

People-Centred Digital Twins for World Heritage

Summary and reflection on the CIPA 2025 Roundtable Discussion:

People-Centred Digital Twins for World Heritage

Report by Verónica Heras and Shuyi Yin, edited by Elyse Hamp and Mario Santana

A roundtable discussion was hosted at the 30th CIPA 2025 Symposium on August 26th in Seoul, South Korea, under the activities of the UNESCO Research Chair on Digital Twins for the Conservation of World Heritage. The discussion focused on people-centred digital twins (DT) for World Heritage, with invited experts in digital heritage and heritage conservation. Co-Chair Mario Santana Quintero (Carleton University) opened the discussion, followed by an introductory presentation by Co-Chair Veronica Heras (Universidad del Azuay).



Current State of Digital Twin Technology for Conservation of World Heritage by Verónica Heras

Digital twin technology has rapidly matured, evolving from a digital tool into a complex, interconnected system that is crucial for the preservation of cultural heritage. According to Cosovic, M., & Maksimovic, M. (2022), digital twins have progressed through three distinct generations, each marked by technological leaps:

- In **Gen 1 (Basic Virtual Models, 2003-2015)**, the creation of preliminary virtual replicas was intended to optimize industrial processes. During this phase, the emphasis was placed on simulating individual components and minimizing failures.
- In **Gen 2 (IoT-Enhance Systems, 2015-2020)**, sensors were integrated into the models for real-time performance monitoring, thereby facilitating predictive maintenance and enhancing the quality of operational decision-making.
- **Gen 3 (AI-Driven Intelligent Systems, 2020 - current)** now integrates artificial intelligence, the Internet of Things, and, fundamentally, community participation. This convergence transforms digital twins into living ecosystems, capable of understanding and adapting to cultural and social contexts, thereby adding invaluable layers of meaning to heritage.

Each successive generation has broadened the capabilities and scope of this technology, thereby enhancing its relevance to the multifaceted nature of cultural heritage (Laohaviraphap, N., & Waroonkun, T., 2024). Furthermore, and in line with Sharma, A., et. al., (2020), digital twins are reshaping the manner in which we engage with and preserve our cultural heritage through the following means of innovation:

1. **Predictive Conservation and Maintenance:** this is the most significant innovation. A DT continuously fed by IoT sensors (for humidity, temperature, vibration, structural strain) can predict deterioration before it becomes visible.
2. **Dynamic Documentation:** the DT becomes a living archive that evolves with the monument. It integrates historical data, archaeological findings, and real-time sensor data into a single, queryable model. Researchers can study the long-term effects of environmental changes or analyze structural behavior under different simulated loads.
3. **'What if' Scenario Testing and Intervention Planning:** DT as a sandbox to test the potential impact of restoration techniques, energy efficiency upgrades, or new visitor management strategies without ever touching the physical asset. This minimizes risk and optimizes resource allocation.
4. **AR/VR Tours:** DTs serve as the high-fidelity, data-rich backbone for immersive experiences, which facilitate the virtual exploration of historical sites.
5. **Participatory Mapping:** acknowledging that a building's preservation is not just a technical problem but a social one. Integrating data on user values, comfort, and behaviors into conservation decision-making models.
6. **Advanced Semantic & 3D Documentation:** using AI to automatically classify and segment architectural elements from point cloud data, dramatically speeding up the creation of rich, intelligent H-BIM models from recorded data.

The objective of this UNESCO Research Chair is to facilitate advances in the application of digital twin technology for the conservation of World Heritage. A literature review was conducted to assess the state of research in digital twin technology for cultural heritage, and some general observations were made:

- **Data Silos & Interoperability:** Integrating diverse data types (sensor data, historical records, social surveys, geometric models) into a unified system is complex (Sharma, A., [et.al](#), 2020).
- **Complexity & Cost:** The proposed systems (especially full DTs) are technologically complex and expensive to develop, deploy, and maintain (Laohaviraphap, N., & Waroonkun, T., 2024).
- **Severe Geographical Imbalance:** Research and implementation are concentrated in high-income countries (e.g., Italy, Spain), leaving heritage sites in low and middle-income countries (often most at risk from climate change) without access to these technologies (Laohaviraphap, N., & Waroonkun, T., 2024).
- **Technological Dependence & Digital Exclusion:** The high-tech nature of these solutions risks excluding communities and regions lacking the necessary infrastructure, skills, or financial resources, creating a "digital divide" in heritage preservation (Laohaviraphap, N., & Waroonkun, T., 2024).
- **Lack of Local Participation:** Most frameworks are expert-driven. There is a significant gap in meaningfully involving local communities in the design, data collection, and decision-making processes, leading to solutions that may not align with local values or needs (Karatzas S; [et.al](#), 2026).

