



Production of Iranian Architectural Assets for Representation in Museums: Theme of Museum-Based Digital Twin

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ABSTRACT

Representation of architectural heritage artefacts with minimum risks to their authenticity has been advised by heritage guidelines; their transport for representation maximises the risk of destruction and questions the authenticity. Contemporary curators turn to Information and Communication Technology (ICT) and Mixed Reality for an improved representation but there are challenges related to audience accessibility, costs of asset transport to and lifecycle management with the museum platforms, and the potential threats to authenticity.

Digital Twin (DT) as a revolutionary concept opens new doors to mitigate the challenges and may facilitate better access to the architectural heritage through digital experiences. In the long term, DT implementation costs may be offset by enabling wider access. This article presents the DT concept, the necessity of its adoption, the challenges of Digital Twinning, benefits and opportunities, and reviews available curation practices of 'digital asset' production.

The core contribution of this article is the comparative studies on two acquisition methods with two data streams presented as case studies. The two techniques, which engage hand recording and digital recording are detailed and compared in terms of construction time, tool requirements, representability, and the interoperability as well as extensibility of the models. This research is significant in two ways: 1) by presenting the analytic framework for adapting DT assets to the complex platforms in museums, and 2) by explicating the curatorial challenges for heritage assets including accessibility, implementation time, authenticity, and reliability of the 3D-documented models.

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Digital Twin (DT) is a concept that refers to a virtual representation of physical objects or systems. DT construction and maintenance utilise a mixture of different digital methods and a life-cycle management. It is potentially costly, but it provides an opportunity for real-time sensing and dynamic representation of the assets.

Built Environment is one of the leading areas where integrated sensing technologies are used for representation (Poli et al. 2020). DT adopts integrated sensors¹ to provide the states' synchronisation between the virtual and physical asset, therefore DT can be considered a complete virtual representation of a physical entity (Jones et al. 2020: 37). Although DT has been introduced only among early adopters in the Cultural Heritage sector, we hypothesise that the research around it and related technologies would help scholars and experts for improving virtual authentic representation of heritage assets. We anticipate that to develop the framework for DT acquisition, it is paramount to establish a foundation based on curatorial priorities and availability of methods.

'As-built data' is a working concept which means an accessible dataset from the current state of the architectural asset. As-built data is one of the main DT Life-Cycle requirements; surveyors either traditionally or digitally record 3D as-built data from the assets. They utilise the related tools such as tape measure in traditional surveying or the geospatial recording tools in digital data recording technique to produce a 3D-based digital replica from the asset. It is vital to choose a highly suitable technique for the aim of each project.

Digital Twinning aims to equalise the virtual and physical states. 'Digital Asset' is the virtual replica produced by professional computer-based activity. Due to its digital attributes, it is usually highly manipulable and remotely representable, while the 'Physical Asset' possesses material originality and has been constructed by natural elements and forces and human material manipulation. Both asset types are the result of human activities, but the main difference for the construction is the methods used. DT as a new concept correlates these two asset types; moreover, 'Virtual Twin' is a Digital Asset reliable on the active sensors from the real structure to continuously equalise the physical parameters' values with their virtual counterpart (see Footnote 1). DT is an integrated version of the Digital Asset, providing connectivity with its reference: Physical Asset. In the Heritage context, Gabellone (2020) has used a photogrammetry-based DT for a virtual tour of an inaccessible asset, but after the construction of Virtual Twin, the connection with the Physical Twin is lost. If the dynamic connection between these two is forged, the result would empower the curation process with assets that are representable in or beyond the physical environment of museums. In a mature implementation, active sensors will play a crucial role in Digital Twinning performance, although without the active sensing capability, the 3D model (Digital Asset) is still representable with different attributes.

Construction of DT by traditionally recorded data starts with the surveying of the structure and gathering the needed information. The heritage data can be limited to only the needed information for digital construction or it can include heritage-specific metadata (Pocobelli et al. 2018). The limited heritage data normally includes length measurements; limited photos from the status of the structure; and gathered historical information about its architecture, alterations, etc.

On the other hand, Digital Heritage Recording would be comprised of all forms of digital data capture (Letellier 2007). Digital data acquisition techniques by geospatial tools have provided precise accuracy in the production of the assets based on their real specifications. Unmanned

¹ Applications of sensors in construction of a DT is dependent on the maturity of the digital replica. A mature DT could be implemented as a 'Virtual Twin' by applying digital sensors which provide the live connection between the Physical Twin and the Virtual Twin as a dynamic (updateable) digital asset. The implementation of sensors would make the process more complex and expensive and introduces noise of real-time signals which must be dynamically managed.

