 7. https://doi.org/10.3390/systems7010007

[27] W. Hu, T. Zhang, X. Deng, Z. Liu, J. Tan. (2021). Digital twin: a state-of-the-art review of its enabling technologies, applications and challenges, Journal of Intelligent Manufacturing and Special Equipment

[28] Rovina, D., Özeren, Y., Zambon, D., Dotis, P., Pregnolato, M., Manzetti, S., et al. (2022). Assessing flooding impact to riverine bridges: an integrated analysis. Natural Hazards and Earth System Sciences, 22

[29] Toni Greif, Nikolai Stein, and Christoph M. Flath. (2020) Peeking into the void: Digital twins for construction site logistics. Computers in Industry

[30] Kazi Masudul Alam and Abdulmotaleb El Saddik. (2017) C2ps: A digital twin architecture reference model for the cloud-based cyber-physical systems. IEEE Access

[31] Pradeep Alva, Martin Mosteiro-Romero, Clayton Miller, and Rudi Stouffs. (2022). Digital twin-based resilience evaluation of district-scale archetypes

[32] Fabian Dembski, Uwe W¨ossner, and Mike Letzgus. (2019).The digital twin tackling urban challenges with models, spatial analysis and numerical simulations in immersive virtual environments. pages

[33] Marra, A., & Fabbrocino, G. (2021). On the SeVAMH survey protocol for safety and safeguard of artistic assets. Overview and validation at the Monumental complex of Santa Chiara in Naples. Restauro Archeologico, 28, 4–17

[34] P. Jouan, P. Hallot.(2022). Digital twin: Research framework to support preventive conservation policies, ISPRS Int. J. Geoinf.

[35] Bruno, S., Grasso, C., Dell'Olio, F., De Fino, M., & Merenda, M. (2022). VERBUM—Virtual Enhanced Reality for Building Modelling (virtual technical tour in digital twins for building conservation). Journal of Information Technology in Construction (ITcon)

[36] G. Fidan. (2014). Analysis of historic buildings in terms of their microclimatic and thermal comfort performances

[37] A. Massafra, G. Predari, R. Gulli, (2022). Towards digital twin driven cultural heritage management: A hbim-based workflow for energy improvement of modern buildings, ISPRS - Int. Arch. Photogramm. Remote Sens. Spat

[38] Vuoto, S., Colucci, C., Pitonzo, R., & Scianna, A. (2023). Shaping Digital Twin Concept for Built Cultural Heritage Conservation: A Systematic Literature Review. International Journal of Architectural Heritage

[39] Egodawela, S., Buddika, H. A. D. S., Harischandra, W. A. N. I., Mahmoodian, M., &Mathota, M. R. S. N. M. (2022). Conservation and management of ancient stupa using digital twins: A case study of UAV-based 3D photogrammetric digitization of RankothWehera Stupa. In Proceedings of the International Conference on Sustainable Built Environment 2022 (ICSBE 2022). Springer Nature Singapore

[40] F. Gabellone. (2020). A digital twin for distant visit of inaccessible contexts

[41] F. Gabellone. (2022). Digital twin: a new perspective for cultural heritage management and fruition, ACTA IMEKO 11

[42] Rajapaksha, I. Climate change impacts on World Heritage built environment in Tropics: An evidence based appraisal on microclimates and visitor influx of Rangiri Dambulla Cave Temple in Sri Lanka.(2020). Publisher: Sri Lanka National Commission for UNESCO

[43] UNESCO, 2019. Policy document on the impact of climate change on world heritage properties, UNESCO-WHC, Paris. France