- **Ethical Data Management:** The continuous monitoring of sites (and potentially people) raises unanswered questions about data ownership, privacy, and the ethical use of collected information (Karatzas S; [et.al](#), 2026).

These observations can be summarized into the following key challenges, which must be addressed to facilitate advances in this field:

1. Lack of local participation.
2. Inequality in North-South collaboration.
3. Lack of training and knowledge transfer.
4. Technological dependence and digital exclusion.
5. Long-term sustainability of the documentation.
6. Lack of ethical principles in information management.
7. Technological tools for monitoring sensory and social aspects.

Some of these challenges are now being addressed through innovative people-centred design and application of digital twin technology. Historically, data used for digital preservation was sourced primarily from specialists, a practice that often led to cultural omissions or biases. Consequently, the resulting models, while technically accurate, remained detached from the lived experiences and cultural meanings of local communities. More recently, the Heritage spaces user digital twin (HSUDT) model transformed this approach by incorporating community input from the very outset (Karatzas S; [et.al](#), 2026). Through the integration of local perspectives, narratives, and emotional connections, digital twins attained cultural richness and authenticity, thereby reflecting the genuine essence of heritage.

Some best practices have been derived for the application of people-centered digital twin technology for the conservation of World Heritage:

- **Participatory Community Co-Design:** engage local communities throughout all stages of digital twin development, thereby ensuring that the resulting solutions accurately reflect their needs and values.
- **Open Code Tools:** encourage the adoption and advancement of open platforms to lower access barriers and foster global collaboration in heritage digitalization.
- **Ethical Management:** develop ethical frameworks to safeguard privacy, data ownership, and cultural integrity across all digital twin initiatives
- **Local Capacity Building:** invest in capacity-building programs to equip community members with the skills required to manage and sustain their own digital heritage assets.

The innovative applications paint a future where cultural heritage is continuously safeguarded by an intelligent, data-driven "immune system" that can predict threats and guide precise interventions. However, the main challenges reveal that the path to this future is not primarily technological. The biggest hurdles are social, economic, and ethical. The most successful future frameworks will be those that can integrate cutting-edge technology with inclusive, participatory processes and find scalable, affordable models that can be deployed globally, not just in the world's wealthiest nations.



Concluding Statement by Shuyi Yin

Following the roundtable discussion moderated by Elyse Hamp (Carleton University), a concluding statement was made by Shuyi Yin (Fulbright Scholar, Columbia University), summarizing the conversation between the panelists, and reflecting the key messages of the co-chairs' introductory presentation.

Over the course of the ninety-minute roundtable, participants explored what it means to create people-centred digital twins for World Heritage. The discussion highlighted that while digital twins are technological constructs, their success and significance ultimately depend on human choices.

The conversation demonstrated how far the concept of digital twins have evolved, from static three-dimensional models, to sensor-enhanced monitoring, and now to AI-driven ecosystems. Each technological leap broadens the capacity for impactful use of digital twins, but also raises the stakes for cultural meaning and stewardship.

Mona Hess (University of Bamberg) stressed that conserving historic places requires more than accurate geometry. It demands multi-scale data, from broad urban contexts to minute architectural details. Her case study of Smart City Bamberg provided an example of how archives, imaging, sensing, and 3D models together create a biography of a place that can guide both conservation and planning. Digital twins, she argued, become powerful only when these layers are integrated and used to deepen cultural meaning rather than reduce heritage to numbers.

Arnadi Murtiyoso (INSA Strasbourg) represented the Chair on Digital Twins for Cultural Heritage at INSA Strasbourg, and focused on the intersection of cultural heritage and climate change. Drawing on case studies from Southeast Asia - a region facing some of the most pressing threats yet, and often under-represented in research - he reminded the group that innovation must be balanced by responsibility to global inequities and climate realities - it must be people-centred. Technological innovation such as AI may help to digitally model these challenges, but the challenges cannot be solved without human agency and for human equity.

David Myers (Getty Conservation Institute), reflecting on decades of work with the Arches heritage information platform, underscored that conservation is supported only when information systems rest on strong principles. Digital inventories provide the foundation for digital twins, but their value depends on the FAIR principles of data management (Findable, Accessible, Interoperable, and Reusable) and the CARE guidelines for Indigenous data governance (Collective Benefit, Authority to Control, Responsibility, Ethics). Open-source models and shared governance are essential to keep these information systems sustainable and relevant to the communities they serve.