Aerial Vehicle (UAV)² Photogrammetry³ and Terrestrial Laser Scanning (TLS)⁴ are two leading methods of real-based 3D data acquisition. They are used for distinct purposes of research, conservation and maintenance, cultural heritage management, and curatorial representation. **Figure 1** presents the results of multiple data capture tools combined into a single data set, a process that required the translation of multiple data types into a common metric and format. The recorded heritage-specific metadata can be developed for an interactive Virtual Twin and its interactive representation would provide remote accessibility in museums and other venues and archives.

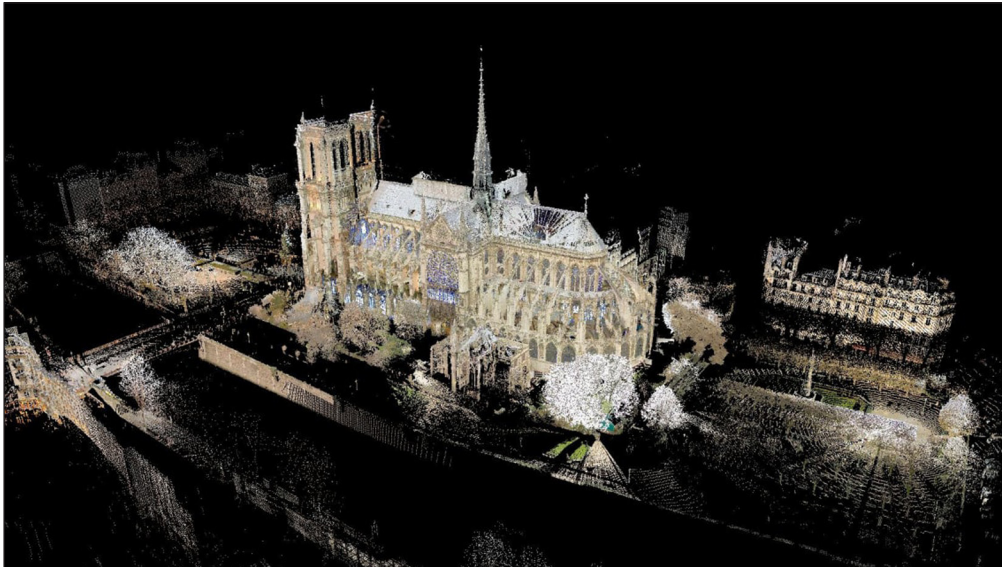


Figure 1 Digital Data Recording of Notre Dame by Professor Andrew Tallon at Vassar College (Lou & Griggs 2019), Photo by © Andrew Tallon – Vassar College, Reproduced with the permission of the owner.

ARCHITECTURAL HERITAGE REPRESENTATION

'Heritage Value' is an interesting and complex term and usually discussed beside 'Authenticity'.⁵ Heritage Values are defined in reference to history, by the offices of governors and politicians, and more importantly by the communities around the places. The value definition is not objective; a decision to designate a particular building in terms of heritage, may be in a governor's interests to manipulate values amongst the communities (Deacon & Smeets 2013) and the manipulation to the communities' preferences would question 'Authenticity' of Heritage Values. Prosper (2007) emphasises the vital role of the communities rather than outsiders in placing the Heritage Values and their dissemination. The historical value of a monument arises from its particular and individual representation of a development stage of human activity in a certain field (Cooper 2007). Development of new representation technologies has potential to help the community perceive the 'Values' and also help the community engage in the curation and dissemination of the architectural heritage with an increased level of accessibility. **Figure 2** indicates the digital documentation of an Iranian heritage site.

² Unmanned Aerial Vehicles (UAVs) are crucial in acquiring 3D spatial data from the architectural assets which have large scales such as building sites, presenting data acquisition requirements different from those of smaller artefacts. The UAV carries or has a camera which is remotely managed by a technician to capture a bird's eye view in short periods.

³ Close-Range Photogrammetry makes the process of recording and processing data simpler and faster (Hassani 2015: 208). It includes four main steps: targeting, taking digital photos, digitally processing the photos using software packages such as Agisoft (2015) and exporting required optimised representations such as orthophotos for drawing accurate as-built plans and generating optimised 3D models. A technician or engineer may use other digital tools to optimise the models, for example, software designed to produce computer graphics.

⁴ The laser scanner is a robotic multi-function station which can acquire data from a target at a high speed and in a short period by repeated transmitting a laser beam to generate a distance measurement; many measurements form an aggregate 3D data point cloud (Hassani 2015: 210). Laser scanners could have a range of uses in cultural heritage recording from small artefacts to massive and complex built structures. This new methodology is continually evolving in its use and capability. The produced mesh cloud usually provides low to moderate data of surface texture, which is less detailed than a mesh cloud produced by Photogrammetry.

⁵ Representation of Heritage Values without relying on the historic facts and evidence would not be 'Authentic' and therefore, the historians and curators seek to disseminate the original facts. Authenticity is defined in multiple terms; in general, it refers to reliable historic data. The Authenticity of architectural heritage artefacts and sites is always being questioned by heritage practitioners, and this concept provides evidence to the validity of the assets' values.



