Abstract: Tangible and intangible benefits of building information modelling (BIM) in heritage buildings presents a constant debate around the ‘value add’ of heritage building information modelling (HBIM). HBIM can create an avenue for detailed modelling of heritage elements in the building envelop, documentation of unique cultural attributes and a platform for maintenance during operational phases. And the debate is often more about the ‘how’. Currently, traditional 2D drawings form the basis for maintenance decisions which makes the process cumbersome. Moreover, such drawing sets are often incomplete. This study aims to leverage BIM from a maintenance perspective to develop a standardised workflow for heritage building maintenance. A ‘simulation’ based methodological approach was adopted in this study. A Leica BLK360 3D scanner was used to capture 100-point cloud scans, then applied to create HBIM profile for an existing heritage roof, service ducts, clock and storage space. Autodesk Recap Pro was used to register the point-cloud and analyse the roof profile. The results revealed critical risk areas to the building roof. Exterior images were relatively similar to the interior point cloud. The workflow developed provides a standard workflow for future maintenance in heritage buildings. The results directly impact decision making by policy makers for transformation to HBIM.

Keywords: Building Information Modelling (BIM); Heritage; HBIM; LiDAR; Maintenance; Workflow.

1. Introduction

Architectural Heritage serves as a physical reminder of the past, culture and thinking of days gone by. It plays an important part in shaping a places current character but also they serve as ‘placemakers’. Thus, it preserves the culture of a place and what makes it unique, but also uniquely New Zealand. Heritage places also include those of Maori culture which are integral to their whakapapa and identity (Heritage New Zealand). Heritage conservation requires accurate data to manage, maintain and operate (Lavay & Sohet, 2007; Lucas, 2012). Roofs are very difficult to survey and analyse as access to them may prove to be dangerous, time consuming and expensive. However, the use of Unmanned Aerial Vehicles (UAV) allows for safe, quick and relatively easier ‘data’ collection of any roof. The analysis of that data could considerably improve the understanding of the roof’s performance, condition and maintenance. This leads to the research question of can heritage building information modelling (HBIM) facilitate improvements in contemporary conservation planning given the shift towards digital technology in architecture, engineering and construction (AEC). Currently, 39% of the industry’s interest group utilised integration of digital asset or spatial information with asset systems which shows a low industry-wide uptake of leveraging of the capability of BIM in asset management (EBOSS, 2019).

Given the need to constantly monitor, maintain and implement conservation plans for heritage buildings, the incorporation of BIM, LiDAR and UAV would provide solutions to the lack of as-built data repository but also the evidence based data required by management. Furthermore, the implementation of a standard BIM workflow could lead to an improvement in maintenance cost and decision making. The pilot heritage building existing roof had early signs of the end of service life and issues around functionality and conservation maintenance arose which requires adequate BIM workflow for capturing current state of the roof and simulation of future intervention plans. Therefore, the goal is to leverage BIM from a strategic maintenance perspective to develop a standard workflow for heritage building maintenance in New Zealand. This starts with a comprehensive literature review of BIM, LiDAR and UAV. The method utilised to achieve the set objectives.
enabled real time data capture using UAV and future development of as-built BIM model. The results of presentation to heritage stakeholder and VR immersion are outlined. The subsequent parts of this paper covers methodology, results from a pilot heritage building, and discussion and conclusion.

2. Heritage Asset Management

Heritage assets bear similar features to facilities such as healthcare, commercial buildings and recreation. Facilities Management (FM) is an interdisciplinary practice related to the management or maintenance of buildings and to facilitate the integration of buildings and building users. FM practices draw on theories and principles of engineering, architecture design, accounting, finance, management and behavioural science (Aziz et al., 2016). Moreover, FM integrates multi-disciplinary activities within the built environment to manage their impact upon people and workplace (Boateng, 2011). FM phase is typically the longest phase in the buildings life-cycle and has a higher cost compared to rest of the phases of the building (Aziz et al., 2018). However, studies such as Lucas (2012), Araszkiewicz (2017) and Haddock (2018) found that the FM phase is one of the most disconnected phases in the building life-cycle because of poorly planned handover processes and inconsistent involvement in the early stages of the building life-cycle. This is too often reflected in the lack of updated as-built drawings, as in the case for the heritage facility of this study.

