Guidance for Implementing Data Capture and Modelling Techniques for Managing Heritage Assets: Vision for Heritage BIM (HBIM)

Research Report

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Executive summary

The research is a sub-project of the SBEnrc project #2.72 titled *“Leveraging an Integrated Information Lifecycle Management Framework - Building and Infrastructure Sectors”*. The study sought to develop preliminary guidance for implementing data capture and modelling techniques for managing heritage assets for the Queensland Department of Energy and Public Works (hereafter DEPW) to lead the successful adoption of BIM for their heritage assets. The project outcomes will assist DEPW in implementing BIM into the heritage asset management process to ensure preservation and proper restoration requirements.

The report presents the results of a study examining BIM-based processes as well as current standards and guidelines which highlight BIM best practices for lifecycle asset management applications, with a specific focus on heritage buildings. A case study review was conducted to capture valid information regarding benefits and challenges associated with Heritage BIM (HBIM). Semi-structured interviews were also conducted with relevant DEPW personnel to gauge the perceptions surrounding BIM adoption, the BIM knowledge of individuals within the organisation and to determine the current status of the systems in place for heritage asset management. Finally, based on the research findings, four HBIM guideline levels were developed featuring various data capture and modelling techniques.

The results from the literature review indicate that HBIM implementation is still in the initial stages, although a few European countries have taken an initiative to utilise application of BIM within the heritage sector. The case studies reveal possible challenges, feasibility of implementation, and overall effectiveness of HBIM. The semi-structured interviews conducted with stakeholders at DEPW demonstrate the current systems in place for managing assets governed by DEPW. Although HBIM would greatly increase the effectiveness of heritage asset management for DEPW, there is a lack of knowledge concerning the amount of information available for a heritage asset, such as the performance data, geometric data, and so on. Nevertheless, the results show that DEPW is overall welcoming of the adoption of new technology that can improve the heritage asset management practices.

To summarise, although the adoption of HBIM withing the industry is still low, advances in technology and software are increasing the feasibility of implementation. As HBIM’s popularity increases, the guidelines and frameworks developed will ensure the success of the preliminary stages of HBIM. However, the effectiveness of HBIM for heritage assets within Australia is yet to be determined. Therefore, a recommendation for further research and potential case study implementation is advised. Future research will assist with the feasibility analysis of HBIM and increase likelihood for further adoption of HBIM.

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1. Introduction

1.1 Background and context

Historic assets provide economic benefits firstly through tourism generated from domestic and international visitors, and secondly, through the repair and maintenance of historic buildings that provide construction economic output for preservation (Historic England, 2019). With streamlined maintenance and repair management plans, the tourism and construction economic outputs can be increased significantly. Moreover, the Taskforce of the Commonwealth, State, and Territory (Taskforce, 2004) states that heritage assets serve as community 'touchstones' that inform and educate the public about the significance of the heritage asset. The purpose of conserving these sites is to enrich the cultural heritage of the nation and promote access to cultural heritage (Historic England, 2019).

The information and data involved in heritage asset management can be represented in a variety of formats and several different locations. Heritage Building Information Modelling (HBIM) can incorporate multiple types of data, such as cultural and historical significance, building plans, maintenance schedules, or any other relevant information available.

Over the last few decades, Building Information Modelling (BIM) standards and guidelines have been adopted and implemented by the Architecture, Engineering, and Construction (AEC) sector due to its increasing effectiveness in organising information and modelling data (López et al., 2018). However, the concept of HBIM in Australia is in the initial stages without any proposed guidelines to manage Australia's heritage sites. Therefore, BIM guidelines must be developed and implemented into the heritage asset management process to ensure preservation and the presence of proper restoration requirements.

The purpose of this research project is to develop preliminary guidance for implementing data capture and modelling techniques for managing heritage assets for the Queensland Department of Energy and Public Works (DEPW). The guidance would allow the department to enhance the lifecycle asset management specifically for heritage assets as they are tailored for the unique preservation and restoration requirements of heritage assets. Due to the absence of information on HBIM in Australia, this project also serves as a literature review of HBIM information, summarising guidelines and industry best practices in countries that have already applied BIM to heritage cultural sites.

1.2 Research objectives

Ultimately, this research project aims to recommend best-practice technologies and information management strategies for DEPW's heritage assets and their unique preservation and restoration requirements. The exploratory work and guidance produced aims to assist DEPW to form a more detailed asset information management strategy for their portfolio of heritage assets.

The research objectives include

- Reviewing academic literature surrounding BIM-based processes and the current standards and guidelines that highlight BIM best practices for lifecycle asset management applications, with a focus on heritage buildings.
- Reviewing case studies on HBIM applications to capture valid information regarding the benefits and challenges of HBIM.
- Collecting qualitative data by conducting interviews with relevant DEPW personnel to gain further information regarding the current systems in place for heritage asset management at DEPW.

- Developing preliminary guidance for implementing various levels of BIM for heritage assets that reflect industry standards and best practices.

2. Background – Heritage Building Information Modelling (HBIM)

The term BIM cannot be conveyed through a simple definition. BIM represents the collaborative process and collection of information and documentation for the production and management of differing types of applications (Aranda-Mena et al., 2009). BIM is commonly misinterpreted as software or a program that generates and defines an asset as a 3D model or through a similar digital representation. However, BIM is not simply a newer version of 3D CAD or a 3D visualisation tool, and it offers more than 3D modelling and digital documentation applications (Historic England, 2017). Furthermore, the information BIM encompasses is divided into primary components, namely geometric and non-geometric information. BIM offers a methodology for the digital representation of an asset to form a centralized hub of shared information to assist in the asset information management process. According to Brookes (2017), "BIM is essentially value-creating collaboration through the entire life cycle of an asset, underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data attached to them."