Figure 2 Digital Photography in Pasargad site, Shiraz, Iran. Photo by Mirasearka. The gigapixel photography technique has been used. Reproduced with the permission of the production company and the photographer.

The dissemination of the heritage values related to the assets is paramount (López-Menchero Bendicho et al. 2017), and the curators and conservation architects are advised in distinct guidelines for keeping the elements of Built Cultural Heritage in situ. One of focus points of the ICOMOS Lausanne Charter (1990) was the role of Cultural Heritage in the development of modern societies. The frequent revision of the methods for promotion of heritage values is vital and the presentation style should follow the updated platforms and knowledge (ICOMOS 1990). Removing and transporting isolated architectural elements such as capital columns or interior elements is a violent threat against the originality of the Built Cultural Heritage. Such guidelines and the recent developments in ICT led to the widespread use of computer-based visualisation methods. In 2006 The London Charter's aim was supporting the necessity of new techniques for documentation and representation of the assets (Denard 2009).

AIM AND OBJECTIVE

An overarching aim of this research is to support the thematic development of museum-based architectural DT based on curatorial priorities of authentic representation, to guide the use of technology in DT construction. In order to inform this larger aim, this article's main objective is to present the comparison of two available data capturing methods for Digital Twinning of architectural heritage: Digital Recording and Hand Recording.

METHODOLOGY

To make a comprehensive comparison between the techniques, case study and action research methods have been adopted. The combination of two methods supported the researchers to investigate the recent experiences of museums such as the British Museum and also activities of MiraseArka Digital Heritage company on two valuable Iranian architectural assets for evaluation of time and effort requirements, authenticity challenges, and precision of the digital replica. The practical production of 3D models assisted in the experimental research on two Iranian case studies with comparable historical values. Construction of digital assets is required for continuous synchronisation and realisation between the Physical Twin and its virtual counterpart. The recording techniques that are utilised for the case studies, as well as the results, assist the researchers in comparison of the heritage recording methods for provision of the connection between physical entity, virtual entity, and representational adequacy in mapping between the two entities.

RECORDING DIGITALLY

Digital Recording adopts high-tech tools to record the accurate specification of the assets, while traditional data capturing does not involve the digital tools. However, traditional data capturing is still valuable as the first step for the digital replica production of the asset. Letellier (2007) describes Digital Recording:

As opposed to hand (or traditional) heritage recording, this type of recording includes all forms of digital data capture, ranging from photographs to rectified images, CAD to photogrammetry, total stations to 3-D laser scanning, and voice to video.

Digital Recording enables the heritage sector to widely adopt the updated tools to record, document, and manage the information of Built Cultural Heritage. However, the new high-tech tools require expertise, and this may present challenges for technology acquisition as well as for a process that makes the activities more complex and interdisciplinary.

CURATORIAL PRIORITIES

Museums use distinct curation techniques for representation of the assets: storytelling, 3D visualisation, photography, audio, and other multimedia tools. Museums utilise new interactive displays, projection mapping; and other high-tech tools to enhance the interpretation, presentation, and curation beyond the confined physical space of museums (Lopes 2020).

The current digital practices by the museums such as British Museum's Google Street View,⁶ Google Art and Culture,⁷ and The Museum of the World⁸ indicate the techniques with specific capabilities which meet curatorial objectives. These platforms are user-friendly and interactive. Some platforms such as Gabellone's case study adopt virtual tour application combined with other interactive applications to make the curation of architectural heritage more engaging. There is one other platform, Sketchfab,⁹ for 3D, Augmented Reality (AR), and Virtual Reality (VR) content that museums use to generously share the heritage data online (Figure 3). Different platforms provide links to one another to help visitors explore their interests in Cultural Heritage. For example, in addition to the information for interoperability of the models with software packages, the Hallwyl Museum has provided some additional links on downloadable art gallery 3D models; these links refer the online visitors to other databases such as Wikipedia, Google Art and Culture, and Wikimedia and they make the digital content enriched and comprehensive.

