

Digitalisation of asset management in Chinese temples in Hong Kong

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ABSTRACT

This paper presents the efforts to digitalise the asset management of Chinese temples in Hong Kong, which is a new trial in the industry. To revitalise these unique heritage buildings and empower the temples' administration with digital tools, three Chinese temples in Ap Lei Chau and Aberdeen directly administrated by the Chinese Temples Committee (CTC) were selected as pilot projects where a digital twin was developed to enable digital asset management. Laser scanning technologies were encompassed, integrated with close-range terrestrial photogrammetry to generate precise 3D Building Information Modelling (BIM). An asset information management platform was built to consolidate the operation data and establish a common data environment to support data-driven management, with parameters collected from Internet-of-Things (IoT) devices and Digital Works Supervision System (DWSS) statistics consolidated. Moreover, Augmented Reality (AR) was leveraged for tourism and education, and different phases of historic temples were modelled to present the evolution and culture over time. Through this project, in addition to the higher operation efficiency enabled by the digitalised workflow and consolidated data source, a digital blueprint was built through the formulation of a digitalisation roadmap, which contains customised recommendations on cutting-edge digital tools' implementation in relation to heritage monuments. This can be extended to 24 Chinese temples in the future as well.

KEYWORDS 3D scanning; BIM; IoT; DWSS; digital twin; historic temple conservation; asset management

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Received 15 June 2023

1. Introduction

This paper aims to share the efforts and experience gained from a digitalisation consultancy service for the Chinese Temples Committee (CTC) in Hong Kong, implementing digitalisation of asset management in Chinese temples for an innovative trial through the implementation of a one-stop digitalised management platform for engineering assets.

When referring to digitalisation, modern skyscrapers with digital foundations such as high-speed network, sufficient data, and electronic documents always come to people's mind as a proper context in which to leverage the power of digital tools. However, with the evolution of the digital era, demand is seen to involve traditional buildings in digitalisation as well, from heritage conservation activities and routine maintenance to the facilitation of education and tourism. In this project, the feasibility of applying digitalisation work in traditional buildings without a digital framework is explored, so that an as-built record can be generated as references for the repair/maintenance and design of major improvement works before our historic building features further deteriorate or become weathered with time. Innovative approaches including as-built scanning/modelling and digital twin development are undertaken to incorporate century-old temples into the era of digital transformation.

2. Project background

In response to the policy of "Construction 2.0" under the Hong Kong Special Administrative Region (HKSAR) Government (Development Bureau, 2020a; Development Bureau, 2020b; The Hong Kong Special Administrative Region of the People's Republic of China, 2021), the CTC intends to introduce a digitalisation blueprint to its 24 directly administered temples through establishing a comprehensive digital platform through the utilisation of advanced digital tools including Building Information Modelling (BIM), Internet-of-Things (IoT) application, and Virtual Reality/Augmented Reality (VR/AR) applications. To enable digitalised spatial data presentation, BIM building is a critical step to facilitate digital twin visualisation. Without existing 3D data available, 3D scanning was conducted as the first step to deliver a point cloud and mesh for modelling. On the other hand, unlike modern buildings equipped with a Building Management System (BMS) to provide comprehensive environmental data, temples required IoT hardware installation to sense and collect the environmental data. Consequently, the integration of BIM and operation data contributed to Asset Information Management (AIM), a 3D digital twin visualisation interface. Finally, the BIM was further utilised to deliver AR and VR applications.

Three Chinese temples, namely Tin Hau Temple in Aberdeen, and Hung Shing Temple and Shui Yuet Kung

in Ap Lei Chau were selected as pilot projects to achieve synergies in this project.

The key objectives of the digitalisation project included:

- Digitalisation of maintenance workflow for all 24 temples directly administered by the CTC through implementing a bespoke Digital Works Supervision System (DWSS).
- Digitalisation of the physical assets in three Chinese temples as a Pilot Scheme, including the implementation of an AIM system and IoT.
- Application of VR/AR to enable an immersive digital experience for tourism and education, thus facilitating historical value preservation.