Cultural heritage is a non-renewable and irreplaceable resource and a common good, but it is frequently under threat from environmental challenges and climate change, disaster risks, neglect, decay, and under-funding (European Commission, 2020). The coherent management of cultural heritage assets is important for transferring history to present and future generations (Piaia et al., 2020). Straub (2003) states that the maintenance, preservation, and reusage of heritage assets is a complex challenge that must consider several decision-making aspects, such as economic, social, historic, architectural, structural, technical, and safety aspects. Additionally, the collaboration between several disciplines and stakeholders is required for efficient management, which adds another layer of difficulty in communication. These inefficiencies tend to compromise the preservation of cultural heritage site for sustainable economic development as it makes the conservation of heritage buildings costly. Nevertheless, there is an increasing interest in the adoption of new methodologies by heritage organisations and workgroups aiming to improve those inefficiencies (Jordan-Palomar et al., 2018).

While traditional BIM use consists of new build constructions where the BIM model is created in the initial stages of the asset's lifecycle and grows as the project's information accumulates, HBIM is implemented during the operational phase of the asset's lifecycle. Dore and Murphy (2017) define HBIM as a new system of modelling historic structures by creating full 2D and 3D models, which include detail behind the surface of the objects concerning its method of construction and material makeup. HBIM involves developing models for sensitive culture assets that require delicate lifecycle management alongside precise intervention techniques. While research based on the implementation of BIM in existing buildings is increasing, Xiong et al. (2013) state that the execution of BIM for existing assets is scarce and needs improvements by using Point Cloud conversion, updating BIM models, and modelling items in relation to existing structures.

2.1 HBIM benefits

The benefits that BIM offers to heritage asset management vary from asset to asset on a case-by-case basis. While some complex assets might require extensive investigations, smaller assets may achieve significant benefits with less research required. Overall, the benefits of HBIM can be divided into two categories: organisational benefits and socio-economic benefits.

Organisational benefits

HBIM's most significant benefits stem from the improvement of the existing frameworks for heritage assets regarding the organisation of information and collaboration of stakeholders. Heritage asset management is challenged by the lack of access to technical information and documentation, which increases the time and costs required for operation and maintenance (López et al., 2018). The implementation of BIM for heritage optimises the collection of data by providing a centralised source of information accessed by all stakeholders. The centralisation of heritage asset information allows for real-time collaboration and decreases the number of errors.

HBIM allows for increased efficiency, reduced costs, better planning, improved carbon performance for historic buildings, improved spatial coordination, and the assessment of design options (Historic England, 2017). The following organisational benefits of HBIM have been stated by Historic England (2017):

- Production of multiple design options for intervention analysis;
- Clash detection for accurate spatial coordination;
- Ability to analyse historic building development over time;
- Integration of datasets such as historic information, legacy data, photographs and drawings, geospatial datasets, geophysics, and remote sensed data and imagery;
- Integration of intangible information such as significance and heritage values;
- Reuse of data across multi-disciplinary teams;
- Integration with other existing enterprise systems;
- Ability to extract information and documentation through a centralised information source.

Socio-economic benefits

The benefits of implementing BIM into heritage are mainly conservation, preservation, and maintenance of the asset. However, BIM-enabled heritage asset management also provides economic, social, and environmental benefits for a country. The World Trade Organisation (WTO, 2016) has estimated that 50% of tourists internationally are motived to experience a country's culture and heritage. According to the Australian Heritage Tourism (AHT, 2018), 43% of international visitors participated in a cultural activity in 2017, while 33.9% were attracted by heritage objects. International visitors provide economic benefits to other industries as well when travelling for cultural reasons.

HBIM increases the accessibility of heritage assets, which significantly enhances the visitors' experiences. Additionally, with the visualisations of the assets, heritage and culture assets inform the public about the history surrounding the heritage assets and serve as a community 'touchstone' landmark. An educated society can further embrace heritage and cultural assets, indirectly increasing funding and crowd support for the preservation and conservation of history.

Besides tourism, several other factors influence the economy produced by heritage buildings. Employment related to the repair and maintenance of heritage assets significantly contributes to the economy. Historic England (2017) states that heritage assets in England contribute £9.6 billion to the economy due to the repair and maintenance construction of heritage buildings and employ 278,000 people. Similarly, according to Taskforce of Commonwealth, State, and Territory (Taskforce, 2004), Australian heritage assets create proportionally more jobs than new construction and provide environmental benefits through the reduction of waste produced and the resources used for maintenance and repairs.

2.2 HBIM challenges and barriers

BIM within the AEC industry has faced several challenges when standardised and adopted for projects. HBIM is no exception. Unlike BIM for new constructions, HBIM relies on the digitisation of data found through investigation and research. Efficiency is considered to be the main challenge in the digitisation and information modelling of heritage buildings (Khoshelham, 2018). The challenge mainly stems from the irregular characteristics and complex shapes of heritage assets. Understanding the geospatial data and transforming it into a 3D model is time-consuming and error-prone as current processes require substantial manual input. Furthermore, according to Khoshelham (2018), most data-capturing methods are considered accurate yet inefficient; as more complex heritage assets are scanned, the time and cost required to undertake a full geospatial investigation increase. After the modelling process is completed, the 3D model may be unfaithful to the heritage asset and misrepresent aspects and characteristics of the historic building.