Hyeseung Shim (Hong Kong Shue Yan University) brought the perspective of human-computer interaction, emphasizing that digital twins must be shaped by communities, not merely for them. She identified three key dimensions of people-centred digital twin design: integrating cultural knowledge into digital simulations, co-designing with communities as co-custodians of the data, and validating prototypes through continuous feedback from the custodians.

Ona Vileikis (Department of Culture and Tourism (DCT), Abu Dhabi) examined the institutional dimension of the use of digital twins. Institutions, she observed, can either reinforce old hierarchies, or act as bridges that share knowledge, set inclusive standards, and make tools widely accessible. People-centred digital twins depend as much on these institutional cultures of knowledge transfer as on technical capacity.

Yeo Hee-Young (WHIPIC) offered a Korean perspective on interpretation and access. She discussed how virtual reality (VR) applications and digital twins can bring World Heritage vividly to new audiences, while also revealing stark inequalities: many European sites maintain robust digital platforms, yet far fewer exist in Asia, South America, or Africa. Without attention to such divides, digital interpretation risks reinforcing exclusion.

The discussion among the panelists portrayed people-centred digital twins as data-rich, institutionally grounded, ethically governed, socially co-designed, and locally meaningful. The accelerating role of AI will inevitably shape all these dimensions. The challenge is to ensure that AI strengthens human insight rather than displacing it.

Across the presentations and wider literature, several recurring challenges emerged:

- **Breadth and integrity of data:** not only technical accuracy but cultural richness and the sustainability of digital information across the life of a site of cultural heritage.
- **Institutional and educational frameworks:** long-term capacity and skills must outlast short-term projects.
- **Ethics, governance, and rights:** questions of ownership, accessibility, authorship, and community custodianship remain central.
- **Human experience:** design is never neutral: user experience determines whether digital heritage empowers or alienates.

- **Interpretation and inclusivity:** digital twins must reach beyond experts to serve diverse publics across languages and cultures.
- **Sustainability:** complex systems are costly and often dependent on external providers: local skill and open tools are vital for resilience.
- **Responsible use of AI:** AI can enhance digital simulations and strengthen analyses, but only when guided by ethical frameworks and local knowledge.

The discussion converged on a central insight: people-centred digital twins are less about building models of places than about building relationships. Three collective commitments emerged:

- **Listen to heritage and its communities:** digital twins should capture both physical reality and cultural meaning.
- **Create equitable structures for collaboration:** training, governance, and decision-making must be genuinely shared to enable reciprocity rather than dependency.
- **Design for longevity, inclusivity, and intelligent stewardship:** infrastructures endure when open and sustainable: digital twins must respect intellectual property and cultural rights while ensuring access and trust. As AI becomes increasingly integrated into heritage data, it should be cultivated as a tool of stewardship - imaginative in expanding access, careful in managing risk, and accountable to communities whose heritage it represents.

Digital twins are not merely mirrors of physical heritage, they mirror collective values: how knowledge is shared, how communities collaborate, and how heritage is made meaningful for the future. Heritage is not only about the past: the digital choices made today will shape how sites are known, experienced, and valued by generations to come. Artificial intelligence will inevitably be part of that mirror, extending what is possible while reflecting the responsibilities we choose to uphold.

References

- Cosovic, M., & Maksimovic, M. (2022). Application of the digital twin concept in cultural heritage. VIPERC.
- Karatzas S, Lazari V, Fouseki K, Pracchi VN, Balaskas E (2026), "Digital twins-enabled heritage buildings management through social dynamics". Journal of Cultural Heritage Management and Sustainable Development, Vol. 16 No. 7 pp. 150–166, doi: <https://doi.org/10.1108/JCHMSD-08-2023-0136>
- Laohaviraphap, N., & Waroonkun, T. (2024). Integrating Artificial Intelligence and the Internet of Things in Cultural Heritage Preservation: A Systematic Review of Risk Management and Environmental Monitoring Strategies. Buildings, 14(12), 3979. <https://doi.org/10.3390/buildings14123979>
- Sharma, A., Kosasih, E., Zhang, J., Brintrup, A., & Calinescu, A.(2020). Digital Twins: State of the Art Theory and Practice, Challenges, and Open Research Questions. <https://arxiv.org/abs/2011.02833>

This report was written by Veronica Heras and Shuyi Yin, and edited by Elyse Hamp and Mario Santana Quintero. Thank you to the experts who participated in the round table: Mona Hess, Arnadi Murtiyoso, David Myers, Hyeseung Shim, Ona Vileikis, and Yeo Hee-Kyoung, and thank you to the 30th Annual CIPA Symposium for hosting the event.