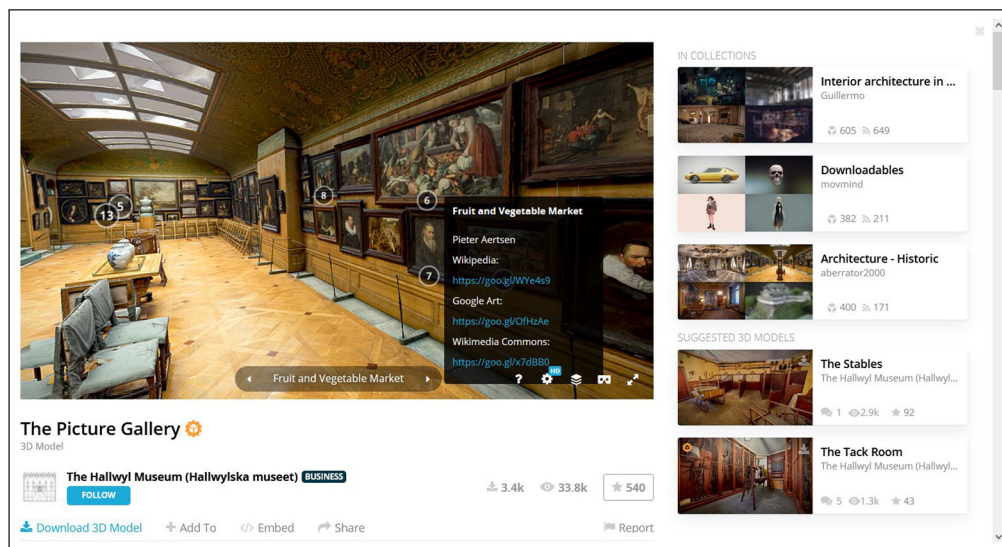


Figure 3 The Picture Gallery on Sketchfab platform includes the referral links to the other online platforms and interoperability information of the downloadable 3D model (Sketchfab 2016). Screenshot by Hossein Parsinejad. Reproduced with the permission of the production company (Sketchfab).

Furthermore, museums use 'mixed reality' methods, including AR and VR, to bestow the Built Cultural Heritage values upon the enthusiastic members of the public in a way that is understandable and perceptible. In the era of digitalisation and new movements, the curation

⁶ Google Street View is a worldwide project for providing accessible panoramic images. Google with the cooperation of the British Museum launched this service for indoor spaces of the museum and linked some of the objects to the Google Art and Culture platform.

⁷ Google Art and Culture is a powerful and universally accessible database of artworks with the contribution of art galleries and museums; since its original launch in 2011.

⁸ The Museum of the World (<https://britishmuseum.withgoogle.com/>) presents an interactive experience through time, continents, and cultures. This project is also a partnership between the British Museum and Google Cultural Institute. Advanced WebGL (Web Graphics Library) technology is used for illustration of time sequences and specification of Artefacts and Objects. The assets are provided with the insights annotated by the museums' curators. Also, hyperlinks to the related assets are provided.

⁹ Sketchfab (www.sketchfab.com) is a website for 3D, VR and AR art to be published, uploaded, bought, and sold. It allows users to monitor 3D models on the web and to use them on any smartphone browser, desktop browser or headset for VR. It offers a WebGL and WebXR-based viewer.

Curating has emerged as an academic discipline in its own right, albeit a nascent, necessarily improvised one. On a broader level, the de-centring of the art world [...], intellectually as well as geographically, has produced a demand for a new breed of curator—forever on the move, internationally networked, interdisciplinary in outlook, [...] who might discern patterns and directions in an increasingly accelerated, expanded cultural field (Farquharson 2003: 8).

Following various guidelines for the curation of Built Cultural Heritage in situ, the computer-based visualisation has become significantly useful. For example, London Charter in 2006 has provided detailed guidance for the correct use of computerised method, advocating that computer-based visualisation technique should be used only when it is ‘the most appropriate’ available method for the project. Since then, digital visualisation has become an essential practice, and subsequently, universities responded by creating new taught courses. The appearance of a Heritage Visualisation master’s at Glasgow School of Art, Digital Heritage at the University of York, and similar courses elsewhere, now prepares the digital skills such as digital reconstruction and immersive visualisation with interactive narratives. The interdisciplinary field skill is also essential to serve museums and Cultural Heritage centres in their application of more innovative interactive visualisation techniques. The ‘digital asset’ produced by the practical knowledge of heritage visualisation is inherently different from the real architectural asset; however, they are comparable.

While it [computer-based visualisation] is recognised that, particularly in innovative or complex activities, it may not always be possible to determine, *a priori*, the most appropriate method, the choice of computer-based visualisation method (e.g. more or less photo-realistic, impressionistic or schematic; representation of hypotheses or of the available evidence; dynamic or static) or the decision to develop a new method, should be based on an evaluation of the likely success of each approach in addressing each aim (Denard 2009).

Based on London Charter guidance above, the necessity of construction of a Virtual Twin would be questioned in some projects for the cost of producing high-tech computer-based visualised assets, therefore, advises such construction only when it is well-developed and aligned with the aim of the project. In other words, DT is highly complex and expensive to implement, therefore, it should be only used when the use of sensors is essential to enable a representation of material that cannot be represented in another way. Moreover, a 3D model Virtual Twin with limited synchronisation and realisation, may be sufficient for most of the interactive representations. For instance, the shared 3D models on Sketchfab with the attached links may be sufficient for an interactive virtual tour, e.g. Gebellone’s Virtual Twin. A 3D model imported in a 360-degree environment for a virtual tour is a rudimentary version of a Virtual Twin constructed by DT Synchronisation.

From this survey of DT, digital asset, digital recording, and curatorial needs, we can move on to the Case Studies of experimental techniques.