The adoption of BIM for heritage buildings may also prove challenging due to the heterogeneous, complex, and irregular characteristics of heritage assets (Jordan-Palomar et al., 2018). The level of detail needed to capture all the intricacies of the objects within a heritage asset may hinder the implantation due to the budgeting or time constraints of the project. According to López et al. (2018), the virtual reconstruction procedure of historical-cultural heritage is not an easy task because the objects to model consist of components whose characteristics and morphologies are not represented in the BIM software libraries. Therefore, it is essential to introduce the historical and technical approaches into the BIM environment and the Point Clouds to model the different virtual parametric components and achieve a BIM as-is model of the analysed architectural heritage asset.

As technology and software advance, the application of HBIM will progress significantly; however, the current state of technology hinders this development. Pocobelli et al. (2018) state that the linking of 3D model information with metadata of the asset needs to be improved for accessibility and effective communication of HBIM.

2.3 HBIM geometric data capture and modelling

Three-dimensional scanning and modelling of sites and artifacts of cultural heritage have increased remarkably in recent years (Khalil et al., 2020). As the implementation of HBIM for a cultural heritage asset takes place during the operation phase of an asset's lifecycle, modelling information is rarely available for the design phase due to technology standards during the time of construction. Furthermore, according to Historic England (2017), acquiring data and information for heritage assets can be much more complex when compared to new-build construction, which is considered a relatively straightforward cradle-to-grave model.

I. Geometric data capture techniques

There has been an evolution of the data scanning and capture technologies over the last few decades, introducing new methods and fast-tracking spatial data collection. While modern technology utilises geospatial data to 3D-model the asset, 2D CAD drawings may still be preferred in scenarios where the asset is geometrically simple (Historic England, 2017). Various techniques for geometric data capture and modelling are presented below.

Manual survey

Out of all the methods for data capture, manual survey is the least expensive, but it is also the most inaccurate and time-consuming (Khalil et al., 2020). It uses simple measurement tools to gather the dimensions of an asset. The technique is useful to capture the geometry of small and uncomplicated objects which do not require a high level of detail. Laser distance meters can help facilitate the process of hand measurement, increase its accuracy, and provide more flexibility in confined spaces. However, it still suffers from the same limitations as manual measurements (Khalil et al., 2020).

Total station survey

Total station surveys are typically used in the initial steps of photogrammetry and laser scanning techniques to precisely identify the control and checks points (Khalil et al., 2020). They incorporate a range of sensor technology to provide accurate geometry data. However, the time-consuming nature and lack of completed 3D modelling are the main disadvantages of robotic total stations.

Photogrammetry

Photogrammetry is a technique that is based on triangulation, where the lines of vision of cameras, which are located in several places, are joined at a common point in the object (López et al., 2018). Photogrammetry is a precise and no-contact 3D measurement technique which is based on several high-quality images; it allows for the collection of semantic and spatial data of a building or object to be accelerated (El-Hakim et al., 2007). When compared to other data capture techniques, photogrammetry provides a more cost-reasonable method while sacrificing some of the precision. Another advantage of photogrammetry over laser scanning is that it adds high-quality imagery and colour information to the data (Dore & Murphy, 2017). Furthermore, photogrammetry is becoming more easily accessible due to the decrease in the cost of digital cameras and the increase in the power of computer processing. While the output of photogrammetry is similar to that of other techniques, the entire process can be quite cumbersome and requires a large amount of time for both the setup and processing.

Terrestrial laser scanning

Laser scanning technologies are adopted for their ability to accelerate the spatial data collection of existing buildings or complex surfaces and for the accuracy and precision of the acquired data. Laser scanners are subdivided into two: aerial and terrestrial laser scanners (TLS; López et al., 2018). Laser scanners are based on one of three ranging principles: triangulation, pulse or time flight, and phase difference accuracy, with differences in the range and accuracy capabilities of each method (Dore & Murphy, 2017). Three-dimensional laser scanners are line-of-sight instruments, where multiple scans are needed to cover invisible parts of the scene, and targets are used as common points to merge the scans (Hajian & Becerik-Gerber, 2010). It is becoming a widely used technology for legacy assets such as heritage.

TLS can output precise data with very small tolerances and can have a range of red, green and blue (RGB) through the pulse intensity of the laser beam (Hajian & Becerik-Gerber, 2010). The output of TLS is known as Point Cloud Data (PCD), a system of geospatial information on the scanned environment (Figure 1). The setup process for TLS is presented in Figure 2.

The disadvantages of the TLS technique mainly concern the high cost and the need for multiple scans to capture all geospatial information of an asset. Additionally, a large number of reiterations is required for complex assets, and multiple steps are required in adjusting and relocating equipment to complete the PCD (López et al., 2018).

Figure 1. (a) Laser scanning process (b) Point Cloud data (Source: López et al., 2018)

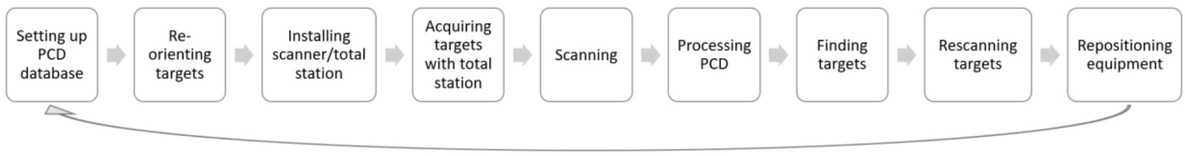

Figure 2. Setup process for terrestrial laser scanner (Source: Hajian & Becerik-Gerber, 2010)

Geometric data capture comparison

Determining the optimal geometric data capture technique requires an understanding of the asset. Thus, manual survey methods lack the efficiency and accuracy required for the complex nature of heritage assets. However, they are by far the least costly and most readily available technique, so they may be feasible for specific scenarios. Photogrammetry and TLS produce similar outputs; however, photogrammetry is considered the least costly and more accessible for small buildings (Khalil et al., 2020). Laser scanning requires significant pre-processing, while photogrammetry directly contrasts instantaneous camera shots while requiring substantial post-processing.