To overcome the various challenges that arose from this new trial in the historical building preservation field, innovative design approaches were undertaken by the professionals from the project team. These included:

- The digitalisation concept typically adopted for modern skyscrapers is further evolved and interpreted to be more appropriate for traditional Chinese temples' use. For instance, the assessment of critical historical features was added to identify critical items for graphical presentation and parameter display.
- An as-built work logic was applied, instead of typical as-design logic, in the 3D scanning and BIM building work stage to contribute to accurate digital replica delivery. Figure 1 shows the 3D mesh for Tam Kung Temple delivered from 3D scanning, with as-built work logic applied.
- Customised workflow digitalisation design was incorporated into the DWSS launched for the CTC. The work procedures were designed to suit temple operation routine work, such as defect inspection.

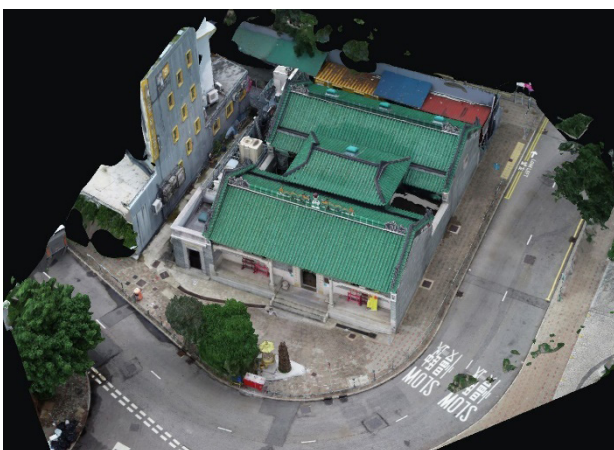


Figure 1. 3D mesh for Tam Kung Temple.

3. Method

The project approach and method adopted consisted of the procedures listed below:

- (1) An Employment Information Requirement (EIR) study was conducted as the first step to obtain a comprehensive understanding of the organisation's operation and user requirements, and such collected information informed the digitalisation strategy.
- (2) A BIM execution plan was defined by the BIM experts. The level of detail, BIM uses, and benchmark with the industry standard were all encompassed to guide the modelling work for accurate delivery.
- (3) A Digitalisation Roadmap was developed as a blueprint to guide the CTC's digital transformation direction. Based on the investigation findings and the organisation's development vision, this roadmap guided the subsequent implementation of digital initiatives and pointed out the phased development strategy for the CTC.
- (4) A 3D asset survey via 3D scanning was one of the procedures utilised to collect the 3D information of all assets in the pilot scheme temples from architectural, structural, and building service perspectives. It was used for BIM production and for safeguarding high-quality 3D digital models of the assets for future application such as 3D printing for repair and maintenance use.
- (5) BIM models were built to demonstrate the graphical information of temples and historical artefacts inside. It enabled the presentation of adequate information for daily maintenance and asset identification and maximised the operation speed.
- (6) DWSS is one of the platform modules to manage all work orders created during daily inspection work and to facilitate coordination among all the collaboration parties, from frontline staff to top management.
- (7) An AIM system was developed with the aim to manage all assets in digital formats and enable the consolidation, visualisation, and querying of all 3D assets' information through a single user interface.
- (8) IoT was used for temple environment air quality monitoring and crowd management. Through collaborating with Government Wide IoT Network (GWIN) developed by the Electrical and Mechanical Services Department (EMSD) of the HKSAR Government, sensing data were collected via the gateways then transferred to a backend data platform to facilitate future predictive maintenance analytics applications.
- (9) VR/AR was applied for better worshippers' experience, as well as assisting daily inspection through the convergence of BIM and these visualisation techniques.