In addition, the loss of information and manuals, and a paper based data-entry has a significant impact on the FM resources and budget (Lavy & Jawadekar, 2014; Araszkiewicz, 2017). This is a major source of concern for building maintenance decision making. Poor management of these buildings can lead to serious consequences relating to loss of vital heritage (Ghosh & Chasey, 2013). In addition, FM teams are also constantly faced with the challenges of reducing resources, personnel, time, and funding (Lucas, 2012). Nonetheless, successful implementation of FM in heritage buildings requires strategic planning, customer care, benchmarking, environment and staff development. Therefore, the redefining of asset management data capturing processes with a heritage user specific BIM workflow has both operational and organisational advantages with enhanced heritage protection.

3. Heritage and Building Information Modelling (BIM)

BIM is a shared data and knowledge platform for all stakeholders involved and provides a basis for decision making during the entire lifecycle of the building: design, build, maintain, operate and finally demolition (Mohanta & Das, 2016; Enegbuma et al., 2014). Application of BIM provides improvements in accurate up-to-date data for FM decisions making processes (Ohueri et al., 2018).

One way to allow for existing buildings to be entered into BIM is through the use of laser scanning. It affords stakeholders the confidence in decision making for high risk redevelopments involving threat of damage to heritage building or harmful building materials such as asbestos (Werner, 2013). The ENEA Research Center of Frascati in Rome has explored improving the quality of heritage documentation with high quality illumination of scanned heritage by using Imaging Topological Radar (ITR) such as RGB-ITR (Red Green Blue-ITR) and IR-ITR (Infrared-ITR) at various wavelengths with colour digitalisation of up to 30 metres aimed at improving the quality of heritage documentation (Francucci et al., 2018). Irrespective of the parametric building elements, cultural monuments such as archived relics can be modelled within an AR/VR environment (Karadimas et al., 2019). This opens a whole new course of revenue stream worth exploring given the challenges of travel restrictions and inability to access certain heritage sites. Access is also limited for people living with some form of disability who wish to experience the same level of customer experience.

To improve HBIM information accuracy, Carleton Immersive Media Studio (CIMS) have extended research into standardising HBIM development level into the level of details (LOD) (Graham et al., 2018). Hence, capturing accurate point cloud scans enables the gradual development of a heritage database to promote easy access to objects and relevant information. In a similar study in Malaysia, LOD 500 has been earmarked as the standard for reviving cultural values in heritage preservation (Ali et al., 2018). Identification of key LOD desirables will ensure asset teams have adequate information when embarking on maintenance decisions. This process would also assist future guidelines and implementation of HBIM.

Cultural heritage knowledge was mapped to project the well-known problems in understanding building decay (Chiabrando et al., 2017). Given the massive scale of the heritage building roof in this study, simulations into future degradation of the roof component can be achieved. To promote a cost effect laser scan, a research on Foinikaria Church preservation using unmanned aerial vehicle generated accurate point cloud data which was exported into BIM with high data accuracy (Themistocleous et al., 2016). HBIM was utilised in tracking strategic
building function in relation to future performance standards for components to withstand seismic risk (Palestini et al., 2018). This precedents further reinforce the position of BIM workflows in heritage asset maintenance.

4. Methodology

Solutions to challenges in heritage building maintenance as outlined in the previous section can be readily approached through a simulation (Fellows and Liu, 2015; Creswell, 2012). The first part of this 'simulation' approach used a drone to map and record the external roof of the building. This was done with an UAV device DJI Mavic Pro Drone. The drone was controlled by a hand set connected to an iPad mini with a preprogrammed flight path using PIX4D CAPTURE. The flight was set to a grid path with an overlapping snake pattern and shown in Figure 1. The drone was completed under Part 101 and required notification to nearby helicopter services. After set up, the drone took off from its designated spot up into the air to follow its path. During its flight the drone camera would take photos every few meters which would then be stitched together in processing. The first flight was set at 50 metres above the ground. However the flight was cut short due to aggressive seagulls circling the drone. The second flight straight after was set at 70 metres from the ground but was also cut short due to strong winds. Another flight was undertaken on a different day in the morning with the assistance of a second drone which emitted hawk noises to scare off the territorial seagulls. PIX4D was utilised in processing the captured images (Arnadi et al., 2019). Several flights were flown for mapping, thermal mapping and scanning of the building facade.

