Smart Heritage: Challenges in Digitisation and Spatial Information Modelling of Historical Buildings

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Abstract

Spatial data and building information modelling are indispensable for smart decision making on the use and management of heritage buildings. This short paper provides an overview on technologies and methodologies for spatial data acquisition and information modelling of heritage buildings. It identifies challenges in smart heritage through a case study of the Royal Exhibition Building in Melbourne, and provides recommendations for future research in this area.

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1 Introduction

Heritage buildings form part of our history and culture, and their protection is important for the current and future generations. Continuous degradation caused by various natural and human factors underpins the importance of preservation and restoration of heritage buildings. Smart heritage refers to the use of technology to optimise decision making on the use and management of heritage buildings.

Spatial information plays a key role in smart heritage. Digitisation is often the first step in the documentation and preservation of heritage buildings. Non-contact data acquisition techniques such as photogrammetry and laser scanning enable accurate recording of the as-is state of heritage buildings. The resulting digital spatial data facilitate the planning and execution of preservation and restoration works. Online visualisations and virtual tours make it possible to access heritage buildings remotely, and use these for interactive teaching and learning purposes.

While smart heritage is digital, the opposite is not necessarily true. To make informed decisions on the use and management of heritage buildings, digital spatial data are necessary but not sufficient. Complex tasks such as structural health monitoring and assessment of environmental effects such as weathering require integrating spatial data with rich semantic information (e.g. from historical records) and topological relations into a building information model (BIM). A heritage BIM facilitates the documentation of all preservation and restoration works on a continuous basis, as well as management and exchange of building information

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between various stakeholders. Using a heritage BIM, heritage experts can perform complex spatial analyses, ask what-if questions, run simulations and predict the results to inform the preservation and restoration projects.

This short paper provides an overview on technologies and methodologies for spatial data acquisition and information modelling of heritage buildings. It identifies challenges in smart heritage through a case study of the Royal Exhibition Building in Melbourne, and provides recommendations for future research in this area.

2 Digitisation of heritage buildings

Photogrammetry and laser scanning are the main data acquisition techniques for digitising heritage buildings. In both techniques, data can be acquired from aerial or terrestrial platforms. Aerial photogrammetry, e.g. using Unmanned Aerial Systems (UAS), is the most convenient method for capturing the roof structure of large buildings. For the facades and the interiors, close range photogrammetry using a hand-held camera is more commonly used. The photogrammetric processing of the acquired imagery to generate a 3D reconstruction of the building is largely automated thanks to recent developments in Structure from Motion (SfM) [7] and dense matching [8] methods. Nonetheless, the process is usually done off-line as it is time-consuming and might require human interaction. The challenge of the photogrammetric reconstruction is the matching failure in poorly textured areas, which results in gaps in the reconstructed surfaces.

Laser scanning on board a UAS can provide dense and complete data covering the exterior of large buildings. Compared to commercial laser scanning systems on board manned aircrafts, UAS laser scanner data are less accurate due to the use of cheaper Inertial Measurement Units (IMU) integrated with the laser scanner. Terrestrial laser scanning on a stationary tripod provides the most accurate data, and is the preferred technique for capturing building interiors. Most terrestrial laser scanners are integrated with a camera, and the acquired point cloud can be readily augmented with colour information from the images. The advantage of terrestrial laser scanning compared to photogrammetry is the higher accuracy of the data (millimetre level), and that the data are readily available after the scanning thanks to automated registration tools. The disadvantage of terrestrial laser scanning is the time- and labour-intensiveness of the scanning process. In particular, for large and complex buildings a large number of scans must be acquired to ensure a reasonably complete coverage, which is a slow and laborious process.

Hand-held scanners such as Zeb [3] are more flexible and efficient for scanning than the stationary laser scanners. These scanners use Simultaneous Localisation and Mapping (SLAM) algorithms to estimate the pose of the sensor while creating a map of the environment. Using a hand-held scanner, the interior and exterior of the building can be scanned in one seamless point cloud, which is a challenge for terrestrial laser scanning due to the limited overlap at the entrances/exits. However, current SLAM algorithms require frequent loops in the scanning trajectory to correct for the accumulated errors, and the resulting data are less accurate than the terretsrial laser scanner data (centimetre level accuracy).

SLAM approaches using depth cameras such as the Kinect have also been studied for mapping indoor environments [11, 5]. However, the application of depth cameras to mapping large heritage buildings is limited due to their short range (5-10 m) and the low accuracy and resolution of depth measurements (centimetre level).

3 Heritage BIM

Early approaches to building modelling from imagery and point cloud data focus on geometric reconstruction of roofs [12, 9] and facades [18, 2]. The more recent concept of building information modelling involves the reconstruction of interior and exterior geometric elements, but also the inclusion of semantic attributes and topological relations between building elements [10, 19]. The reconstruction of geometric elements usually involves fitting parametric solids to 3D points [15]. A number of software packages have been developed [14] to facilitate the reconstruction of building elements in accordance with standard data models such as the Industry Foundation Classes (IFC) [13]. The challenge in heritage BIM is the generation of parametric models that best fit the actual data representing complex elements such as domes or sculptures. For such complex elements, flexible parametric surfaces such as NURBS have been found more suitable [16, 1].

The real power of heritage BIM is in the wide range of semantic attributes augmenting geometric elements, which enable complex analyses and what-if scenarios and simulations, such as energy efficiency analysis, air flow modelling, cost estimation of preservation and restoration works, and analysis of environmental effects such as weathering. Example applications of heritage BIM for such analyses can be found in [4] and [17].