Internationally, digital heritage is a new trend to preserve heritage information digitally (Kruglikova, 2020). The Chinese temples' digitalisation trend by gathering and connecting data on different cultural and religious information such as Taoist and Buddhist is also popular in East Asia, including Hong Kong. Digital platforms containing digital information about Chinese inscriptions,

Chinese temples and associations surveys, and archival and historical sources were also referenced, such as the Singapore Historical Geographic Information System (SHGIS), which covers Taiwanese, Japanese and Tibetan Buddhist monasteries across the region (Yan et al., 2020). Common challenges are not always easy to surmount when faced with issues such as cost, lack of human resources and skills, sustainability policy and digital road map limitations (Ocón, 2021). Recently, 3D laser scanning, close range photogrammetry and aerial photogrammetry have become key technologies to provide a cost-effective approach to digitalisation related to 2D and 3D information intuitively and efficiently in the form of digital photography, 3D digital point clouds, 3D BIM models and orthogonal photographic mosaic and panoramic photographs, which form Heritage Building Information Modelling (HBIM) (Fang et al., 2022; Jo and Hong, 2019; López et al., 2018; Rodríguez-Moreno et al., 2018; Sun et al., 2022).

A desktop study and stakeholder engagement was the beginning point of this project to understand the organisation's long-term development strategy, expectations, and challenges met in operation work.

A comprehensive question list was prepared for circulation to relevant stakeholders including CTC staff from various sections and external stakeholders such as contractors and temple keepers. To align the circulated information, the same question list with specific supplemental questions were distributed to the CTC for preview and preparation before the interview. For instance, operational workflow and Information Technology (IT) facility-related questions were specifically added for the administration section, while temple promotion-related questions were specifically added for the Temple Unit's promotion team due to the work scope.

Considering that some technical items in this project might be unfamiliar to the interviewees without advanced knowledge background, a briefing session was arranged at the beginning of the interview sessions. The project objectives, deliverables, and project method for technical deliveries were briefly introduced as knowledge sharing to facilitate interviewees' understanding and to support their further opinion inputs during the sessions. Nine stakeholder interview sessions were held in total to depict a full landscape for data utilisation and operational workflow in the CTC.

4. Feasibility study

On top of the requirements collected from stakeholder engagement sessions, a feasibility study and industry benchmarking were conducted for several disciplines to facilitate the recommendation made to the CTC on an appropriate digitalisation roadmap.

4.1. Heritage assessment

Heritage assessment is a unique procedure of this project compared with other digitalisation work, where engineers' expertise is leveraged to identify the key Mechanical, electrical and plumbing (MEP) components which need visualisation in a digital replica. In historical temples, heritage items' significance assessment is an indispensable procedure to judge the valuable items that should be the focus of scanning and modelling work. Hence, international heritage standards, national heritage standards and Hong Kong local heritage standards such as those issued by the Antiquities and Monuments Office (AMO) were studied.

With reference to the Conservation Plan (Kerr, 2013), the assessment of the level of historical items' significance was based on:

- An associated event or person's importance level to the locality or to the nation;
- Intimacy level and duration of the association;
- The evidence of the association's survival level, either in physical evidence at the place, or as evidence of the impact of the place on persons, literature, and events; and
- The place's intactness or evocative quality, and its setting relative to the period of the association.

Based on the abovementioned criteria, assets in temples were evaluated, and for those with high significance, detailed scanning was applied in a later work stage and comprehensive parameters were recorded in BIM model fields.

4.2. DWSS

DWSS implementation entails reference to the Development Bureau (DEVB) of the HKSAR Government circulars as the local standard, echoing the changes as a result of implementing "Construction 2.0", and advocating "Innovation", "Professionalisation" and "Revitalisation" to enhance productivity, quality, and sustainability.

The five mandatory modules of the DWSS as specified in the DEVB technical circular are:

- (1) Request for Inspection/Survey Check (RISC) Form;
- (2) Site Diary/Site Record Book;
- (3) Site Safety Inspection Records;
- (4) Cleansing Inspection Checklists; and
- (5) Labour Return Record.

However, the abovementioned five modules are not exactly applicable to the temple context, where routine defect inspection is the core work procedure, rather than construction work. A customised DWSS design was scheduled for the CTC to include work procedures such as defect report, approval, quotation, and verification, etc.