One possible technique is using all the mentioned capture methods in parallel for a single heritage asset. Total station is suitable to survey a site control network to precisely identify scanning points for other scanning methods. Photogrammetry can be used for mapping surface colours and details whilst 3D laser scanning may be used for its accuracy (Khalil et al., 2020).

II. Geometric data modelling techniques

According to Khalil et al. (2020), the geometric data category can be the most important data category as a geometric model is usually needed for the representation of other data forms of heritage assets. The modelling of the captured geometric data is one of the most essential steps to a successful application of HBIM. The digitisation and interpretation of geometric data reflect the character and qualities of an asset that can assist in developing an understanding for all relevant stakeholders. A successful HBIM model will assist in the preservation, planning, and maintenance of an asset. Additionally, 3D models bring public awareness to cultural history. Two techniques for modelling captured data are semantics and parametric modelling.

Semantics

Semantics is defined by complex algorithms that are able to detect different surfaces of an asset and label them accordingly as walls, floors, or ceilings (López et al., 2018). This technology is still in its infancy stages; however, it has great potential for the future of HBIM and other applications. Nevertheless, the conversion from PCD to parametric BIM model still requires further research and development before it can be applied effectively.

Parametric modelling

One of the major challenges of modelling existing and historic buildings is the lack of pre-defined parametric objects compared with the extensive libraries used to model new buildings (Khalil et al., 2020). The geospatial data represented by the PCD are points that define the scanned asset in a highly accurate way. However, the PCD lacks detail on the additional information of the scanned asset, such as geometrical, topological, and semantic attributes (López et al., 2018). To produce the missing attributes, it is necessary to create 3D parametric objects to represent them within the model. Thus, reverse engineering is required. The initial steps of the modelling process are identifying the correct surfaces and modelling the parametric objects. Due to the advances in BIM software, these steps can be carried out semi-automatically or fully automatically.

2.4 Heritage asset documentation and stakeholders

The specific documentation and information involved within an HBIM model can be categorised into four components: archaeological and historical, geometry, pathology, and performance data (Figure 3).

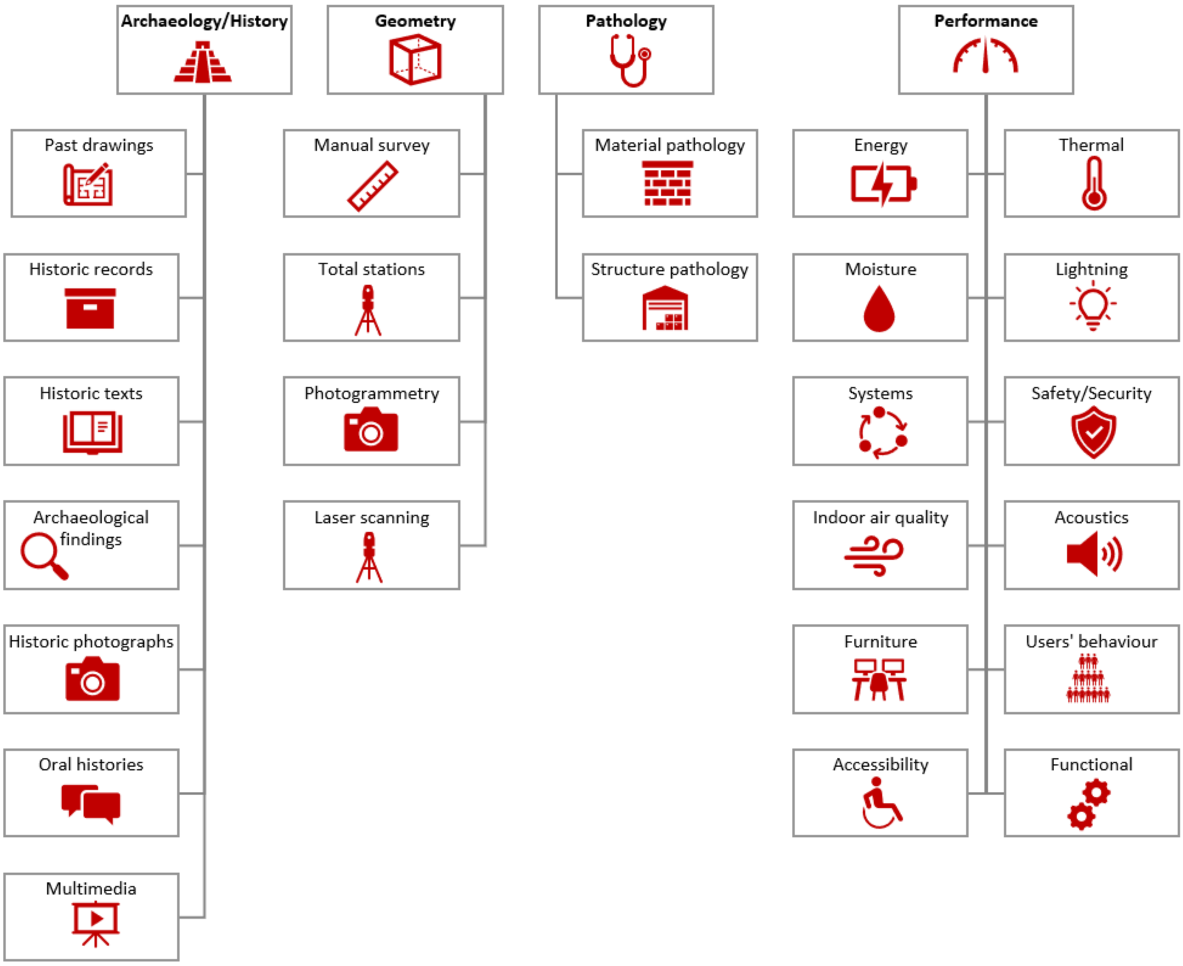

Figure 3. Categories of digital documentation of heritage buildings (Adapted from Khalil et al., 2020)