INTRODUCTION TO CASE STUDIES

The first case study is a digital asset of an Achaemenid¹⁰ capital column from Persepolis (*Figure 4*); the second case study is a digital asset of Iran National Bank site (*Figure 5*). Two different digital assets were produced by adoption of two different techniques to compare their representational capabilities. For example, the produced digital replica of Iran National Bank clearly represents the historical facts about the eclectic nationalism style of Pahlavi (Rouhani 2011).

Iran National Bank was built in 1935 by the first Pahlavi government in line with the new Iranian nationalism movement. It indicates the attempts of Pahlavi governors to revive the ancient eclecticism school of thought of the Achaemenid empire in architectural heritage; specifically, the main archaeological site for political and artistic inspiration was Persepolis (Grigor 2009). The capital columns which were used as the references for the construction

10 Achaemenid Empire is founded by Darius in 518 BCE (Naderi, Raeisi & Talebian 2014).



Figure 4 Achaemenid capital column has been digitally recorded by close-range photogrammetry technique. Photo by MiraseArka. Reproduced with the permission of the production company and the photographer.

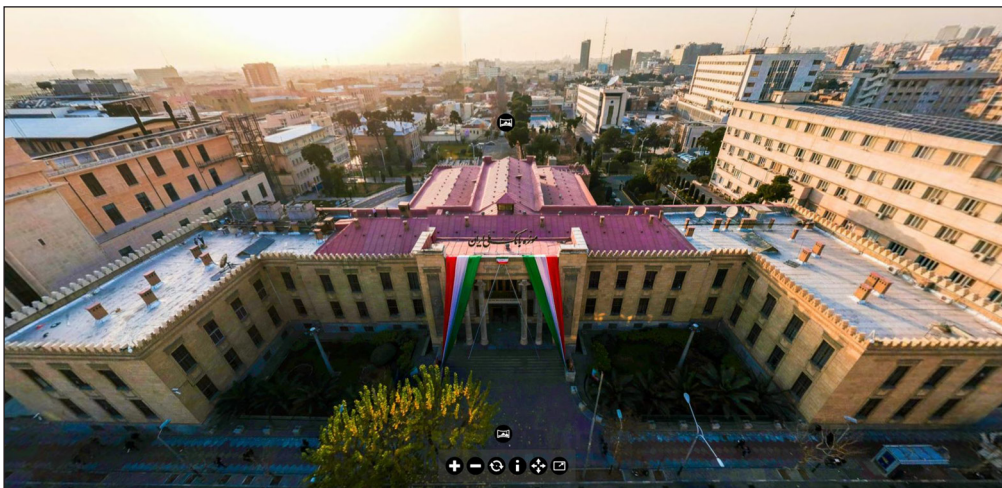


Figure 5 Virtual Museum of Iran National Bank Building. This structure is currently museum of Iran National Bank; the photo indicates the building after the extension of the building (Bank Mellī Iran 2018). Photo by MiraseArka. Reproduced with the permission of the production company and the photographer.

of such Neo-Achaemenid buildings are maintained in different museums including the Iran National Museum.¹¹

Moreover, the Achaemenid capital column has been conserved in the Iran National Museum, while its on-site representation was more beneficial. Due to the focus of Lausanne Charter on not relocating the Built Cultural Heritage elements, the authenticity of physical representation is threatened for elements such as Achaemenid capital column and the other elements from the site in museums, that have been transported to the Iran National Bank and the Louvre Museum. In the case of on-site preservation and their remote representation, the threats to the authentic heritage values of the assets would be minimised.

Lausanne charter explicitly advised (1) not to threaten the authenticity of assets by their relocation and paying high costs for preservation in a museum, and (2) Cultural Heritage elements must be preserved and represented on the assured original site (ICOMOS 1990). After the London Charter, the widespread use of computer-based visualisation methods and acquisition of new representation techniques have aided curators to represent assets remotely.

¹¹ During the first Pahlavi, the art historians and surveyors from different countries including France undertook a series of excavations in Iran, and the architectural assets were transferred to museums for both preservation and the further research. Apart from the European and American museums, the Museum of Ancient Iran as part of the National Museum of Iran hosted many invaluable assets from excavations of Pasargad and the other sites.

ACHAEMENID AND NEO-ACHAEMENID DIGITAL ASSET PRODUCTION

The structure of Iran National Bank has seen alterations in different decades after construction; including the extension of the building and change in function to the Iran National Bank Museum. In 2018, the structure was traditionally surveyed and modelled in computer graphics (CG) software (Cinema4D) and was optimised for 3D printing (see [Figure 6](#)). Two of the authors had the opportunity to apply 'mixed reality' techniques on this asset to produce the representable 3D model. The museum's manager introduced the project to the authors mainly to produce souvenir maquettes; he also considered using the model for different purposes such as representation and documentation.