4 Case study of the Royal Exhibition Building

The Royal Exhibition Building (REB) is the first building in Australia to achieve World Heritage listing[1]. Built in 1880, the building served as a great exhibition hall, and is still being used for exhibitions and events. Figure 1 (left) shows a bird's eye view of the Royal Exhibition Building. In December 2017, a team of researchers from the University of Melbourne carried out a data acquisition campaign to capture data of the interior and exterior of the building and generate a heritage BIM. The data acquisition included aerial laser scanning, terrestrial laser scanning, Zeb scanning, and photogrammetric image capture.

A Phoenix lidar system on board a large UAS was used to record a dataset of 105 million points covering the roof of the building and the surrounding gardens. To capture overlapping images of the roof and the facades, a small DJI drone carrying a consumer-grade camera was used. Figure 1 shows the aerial laser scanner data (middle) and the photogrammetric reconstruction (right) of the exterior of the REB. For the interior, a Faro terrestrial laser scanner integrated with a camera was used to record over 40 scans on the ground floor and the first floor. Spherical targets were used to allow automatic registration of the scans resulting in a point cloud of over 1 billion points with colour. A Zeb-1 hand-held scanner was also used to capture data of the interior and the exterior. The Zeb dataset contained 78 million points without colour. Figure 2 shows the terrestrial laser scanner data (left) and Zeb data (middle) of the interior of the REB.

A preliminary analysis of the data captured by different scanners revealed that the terrestrial laser scanner point cloud was the most accurate with a mean accuracy of 4.4 mm in individual scans and a mean registration accuracy of 3.4 mm. The accuracy in individual scans was measured as the average root mean squared (RMS) point-plane distances obtained by plane fitting over a number of planar surfaces. The accuracy of the Zeb point cloud as measured by the average RMS plane fitting error was 17.7 mm. The main limitation of the Zeb sensor, however, was the limited range of the sensor (30 m), which resulted in the dome

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[1] https://museumsvictoria.com.au/website/reb/history/

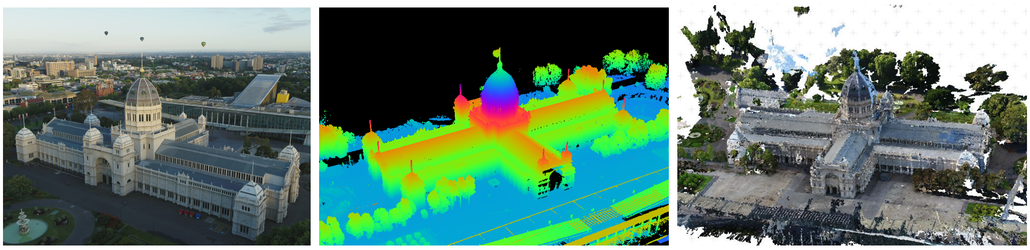

Figure 1 A bird's eye view of the Royal Exhibition Building (left), UAS laser scanner data (middle), and the photogrammetric reconstruction of the exterior (right)

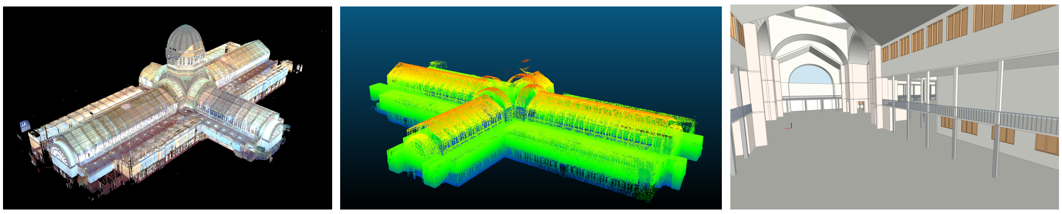

Figure 2 Terrestrial laser scanner data of the interior (left), Zeb-1 data of the interior (middle), and the BIM created from the terrestrial laser scanner data (right)

of the building being completely missed in the data (Figure 2 middle). The accuracy of the UAS laser scanner data as measured by the average RMS plane fitting error was 54.5 mm. As for the photogrammetrically generated point cloud, the main issue was completeness, since the data contained many gaps due to matching failure in poorly textured surfaces.

Using the terrestrial laser scanner data of the interior, a baseline BIM was generated in Autodesk Revit software. Only the main structural elements were reconstructed using the existing Revit families. The workflow consisted of first placing levels guided by vertical sections of the point cloud, followed by placing parametric solids corresponding to building elements within each level guided by horizontal sections. The resulting model contains the reconstructed elements in a hierarchical structure in accordance with the standard IFC data model. Figure 2 (right) shows a perspective view of the inside of the BIM.

5 Conclusions

This paper provided an overview of technologies and methodologies for data acquisition and spatial information modelling of heritage buildings. Based on the experience of the REB case study, the main challenge in digitisation and information modelling of heritage buildings is efficiency. Data acquisition using terrestrial laser scanning, while accurate, is very inefficient. Scanning the interior of the REB took over 40 scans and more than 20 hours of work. Hand-held scanners based on SLAM are far more efficient, but the resulting data are less accurate. Developing more accurate SLAM algorithms, e.g. based on optimal pose estimation from plane correspondences [6], is an interesting topic of future research, which can lead to new ways of digitising heritage buildings accurately and more efficiently.

The process of building information modelling is also largely manual and therefore inefficient. Another challenge in heritage BIM is the faithfulness of the model to the acquired data representing the true geometry of the building elements. Existing BIM elements only provide an approximation to the true gemetry of heritage buildings. Developing methods for efficient yet accurate reconstruction and modelling of heritage building elements is a topic deserving further research. Another direction for future research is the development of procedures based on BIM for continuous documentation of all preservation and restoration works and life cycle management of heritage buildings.

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