Historical documentation

The historical and archaeological documentation data category focuses on the analytical study of the building's history, its historical context, and the variation of its form and function through its lifetime (Khalil et al., 2020). Historic documentation is categorised as the following: historic texts, archaeological findings, historic photographs, oral histories, past drawings, and multimedia. The collection of historical documents typically requires collaboration with relevant stakeholders to discuss the transfer and availability of asset information. An investigation into the asset's cultural history may be needed if certain information is missing.

Pathology documentation

Investigating and documenting the pathology of heritage buildings has a significant impact on the decision-making and conservation processes (Khalil et al., 2020). Building pathology documentation contains all the information regarding the original materials used, construction methods, deterioration, and historic fabric (Historic England, 2017). Building pathology documentation is categorised into two categories: materials and structural surveys. Geometric data capture techniques may be used to capture information regarding the building's surface-level materials, while subsurface material surveys are more complex (e.g., wet chemistry, optical microscope, ultraviolet, or infrared light). One of the main conservation requirements of heritage buildings is structural pathology, which requires several techniques and methodologies to be successful. A geometric survey could help with the structural pathology, but, in many cases, more in-depth structural investigations may be needed (Khalil et al., 2020).

Performance documentation

Performance documentation is defined broadly as it entails several categories of a building's performance and surrounding systems. Monitoring and surveying the current status of the building and its performance capacity on various levels is the first step for the analysis and determination of any deficiencies the building could have and to develop the objectives of any required rehabilitation or retrofitting works. Khalil et al. (2020) suggest that performance documentation can fit into the following categories:

- Energy performance;
- Thermal performance;
- Moisture survey;
- Lighting/visual performance;
- Acoustic performance;
- Indoor air quality;
- Systems;
- Furniture and equipment;
- Users' behaviour;
- Functionality;
- Accessibility;
- Safety and security.

Collaboration with relevant stakeholders may be required to develop a network of information related to performance documentation.

Stakeholders

Stakeholders of heritage assets can be narrowed down to parties who affect or are affected by the decision-making process of heritage asset management. The level of responsibilities for each stakeholder is not equal; some parties and departments have little to no influence on the management of an asset while some are key to these processes. Khalil et al. (2020) have compiled and categorised a list of stakeholders (Table 3). However, for some heritage assets, not all the stakeholders listed may be actively involved in decision-making. Typically, the stakeholders with the most influence over an asset are in charge of managing the asset information. The extent of the information available depends on the preservation of the documentation through the asset's lifecycle – some information may be unavailable.

Table 3. Stakeholders and their relation to the various categories of data (Adapted from Khalil et al., 2020)

Stakeholder	Historic data	Geometry data	Pathology data	Performance data
Owner	●	●	●	●
Listing authority	●		●	
Archaeologist	●	●	●	
Architectural historian	●	○	○	
Museum	●	○		
Public dissemination	●	○		
Architect	●	●	●	●
Structural engineer		●	●	○
Contractor		○	○	○
Conservator	○	○	○	
Energy auditor		○		●
MEP engineer		○		●
Lightning / Acoustic engineer		○		○
Facility / Asset manager		○	○	○
End-user	○	○	○	○

Note:
- ● High interest
- ○ Moderate interest

3. Data collection

In this study, the data collection involves reviewing case studies of HBIM application and conducting semi-structured interviews with DEPW representatives to gather more qualitative data.

3.1 Case study review

Reviewing case studies in different countries can assist in developing knowledge regarding the possible challenges, feasibility of implementation, and overall effectiveness of HBIM. Four case studies have been selected for review of the implementation of HBIM for heritage asset management. These case studies were chosen due to their successful application of BIM and because the chosen heritage assets are in the same or similar class of heritage listings as ones managed by DEPW.

3.2 Semi-structured interviews

Semi-structured interviews were conducted to gain further information regarding the current systems in place for heritage asset management at DEPW. An interview protocol was created before the interviews to ensure the proper collection of information. The questions were predominately based on the current practices and guidelines in place for the heritage asset information management processes at DEPW. The interview protocol is presented in Appendix A.

Four key stakeholders were identified. The participants were from the Queensland Government Accommodation Office within DEPW; their roles were the following:

- Director of Asset Portfolio
- Principal Asset Manager of Property Group
- Assistant Director of Property Group
- Principal Project Manager of Property Group

4. Data analysis and findings

This section presents the findings from the case study reviews and interviews conducted with DEPW personnel. The results are discussed in relation to their significance concerning the HBIM for asset management and industry best practices and provide a foundation for the preliminary guidance for the various levels of HBIM implementation in the organisation.

4.1 Case study reviews findings

I. Summary of case studies

Case Study – Waverley Station

The first iteration of the Edinburgh Waverley Station opened in 1868, with two other construction stages expanding and adding more stations in the following years. Waverley station was the largest train station in the United Kingdom until Waterloo Station opened in 1921. The main area of interest for BIM was the ticket office and adjacent staff areas at the station; the survey encompassed two floors and was to include the roof and concourse areas (Historic England, 2017). An architectural and building consultancy company named AHR was contracted to undertake the survey and develop a BIM model of the station.