The second part used a 3D Leica BLK360 scanner to scan the internal roof space, the methodological process flow is shown in Figure 1 below. The scanner was kept along the central planked path of the roof space. It was controlled via an iPad which was then placed under the scanner between scans to maintain a strong WiFi connection. The iPad was set up with Autodesk Recap Mobile to allow for manual registration during the scanning process. It was important to keep scans close together to allow for the software to readily register each scan to other scans. This was especially important because of the repetitive nature of the space (trusses, ducting, sarking etc.). Leica recommends distances no wider than 6 metres, we scanned every 2 metres. This meant that in the central section of the building we scanned on either side and on top of each truss. Each scan took around 3-4 minutes. A total of 90 scans were transferred onto a desktop computer and registered using Autodesk Recap Pro.

5. Result and Discussion

The result from the processing was a realistic point cloud model of the interior and exterior heritage roof spaces shown in Figure 2. A small number of scans did not transfer due to WiFi errors during scanning and the edges behind all the ducting that the scanner could not be reach and hence could not be modelled in the point cloud. However, the central section of the building scanned well because of the lack of obstructions. Both side wings were harder to scan due to the high density of ducting and services. Subsequent scanning sessions were required to fill in as much of the missing areas as possible. Due to safety concerns not all of the roof space could be scanned to a 100% complete model. This was because of ducting and services and the lacking of planked path way to safely get to hard to reach places.
The data was then processed on PIX4D software. This software gave a variety of outputs, including a point-cloud model, aerial imaging and a geographically located KML file that could be placed in Google Earth. The aerial imaging and point cloud was problematic around the chimneys due to the relatively low points on a vertical face, such as a chimney. Data from the first, second and subsequent flights were merged together which allowed a high quality aerial image and point cloud to be formed. However, areas around the chimneys were still blurry and remain an issue for further research.

The 3D scanning using the BLK scanner became the centre piece for this work providing not only a HBIM platform but also an ‘as built’ drawing of the building’s roof space. No previous plans were available. The resulting point cloud model gave a detailed representation of the inside of the roof which also brings an accuracy level hard to achieve from regular drawings. However, the attainment of LOD500 is was contrary to the findings of Ali et al. (2018) where this was set as the ideal target for HBIM due to data size, storage and asset teams accessibility to BIM models. Although, due to the complexity of the spaces and its various components, this stage has proved extremely valuable. This can further be used as more accurate reference for
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documentation and as an as-built copy to be used for presentational opportunities. Asset managers of heritage properties develop immersive VR environments from the developed workflow in this study which is similar to the findings of Karadimas et al. (2019).

This workflow in Figure 3 was developed for use for future heritage building assessments. However, the equipment and software was chosen due to its availability and this could vary depending on the subscription and expertise of the assessors. This workflow (or variation of) can be applied to any heritage building assessment. It can be used for another roof assessment or can be applied to a facade or a whole building. The assessment can then be passed onto a specialist that can use this assessment to distinguish the most appropriate solution. Assessing heritage buildings this way can broaden our understanding of these special buildings and allow us to take better care of them.

6. Conclusion

This study began with the aim of leveraging BIM from a maintenance perspective to develop a standardized workflow for heritage building maintenance in New Zealand. This was achieved by a comprehensive literature review which highlighted the current challenges in heritage maintenance, gaps in application of BIM workflows and potential of UAV for heritage data capture. The registered point cloud scans provided a platform for future BIM modelling and development of heritage components. The point cloud scans would also serve as documentation for future interrogation to determine changes in building property over time. The standardized workflow can be applied to future maintenance projects and extensive use in heritage maintenance. This study is limited in a couple of dimensions such as use of proprietary equipment and software, lack of cost benefit analysis and inadequate lack of measurement of as-built accuracy to point cloud scan. Future research would focus on developing the BIM model and assessment of indoor environmental quality.

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