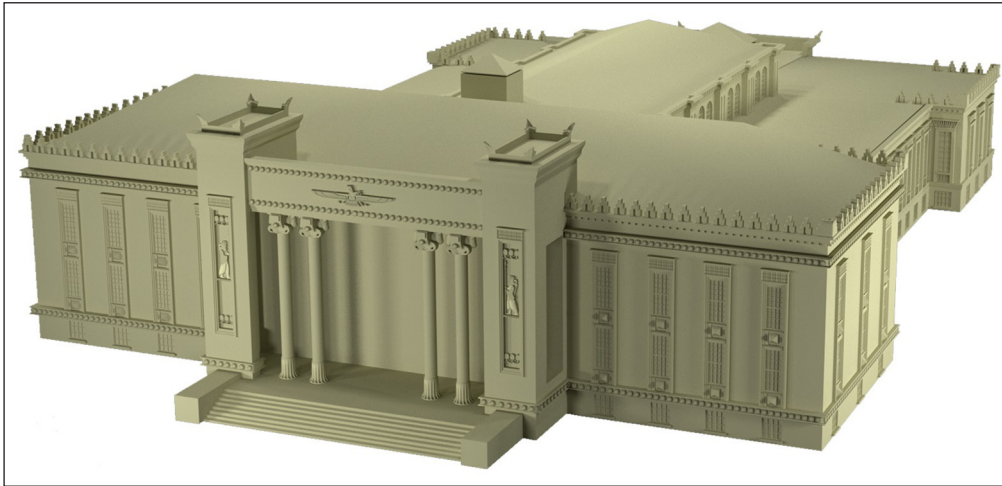


Figure 6 Rendering of Complete model; the structure is indicating the situation before the extension due to the stakeholders' request, Rendered by MiraseArka. Reproduced with the permission of the production company.

The modelling team designed the process based on the project's budget and using trial and error of multiple methods; a small part from the structure was modelled separately to test out the process using the applications Cinema4D and Netfabb, which is optimisation software for 3D printing. The 3D printing method was limited for construction of details; the team tested the technique for construction of the part and it was successful. After testing the procedure, the modellers reconstructed the structure in Cinema4D and exported the front part of the model to Netfabb. The entrance of the building was chosen due to the 3D printing limitations and the budget of the project for producing the maquette (see [Figure 7](#)).



Figure 7 3D printed model of the front part, Photo by MiraseArka. Reproduced with the permission of the production company and the photographer.

3D Printing was only one of the capabilities enabled by the produced 3D model of the bank, but due to the project limited brief, the team did not continue modelling for the virtual representation or other applications. The building had not been surveyed by any accurate digital tools such as Total Station or 3D Laser Scanner, so the scales of the different parts of the model were being revised to preserve the aesthetics of the digital replica; the model was highly modifiable in its original construction software. As explained above, the stakeholders were initially looking for exporting the models to different representation and documentation platforms. During the 3D construction based on the traditional surveying data, the manipulability of the model assisted in making different changes in shorter periods of time with no need for modelling the structure from scratch, which would have been required when using Photogrammetry modelling production with digital recording.

On the other hand, the Achaemenid capital column was recorded digitally in 2017 by Close-Range Photogrammetry (*Figure 4*). The client, Iran National Museum, assigned MiraseArka the task of 3D documentation of the asset to preserve the model for future practices, such as research and conservation. The 3D model of Achaemenid capital column was produced with almost 300 quality photographs from different angles by importing the photos using Agisoft. The process started by targeting; this stage is needed for asserting that the scale of the photogrammetry model would be accurate across all source images. The technician placed simple reference objects such a pen near the model. During the processing of the images by Agisoft, five semi-automatic stages required 48 hours to finalise the accurate 3D model. The constructed model was used in web-based platforms for representation on diverse devices such as displays and tablets.



Furthermore, the final asset was converted to an open source format (.OBJ format) for export to Autodesk Netfabb to optimise for 3D printing. The process developed for Iran National Bank model was applied. The optimisation included the semi-automatic steps for changing the attributes of the 3D model from an empty shell which had some holes, to a solid closed 3D-printable model. In the resulting model, the optimisation was more complicated because different components were used for construction of the Digital Asset and some of the components were not intersecting in the digital model. If 3D printing is one of the purposes for the digital asset, the 3D modeller needs to consider this in advance; for example, verifying the proximity of the digital components to produce a consistent solid 3D model with minimum issues that are resolvable. This consideration would reduce importing and exporting to different software packages to resolve the modelling issues for constructing a 3D model with closed surface.

TECHNICAL COMPARISON OF METHODS

Following are findings from implementing and applying two DT production techniques.