The main reason that BIM was used for the heritage asset's management was that it was capable of assisting with cost estimations and maintenance planning (Historic England, 2017). One of the most crucial steps that ensured the success of the process was the development of a BIM execution plan (BEP). Furthermore, a Common Data Environment (CDE) was specified within the BEP to support the information flow and collaboration for the project.

Laser scanning was chosen to collect geospatial information as it provided a highly accurate and non-contact method that would be nonabrasive to the structure. The reduced risk of undertaking the work at ground level was also one of the selection criteria. Laser scanning was chosen also due to the spaces within the building as well as the short period available for the collection of geospatial information.

The proposed deliverable output of the project was an as-built 3D Revit Model. The 3D model was supplemented with a colour Point Cloud model (Figure 4) to add further information to it. The model was relatively straightforward, like most train stations; however, the ticket hall had an intricate domed skylight involving complex geometry (Historic England, 2017).

Figure 4. Waverley Station: Section view through the laser scan Point Cloud (Source: Historic England, 2017)

Case Study – Woodseat Hall

Woodseat Hall was built in 1767 as a home for the High Sheriff of Derbyshire and is south-west of Rocester, in Staffordshire (Historic England, 2017). Following the death of the High Sheriff, the ownership of the asset was contested for 40 years, leading to the decline of the structure's health. When JCB purchased it in 1986, the hall was in a dire state. The overall symmetrical design of the asset is still noticeable in its current condition, while the main body of the building has deteriorated to a point where it is almost unrecognisable. In November 2016, JCB contacted Bridgeway Consulting to undertake surveys to assist with the application process of a planned restoration of the Hall and transformation into a golf clubhouse. The client requested the capture of all structural defects and major architectural features.

BIM was chosen to facilitate the application process for the planned remodelling project. The centralised information that BIM provides allowed for faster coordination and collaboration as the application progressed through each approval stage. The entire lifecycle of the asset was captured and produced within the model, detailing factors including the current structural defects, material characteristics, up-to-date inspection reports, legacy information, photographs, sketches, drawings, future proposals, and meeting minutes (Historic England, 2017). The CDE allowed for all relevant stakeholders to access the relevant information.

The three-dimensional geospatial information of the asset was gathered through laser scanning, specifically Leica ScanStations P30 and C10. Each ScanStation was installed at a specific location and calibrated using GPS to assist in the registration of PCD. Using an efficient laser scanning methodology, completely accurate PCD was produced within one day of the surveys. The accuracy and time effectiveness were the main reasons that laser scanning was chosen. Access to the heritage asset was relatively unrestricted, allowing for effective time management when capturing the information. The entire process of capturing data and processing it into a 3D model took only four-and-a-half days (Historic England, 2017).

The deliverables produced by the investigations were the following:

- PCD produced through 3D laser scan;
- Revit AutoDesk 3D Model (Figure 5);
- External elevations and included site topography in requested formats.

Figure 5. Woodseat Hall: 3D model (Source: Historic England, 2017)

Case Study – Durham Castle and Cathedral

Durham castle is in the city of Durham, England, and it was built in 1093 for a community of Benedictine monks (Tapponi et al., 2015). Currently, Durham Cathedral mainly serves as a tourist destination and a place of pilgrimage and worship. The current cost to maintain the cathedral is £60,000 per week, and it holds 1,700 services a year (Tapponi et al., 2015). The facility manager of the Cathedral decided to change the workflow of the asset through the application of BIM. It allowed them to decrease the cost of renovation and maintenance and make the process more efficient and sustainable.

BIM was chosen to transition the traditional methodology of information management to a new approach involving a 3D model and digital information. Only one section of the Cathedral was chosen for the initial BIM study: the Chapter House.

Laser scanning was determined as the most suitable methodology for geospatial information capture. The accuracy and ability to utilize a range of laser scanning devices for specific cases such as narrow staircases proved to be the deciding factor.

A range of information and documents regarding the architectural and structural drawings were either misplaced or judged inaccurate for determining the structural condition of the asset. Abrasive methods could be used to investigate the condition; however, these need to be carefully undertaken. The deliverable of the project was a completed 3D model produced from the PCD alongside parametric data to produce an 'intelligent' model (Figure 6).

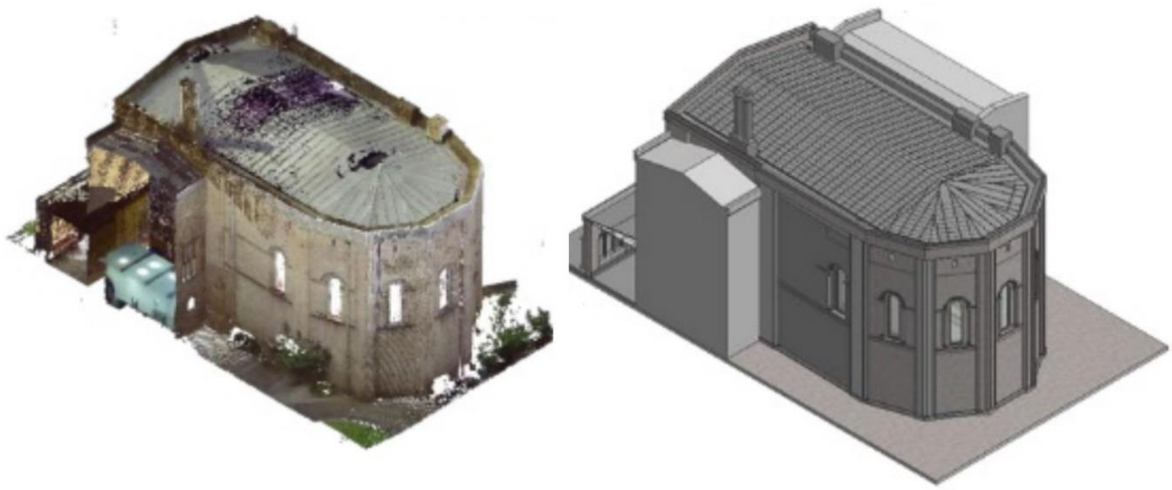

Figure 6. Durham Castle and Cathedral: 3D model created by Point Cloud scans (Source: Tapponi et al., 2015)