To facilitate the user experience, the DWSS was designed to be web-based, and accessible through a secure network connection on laptops, workstations,

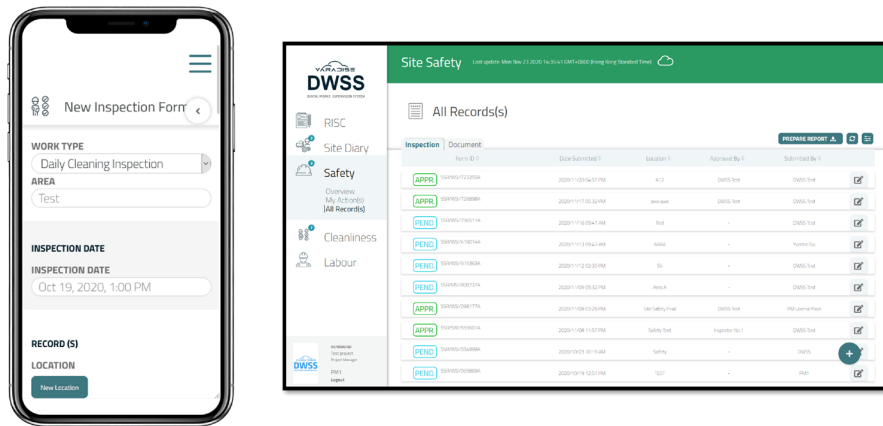


Figure 2. DWSS user interface mock-up.

mobile devices, and tablets, etc. The captured data can be automatically synchronised among all the end devices to support an efficient workflow, including site records’ circulation among contractors, inspection report approval by supervisory staff, and timely construction work progress and performance alerts.

4.3. BIM - AIM

The AIM standard adopts general industry standards including the BIM Guide for Facilities Upkeep (Version 2.0) issued by the Architectural Services Department (ArchSD) and the BIM-AM Standards and Guidelines (Version 2.0) issued by the EMSD (Electrical and Mechanical Services Department, 2022).

User requirement studies on the current system workflow, entities, data storage and process flow were conducted via systematic system analysis and design approach. All data entities, data list, and process functions to be programmed were analysed and designed through standard entity relationship diagrams and graphic user interface design. Each asset was defined according to the required asset data characteristics with key data attributes identified in the BIM to provide an automatic process for handling BIM data transparency and open architecture using international data exchange formats such as Construction Operations Building Information Exchange (COBie). The AIM user interface with a 3D model display is shown as Figure 3.

5. Data acquisition

The first procedure of on-site work in this project was 3D scanning for spatial data acquisition. This facilitates the BIM modelling work and the following AIM development based on it. In the meantime, asset information and operation workflow were collected from the CTC for integration with spatial data for comprehensive display.

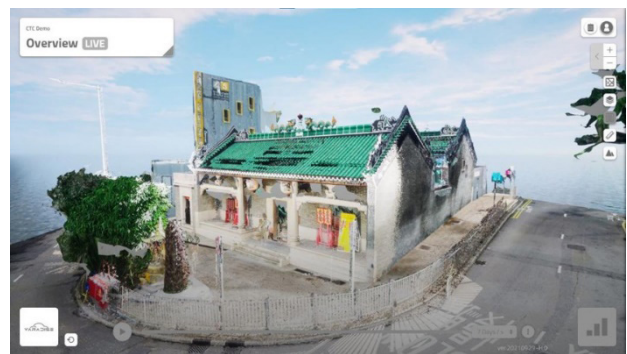


Figure 3. Consolidated digital platform user interface mock-up.

As part of the Pilot Scheme, 3D scanning via Light Detection and Ranging (LiDAR) scanning as well as photogrammetry scanning were conducted. All features and elements within the lot boundary of the three temples were scanned, including both exterior and interior.