1. Requirements of automation vs. manual modelling: Digital Recording requires more complex tools such as professional camera, Unmanned Aerial Vehicle (UAV) or TLS which costs more than the employment of a 3D modeller to model the structure with CG technique using a mid-range gaming laptop. Whereas, 3D modelling in CG software is time-consuming. Had Iran National Bank model been produced by photogrammetry, the manual 3D alterations and revisions would have been time consuming and therefor costly.
2. Level of detail: The point clouds of the photogrammetric model can include only the externally visible part of the asset (Ioannides, Magnenat-Thalmann & Papagiannakis 2017: 277). This constraint reduces completeness to focus only on visible surfaces, which makes this technique highly suitable for representation in different software platforms and in 3D printing.
3. In some cases, the modellers need to illustrate a state which is missing from the current state of the asset; for instance, the state of the Iran National Bank before the extension. Under this condition the traditional surveying technique and modelling from the scratch in Cinema4D maximise the manipulability and playability of the model in its original model production context.

Table 1 indicates the comparison between the two models with different processes. The Cinema4D-based model of the bank is capable of being enhanced with a simulated surface texture in the original platform, while due to the attribute of the photogrammetry method, the capital column possesses the embedded data from the native texture, without requiring further effort by a modeller. The texture on the capital column surface makes the model more

OUTCOME PICTURE	ASSET	DATA CAPTURING	DATA GENERATION	OPTIMISATION AND ORGANISATION	CAPABILITIES OF THE OUTCOME
	National Bank Building	Traditional: By Surveying Notes from Spatial Data and Historical Data	Computer Graphics (CG) Modelling: Solid Modelling – Cinema4D Nurbs Modelling – Cinema4D Sculpting (Limited) – Cinema4D 3D Printing Optimisation – Netfabb	Semi-Automatic Tools	3D Printing & Painting Virtual Representation
	Achaemenid Capital Column	Digital Recording: Image-Based Data Having Texture and 3D Spatial Data	Close-Range Photogrammetry: Mesh Modelling - Agisoft Texturing - Cinema4D Sculpting - Cinema4D	Semi-Automatic Tools	Virtual Representation Web-Based Virtual Tour

presentable (Figure 8), delivering especially high impact in virtual platforms such as web-based virtual tours. The texture of the model helps it to be more realistic; when the model is needed for any virtual representation platform such as animation or a virtual museum display. By producing the textured model, the audience will perceive the assets realistically and well, with no need to separately produce a simulated textured surface.

Table 1 Comparison of attributes of two digital replicas.



Figure 8 Rendered Achaemenid capital column with close-range photogrammetry method, Rendered by Hossein Parsinejad by permission of the production company (MiraseArka).

The modelling time required for CG modelling based on traditional survey data is dependent on the professional expertise of the surveyors and the modellers. On the other hand, Photogrammetry consists of taking a reasonable number of quality photographs manually or automatically by UAVs or Camera, and software will construct the shell of 3D model automatically. The time of model production is dependent on the software and hardware quality. After the model is generated, it would be ready for optimisation using CG modelling packages such as Maxon (2016) Cinema4D for 3D virtual representation, or other software packages like Autodesk (2018) Netfabb for 3D printing. However, only the shell data will be available through the Photogrammetry method, whereas a full model is produced using the survey and model method.

In the research case studies, the time required to model the Bank building was lengthy, while the stakeholders achieved higher manipulation. The modellers surveyed the structure by using traditional tape measure and the actual dimensions helped the modellers maintain the

aesthetics of the building; if one dimension was not recorded, the modellers referred to the photographs during the virtual construction. The high-tech tools of surveying would reduce the time needed to provide acceptable accuracy; for example, by using TLS, the model would be highly accurate and capturing would be fast. In hand surveying, the more time the modellers spend for surveying, the higher level of accuracy is achieved. Therefore, the model tends to be more reliable in terms of level of accurate detail.

The second case study, Achaemenid capital column, confirms that the photogrammetry technique is fast and provides a good representation of the asset (Ioannides et al. 2017: 37). Dependencies include the quality and number of taken photographs, the targets, and the computer hardware and software. Optimisation of the models can be challenging since the produced model is an empty shell and may include data noise such as unnecessary surfaces which are located on site in proximity to the original architectural asset. The revisions to the processed model are also possible by using CG packages, i.e., Adobe Photoshop and Cinema4D for the texturing and Cinema4D for form revisions and changes. Such changes are usually limited and time-consuming in comparison with using CG modelling from the outset. *Table 2* summarises these findings.

TECHNIQUE	MAIN BENEFIT	MAIN DRAWBACK
Traditional Surveying and Digital Replica Production in Cinema4D	Highly Manipulable	Time-Consuming
Close-Range Photogrammetry in Agisoft	Highly Representable	Complex, especially in Optimisation

Table 2 Comparison between the techniques used for production of the digital replicas.

THEME DEVELOPMENT FOR DIGITAL TWIN CONSTRUCTION

After the production of the digital replica, the researchers can present a comparable specification for the theme development of DT construction. The two techniques above indicate that depending on the intended purpose of the digital replica, suitable techniques can be chosen case-by-case. DT uses Internet of Things (IoT) methods to connect Physical Twin to Virtual Twin. Moreover, it provides diverse opportunities for the authentic virtual representation of the assets.