Case Study – Nasif House

Nasif House is located in Jeddah, Saudi Arabia, and was built in 1881 for the then-governor of Jeddah and their wealthy merchant family. Most components of the heritage asset within Jeddah suffer from issues related to their management, conservation, documentation, and monitoring of this important building sector (Baik, 2017). The selection of BIM (Figure 7) was driven by the advantages that BIM provides regarding preservation, conservation, and maintenance. The case study primarily focused on two factors, namely the level of detail and the project delivery time.

Figure 7. Nasif House: From 3D Point Cloud to BIM (Source: Baik, 2017)

The Leica scan-station C10 was specifically chosen to capture the geospatial information because of its many features and high accuracy of scans. In addition to the laser scanning methods, photogrammetry was used to help capture parametric data of the asset's conditions. Considerable work was required to model the PCD, software was used to assist in removing noise from the data set. Some sections of the data model were chosen to be modelled separately for the Architectural Heritage Object Library to reduce the complexity of the asset, while the main body was modelled through the original dataset. Revit Autodesk provided quick modelling which allowed last-minute changes of the model.

II. Methodologies of the cases

Although the heritage assets reviewed are similar, differing methods of capturing information were used across the studies. All the case studies had similar deliverables and outputs. A common deliverable was a 3D model to visualise the geometric data captured. The pairing of qualitative information with a 3D model is defined as a 'smart' model (Historic England, 2017). Few of the projects actively used a smart model to visualise further information related to deterioration, maintenance schedules, and so on. Table 4 presents the methodologies used and information captured for each case study.

Table 4. Utilised methodologies and information for case studies

	Case study			
Methodology	**Waverley Station**	**Woodseat Hall**	**Durham Cathedral**	**Nasif House**
Terrestrial laser scanning	✓	✓	✓	✓
Photogrammetry				✓
Total station survey	✓	✓	✓	✓
Manual survey				
Semantics				
Parametric modelling	✓		✓	✓
Asset pathology				
Performance data	✓			
Level of Detail	High	Medium	High	High

III. Challenges and benefits

The case studies form an essential part of understanding the key benefits and challenges of the implementation of HBIM. This section outlines the challenges and benefits evidenced by the case studies. The similarities within the challenges and benefits have been divided accordingly in the following subsection.

Challenges

The major challenge that most cases had to confront was the modelling process of the PCD. The higher the complexity of the scanned asset, the greater the size of the PCD, resulting in difficulties with creating a 3D model. Within the Waverley Station case study, third party software was required to model complex components, leading to major delays and a prolonged delivery time.

Another common challenge was determining the right level of detail and level of information. By reducing the level of detail of a complex asset model, it is possible to reduce time and cost. However, factors such as usability and interoperability may be affected. For all the case studies, the earlier the most appropriate level of detail was determined, the fewer resources were wasted.

Within some of the cases, other challenges were faced that were unique to the case study; these minor challenges are detailed in Table 5.

Table 5. Case study challenges

Case study	Challenges
Waverley Station	• Miscommunication of client's expectations and handover stage of project; • Compromise of level of detail/level of information and usability/feasibility.
Woodseat Hall	• The large file size of PCD required individual features to be modelled as a group to reduce size; • Environmental factors affecting scanning.
Durham Cathedral	• Lack of prior information and documentation; • Uniqueness of asset led to difficulty extrapolating knowledge and skillsets; • On-site staff training required to manage HBIM, while still requiring contractors for future planning of works.
Nasif House	• Managing large file size due to the size of PCD. • Level of detail changed throughout the project, delaying delivery times.

Benefits

The main benefit of all four case studies is also the main benefit of BIM outside of the heritage sector. The centralised single source of reliable and accessible information provides stakeholders with updated information while improving efficiency and time management. HBIM also reduces the physical storage of information required as the virtual model can control the majority of the information (i.e. past, present, and future). Although the level of maturity of BIM differed slightly between the case studies, there was evidence of the benefits throughout, with the benefits increasing significantly as the level of maturity increased. The CDE ensured that all information regarding the project was located within a single source to avoid miscommunications and duplications. Evidence from Waverley Station demonstrated that the CDE increased project coordination and the efficiency of the application process for approval.

One benefit that was inconsistent throughout the case studies was the ability to extrapolate the knowledge and skillsets acquired from the studies and continue to use them on other heritage assets. In the case study of Nassif House, the heritage asset captured and modelled was of a similar class and structure to those within the area; thus, the knowledge acquired could easily be used again on a different asset. However, the uniqueness of Durham Castle's captured sector meant that some of the modelling techniques could not be used for further sections of the castle. For the Durham case study example, Tapponi et al. (2015) outlined the following list of HBIM benefits:

- Allows precise information of the building as a single reliable source of information;
- Further intrusive investigation and surveys were unnecessary;
- Allows traditional outputs of elevation plans at no extra cost;

- Linkage of non-geometric information regarding the condition of the elements with set colours indicating the severity of objects condition;
- Creation of maintenance schedules linked to the model and a detailed list of past issues and solutions;
- Three-dimensional virtual walkthrough of the asset for easy communication;
- Simulation of refurbishment scaffolding plans and setups;
- Facilitated scenario planning (e.g., exhibition plan inside a room);
- Convenient and efficient access to the model through the use of tablets while on-site.