Main 3D scanning approaches nowadays are LiDAR scanning and photogrammetry scanning. LiDAR scanning means laser scanning, which uses a laser beam as light beam to measure all objects via distance measurement. Using professional geospatial LiDAR scanning, the accuracy can reach the mm level, while LiDAR scanning via laser beam only reports position in three dimensions as 3D points without colour. It needs to work with separate photography to remeasure all colour from photography and impose it back to the raw LiDAR 3D points. Hence, industrial LiDAR scanning is mainly used to capture the geometry but not the colour or texture of an object.

Photogrammetry scanning means photography measurement scanning, which uses a series of overlapping or stereo-pair photographs to measure objects in the photography in three dimensions. It uses a normal light beam reflected from an object to the camera to achieve the

photographic image and perform measurements. The digital photogrammetry approach uses digital photographs to reconstruct reality in coloured 3D point cloud format. The colour retains the original digital photograph colour that can be further transformed into a 3D colour textured mesh model.

In this project, 3D scanning of critical historical features with a level of detail that enables future 3D printing for re-producing elements was conducted as well. For 3D printing requirements, a close-range digital photogrammetry scan is suggested but the required object should be placed in an open space and the scanning team should be able to scan around in a full circle horizontally and full circle vertically. All directions from left to right and all directions from top to bottom should be fully scanned to achieve whole object completeness. Sometimes, the object may need to be suspended to achieve 360° scanning or rotated on a scanning table to achieve a complete scan. A very detailed scan may also need an iterative scanning process to reach a certain expected level of detail. No matter which approach, all of them are dependent on

line-of-sight and lighting conditions. Some shadowing areas cannot be scanned from any direction if there is a complicated and curved surface hidden inside the object. This is particularly common in sculptures on walls such as stone sculptures. Post-processing by manual editing or interpretation referencing from other similar objects and research documents may alleviate the issue.

Both LiDAR scanning and photogrammetry scanning produce a 3D point cloud. Both technologies need line-of-sight conditions to capture real-world objects for virtual digital 3D models. Survey control points are essential to reposition all 3D scanning raw data from default local coordinates (0,0,0) to the local government coordinate system.

There are two coordinate systems in Hong Kong. The first is the horizontal coordinate system for X and Y. It is called the HK 1980 Grid system (HK80). HK80 is a map projection system to convert longitude and latitude degree unit coordinates, i.e., geographical coordinates, into those which are compatible with the local Hong Kong flat area system.

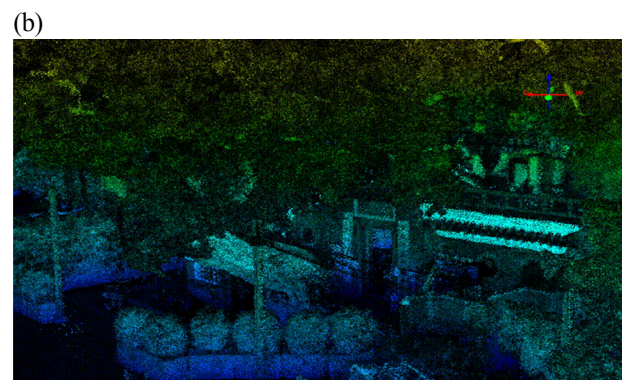
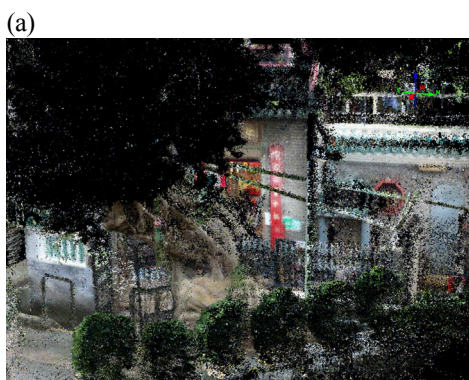


Figure 4. Standard-level 3D scanning for Shui Yuet Kung, Ap Lei Chau.