These recent developments have changed the way that the architectural heritage is being presented. Representations are more realistic than idealised. For example. An audience may be interested in the actual behaviour of the structures in the real weather conditions. DT with IoT-enabled sensors can represent the condition of the Built Cultural Heritage under diverse circumstances. The audience can observe the condition of the structure when it is virtually simulated by computer software. The sensors can also detect the current condition of real buildings and generate simulations of the previous states or predict future states; it is being used in complex systems (Jones et al. 2020). Time travel experiences can be useful when the climate in some areas is changing between historical periods; especially, after the formation of the new parts of cities. The climate of Tehran has changed since 1935 when Iran National Bank was built. DT can assist in visualisation and simulation of the weather conditions by using the active sensors on the structure.

There are always different archaeological hypotheses by archaeologists and art historians for the formation and existence of built cultural heritage. ‘Mixed reality’ methods assist in visualisation of assets (Sénécal et al. 2017), and the sensors on the real structures can be useful not only for attractive representation of buildings but also for the investigation of the authenticity of the hypotheses. Multiple DTs presenting diverse perspectives can be representable in virtual museum platforms to allow the audience to think critically about the authenticity of the archaeological hypotheses, and to choose areas of the site to explore and discuss.

Following the construction of different Virtual Twins from physical assets, they are simultaneously representable to explicitly illustrate the history of the architectural asset. A DT concept can change the archive and documentation process applied to assets. For instance, if we had a DT of the different alterations of the Iran National Bank building, its history would be representable in interesting ways. Regardless of choosing Digital Recording or Traditional Recording, DT construction and its interoperability with representation platforms provide opportunities for Cultural Heritage.

Cultural Heritage activists often argue for the democratisation of Cultural Heritage information and the dissemination of authentic data. DT provides the opportunity for real-time information to be shared with the community depending on the experts’ and curators’ preferences.

CONSIDERATIONS FOR FUTURE WORK

As discussed above, DT is a combination of different technologies. In an ideal implementation, DT is interactively connected to an audience with VR and AR display systems, live sensors, and highly responsive virtual or actuated models so that they can dynamically respond to users' real-time interaction. The future proposition is that DT will be engineered as an integrated platform providing an audience interface for authentic heritage information. The proposed DT conceived as an interface would make the representation of the asset more realistic and its differentiation from the experience of visiting the original site becomes an alternative view or extended view of the asset.

Imagining future applications, we envision that sensors placed on different assets from distinct lands and different historical eras, could provide the opportunity for visitors to choose the related assets together and visit them simultaneously. In an interactive DT environment, users would have the option to design which collections of assets they want to explore; for instance, they might read about the historical relations between Achaemenid dynasty and Pahlavi and seek to observe two of them together. Also, visitors would explicitly look at the details of the Achaemenid eclectic site, Persepolis, in addition to the contemporary public buildings' nationalism movement characteristics. Immersive technology would assist in the development of authentic representations of architectural assets by using interactive DT assets from the heritage assets.

Several large-scale challenges remain for future consideration. To reliably instrument a heritage site and transmit live data for museum visitor experiences, considerable resources are required, including technology, labour, and availability of specialist expertise. Data transmission is often inconsistent in terms of quality and reliability. Real-time sensors generate noise which must be corrected in real time to provide visitors' experiences of high quality. And in terms of cultural norms, the brand identity and value proposition of many museums depends on the exhibition of artefacts that have been appropriated from heritage sites and interpreted in a light that does not examine the problems of this colonial practice. New perspectives on cultural authenticity are required to enable museums to develop alternative post-colonial institutional brands.

CONCLUSION

Development of DT for heritage is an opportunity to make a strong connection between the real data from the architectural assets and their digital replicas, regardless of the limitations of access to a physical heritage site. In this regard, DT assists in meeting the challenges for the dissemination of authentic Cultural Heritage data.

The present investigation of the availability of the new methods in Cultural Heritage enabled the authors to understand the potential capabilities. This article makes a wide comparison between two designed methods for DT construction with descriptions of professional high-tech tools and technological expertise required for Virtual Twin construction and its development.

In summary, each of the applied methods possesses unique attributes helpful for different purposes in architectural curatorial representation. The case study of the Iran National Bank presents the use of traditional recording to develop the model in CG modelling software, Cinema4D. This case illustrates the great manipulation capacity depending on the main purpose for the construction of DT. However, the process was time-consuming and dependent on a particular modeller's approach. The second case study, Achaemenid capital column, shows that a photogrammetry-based model is finely representable and interoperable in different platforms. However, the model production was challenging because photogrammetry generates point-cloud data, which requires conversion into a geometric model, and this optimisation is challenging.

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