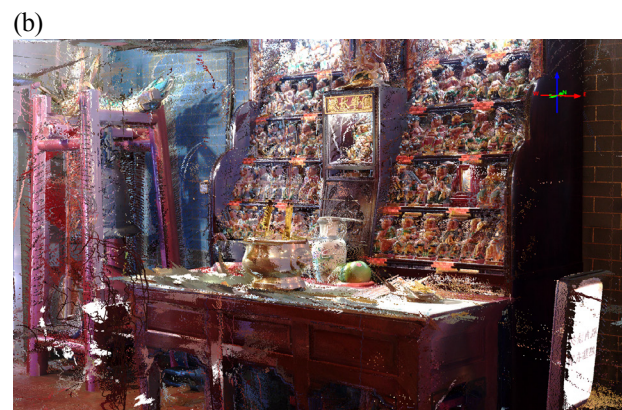


Figure 5. High-level 3D scanning for Hung Shing Temple, Ap Lei Chau.

(a)



(b)



(c)



Figure 6. Optimal 3D scanning for 3D printing applications, Shui Yuet Kung, Ap Lei Chau.

The second is the vertical datum for height or elevation measurement. It is called the HK Principal Datum (HKPD). In this project, the HK80 and HKPD systems were both embedded in 3D scanning point cloud data for all basic scanning. Considering the consequent information conversion to BIM, all drawings produced from BIM capture the HK80 and HKPD. This creates a complete system where all 3D digitalisation newly acquired from this project can integrate with all local government data such as the Lands Department base map, the basic mapping system data, the lot boundary data, the cadastral information system data, and other departments' data references from the Lands Department.

Detailed scanning of critical historical features as defined by the Heritage Specialist was conducted with a level of detail that enables future 3D printing for re-producing elements. For 3D printing, close-range photogrammetry and handheld LiDAR scanning were considered. However, a handheld LiDAR scanner mainly provides geometrical results with a relatively poor colour texture outcome. It was evaluated as not cost-effective for Chinese heritage conservation where both geometry and colour texture are required at a very high-quality level; thus, close-range digital photogrammetry utilising a decimal millimetre standard approach was considered.

The scanning results in various resolutions are shown in Figure 4 to Figure 6.

6. Digitalisation deliverables

6.1. BIM

The challenge in BIM is that the international BIM technology is basically developed from a building design perspective and for modern object modelling instead of historic building/asset modelling.

First of all, BIM aims at the modelling of building information for design and construction, and the representation of real-world objects is for design and cost optimisation purposes, etc. The second obstacle is that specific Chinese architectural elements do not match any existing kinds of object library or BIM family, type and instance in commonly used software.

The conventional BIM design logic was replaced by BIM as-built logic for Facility Management (FM) and Asset Management (AM) requirements in this project. The CTC required both design and as-built logic because most of the cases are for FM or AM operation. The use of BIM is an appropriate digitalisation approach but requires post design management logic and an application mindset to extend the BIM design practice to more building management business models.

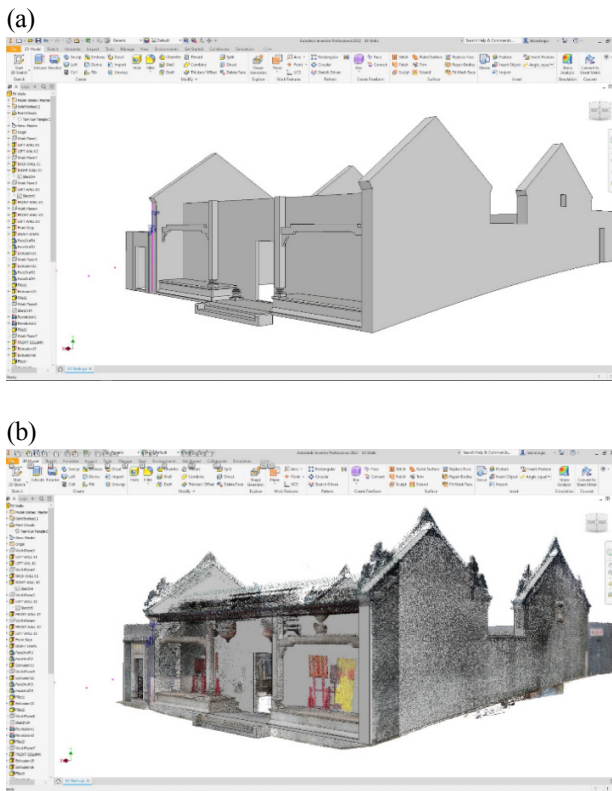


Figure 7. BIM modelling for Tam Kung Temple based on a point cloud.

6.2. DWSS

Following the desktop study and stakeholder engagement discussions with CTC users, a DWSS consists of four modules, namely Defect Report (M1), Site Inspection Record (M2), Quote Tracking (M3), and Work

Completion Report (M4) developed for the CTC. With a comprehensive understanding of the CTC’s various levels of user, including project manager, maintenance officer, and technical officer, etc., a role-based system logon and authentication control approach was provided.

Considering that the temple operation context faced by the CTC is different from construction sites where a DWSS is typically adopted, a customised digitalised workflow design method was incorporated into the work, instead of full compliance with the six mandatory modules listed in the DEVB technical circular.

In addition to the digitalised workflow, insightful dashboards were also provided in the DWSS. Vivid charts and summary figures as shown in Figure 8 enable temple operators to understand the work progress, and work orders in various stages are categorised and visualised to empower the operators with a clear understanding of the work status.

6.3. AIM

The AIM built for the CTC contributes to establishing a Common Data Environment (CDE), integrated with IoT sensor data and temples’ operation records to build a centralised data repository. Through leveraging a unique ID of BIM components, the 3D element and related asset information stored in databases can be linked, thus enabling interactivities and a user-friendly operation experience via the delivered solution.

Within the AIM’s 3D user interface, three designated temples’ BIM models were processed, rendered, and equipped with different display effects. A user-friendly portal for asset management was delivered to the CTC with functions including:

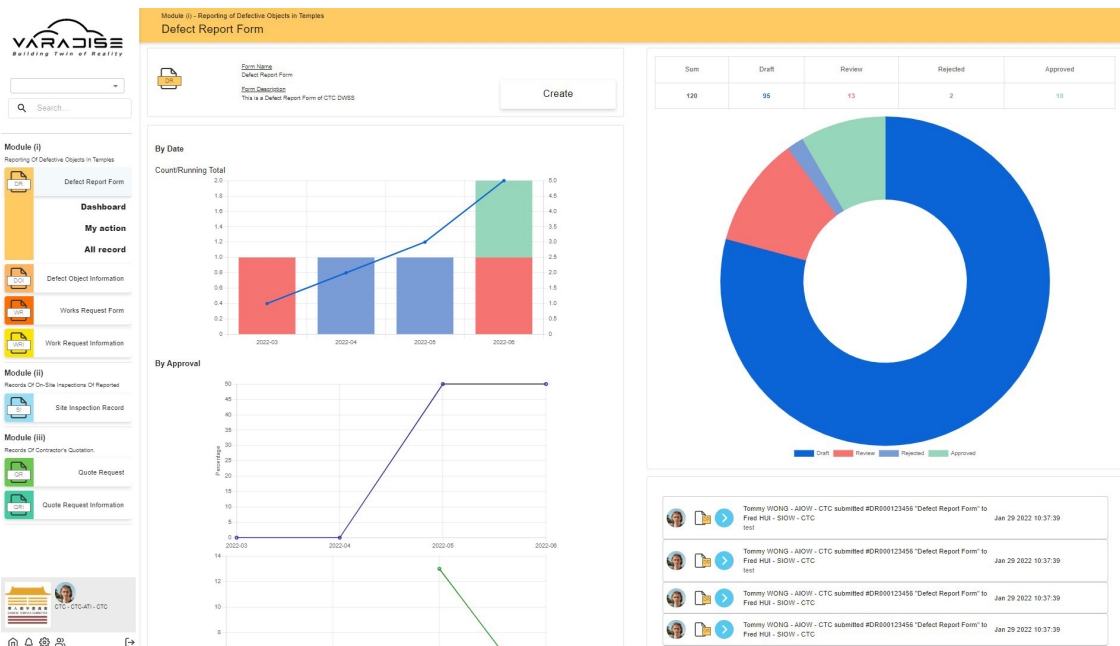


Figure 8. DWSS dashboard.

- Section cut. The temples' 3D models can be cut from various directions, thus enabling interior environment inspection.
- Measurement. With accurate dimensions in BIM buildings, the distance, height and angle within the 3D model can all be measured via the AIM measurement tool.
- Navigation. A virtual walkthrough within the 3D model from a visitor's view is enabled within AIM.

Figure 9 shows the captured user interface from AIM.



Figure 9. AIM user interface.

6.4. VR/AR and positioning system

The VR/AR system provided to the CTC uses 3D BIM models for presentation, visualisation, and maintenance operation. The positioning system uses new Image Coding technology without a QR code, where the image can be a well-designed graphic without showing any QR code. The user initiates the web link and scans the image on site to trigger the corresponding image copies on the server to display the VR/AR models on mobile devices, thus showing BIM elements in 3D superimposed onto the reality perspective view in a predefined direction, showing any inaccessible temple information for tourism or educational use, and displaying hidden building services such as cabling inside the physical walls using 3D model virtual display on the specific wall with the image code.

To attract more young people to visit the temple and become interested in traditional culture, creative AR

applications that allow customised decoration by visitors were provided. During traditional festivals, such as Spring Festival, visitors can scan the temple's main entrance in the AR application, then add customised virtual 3D decorations like lanterns in the temple, and captured images can then be shared via social media.

6.5. Knowledge management

Good knowledge maintenance for all stakeholders, internal staff, and external partners plays an important role in contributing to the success of the new digitalisation concept. To guarantee long-lasting benefits to be brought by this project and a sustainable future development plan, knowledge management approaches were undertaken to push innovative ideas and digital transformation.

In this project, knowledge management was conducted through various methods and techniques, including appropriate training for various levels of staff to suit the digitalisation deliverable operation needs.

Knowledge management assists in identifying the definition of digitalisation and optimised approach to achieve digitalisation. This reduces the cost associated with digital transformation and describes a clearer direction for digitalisation work including scanning, modelling, and data integration in this project.

7. Concluding remarks

This is the first digitalisation blueprint for the CTC, in which various innovative initiatives are proposed, explored and implemented to contribute to the project's success. Enhanced operation efficiency is seen as a result of the digitalised workflow and consolidated data visualisation interface. Hong Kong has yet again achieved innovation ahead of the curve through preserving our ancient Chinese culture and historical identity. The team concentrated on bringing new ideas and technologies into this traditional workflow, as well as re-engineering the traditional maintenance logic. The definition of traditional concepts, from naming and terminology to process flow and sub-tasks, has been newly defined and redefined to suit the new conceptual design and new logic design. This project management approach outperforms the typical traditional system as a breakthrough, providing good lessons for other similar projects to achieve a cost-effective blueprint design and implement it at the physical operation level with high efficiency.

Acknowledgements

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Mr Sankar S Villupuram is a Director, holding the responsibility of leading Digital Services & Products for ARUP in East Asia. This involves creating Software as a Service and data-driven digital solutions enabled by AI apart from advising clients on the integration of data silos in built environments. He has over 23 years of experience in the design and implementation of transformational smart operational solutions leveraging Internet of Things (IoT) and data analytics across various domains viz. construction, public security, gaming, property, supply chain/logistics, etc. He has managed several landmark projects in Hong Kong and gained extensive multidisciplinary experience in a bid to achieve strategic delivery. His pro-bono work includes a board of director position at the Hong Kong Internet of Things Alliance and serving Project Management Institute (Hong Kong Chapter Board). Mr Villupuram holds a MBA (HKUST) with a bachelor's in Electrical & Electronics Engineering. He is a professionally qualified CPIT (Project Director), PMP, CISA (Information security auditor), CISM (Information Security Manager) and CDPSE (Data Privacy Solution Engineer). He completed the executive course from MIT on Innovation & Leadership in 2018. He

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