IV. Lessons learnt

The following points summarise the lessons learnt and key findings of the case study review:

- Initial BIM execution meetings and a BEP are essential to the success of project communication with the client;
- Laser scanning is the most common data capture technique and proved its value due to the collection of accurate results and effective time management;
- If the heritage object is too complex, modelling complex objects separately can increase efficiency;
- Level of detail and level of information should be specified within the BEP to identify the appropriate levels;
- Careful management of BIM files to ensure the usability of the model is not exceeded;
- Narrowing down the heritage asset's scope of work on a particular section allows for a feasibility test to be undertaken;
- Combination of adequate hardware, software, and skills is required to successfully achieve the whole process from laser scanning to producing a BIM model;
- Extrapolating gained knowledge and skillsets may prove difficult with heritage assets featuring a different level of complexity;
- Clear communication regarding the level of detail and level of information is key for the efficient use of resources.

4.2 Semi-structured interviews findings

Interviews were conducted with four key staff members from DEPW from the Queensland Government Accommodation Office. The interviews were semi-structured and involved open-ended questions relating to several key areas of heritage asset management and potential BIM implementation. The interview questions were designed to prompt discussion and allow interviewees to talk in detail about the topics. The following topics were discussed: roles and responsibilities, BIM knowledge, current asset management systems, HBIM implementation and readiness, and the heritage asset portfolio of DEPW.

I. Roles and responsibilities

During the interviews, it was important to gather an understanding of the participants' roles within DEPW and their responsibilities. The roles of the participants are directors and assistant directors as and property or asset managers of the property group. All the participants indicated that the majority of the assets under DEPW were not classified as heritage, and only a minority of the assets are classified as heritage. Furthermore, the asset manager provided information on the statistics of their portfolio; approximately 20% of all the owned assets are classed as heritage listings, comprising 30 heritage assets to 180 total assets.

The director and assistant director of the property group primarily act as owners of the property portfolio, with responsibilities including decision-making about buying, upgrading, or selling of assets. The asset and property managers of the DEPW are mainly responsible for the team that controls the leasing of owned assets and their responsibilities are related to operational processes such as contracts, servicing, maintenance, and cleaning.

II. BIM knowledge

One of the first critical steps within the semi-structured interview was to develop an understanding of the participants' knowledge on the topics before questioning them on specific information. When the participants were questioned about their knowledge of BIM, all participants answered that while they are aware of BIM, they had no further knowledge of BIM's applications. The lack of knowledge of BIM is not uncommon: many government agencies and departments are very slow with the adoption of new technologies and although some professionals within some departments may be aware of BIM, the majority have little understanding of the BIM implementation process. A common point that both the director and assistant director brought up was the availability of funding for their department in relation to managing their assets. The lack of initiative for BIM adoption may stem from the constraints due to the lack of funding.

III. Current heritage asset management practices

All participants confirmed that within the heritage asset management there were no current BIM systems in place. The asset and property managers confirmed that the majority of the information available regarding the heritage assets could be found within the department. All participants confirmed that the majority of the information was paper-based, with only basic information such as the contracts available digitally. The majority of the modelling information of the assets was basic CAD elevation drawings that were stored within the department. However, the director and asset manager confirmed that the majority of the information could be eventually found, and it was just the efficiency of gathering information that could prove time-consuming.

When questioned about what geometric and non-geometric data was available, none of the interviewees could respond with certainty whether performance, geometric, historic, or pathology information was available. Furthermore, while the director and property manager could confirm that some PCD capture had been previously conducted, the responses lacked depth of information and contained uncertainties. These two interviewees claimed that no geometric data capture that they were aware of had been undertaken on their heritage assets. This response outlines the uncertainty within the department regarding their heritage assets; lack of information is one of the main factors affecting efficiency and growth within the department. When asked whether there was any existing data platform to share information on, all interviewees stated that there was not. Therefore, there is no current form of technology allowing for smooth in-house collaboration for the department but also between the department and any agencies they are working with.

IV. HBIM implementation and readiness

When asked why HBIM or BIM technology had not already been implemented within the department, everyone indicated that the lack of knowledge and funding were the main barriers to adoption. When questioned about the readiness to adopt new BIM systems for the management of heritage assets, all interviewees confirmed that the department would welcome new systems that could enhance heritage asset management. However, the issues surrounding the funding and time needed to implement such a system could deter or interfere with the implementation. The director and asset manager confirmed that implementing a high level of HBIM would be hard to achieve; however, starting at a lower level of HBIM maturity could serve as a foundation to build upon as further investigations are undertaken. There is currently a limited number of team members within the DEPW that has the skillset or knowledge to begin or maintain a BIM system; therefore, further training would be required if this occurred.

V. Department of Energy and Public Works heritage asset portfolio

The topics discussed within this section focus on the nature of the heritage assets, to develop an understanding of the complexity and popularity of their assets. When asked about the complexity of all heritage assets, the responses varied from medium complexity to high complexity. The range of the complexity of the assets differed as some of the heritage assets comprised simple features and some were more complex.

When the interviewees were asked about which of the heritage assets would be the most suitable for a feasibility case study, the responses varied significantly. The director and asset manager responded by saying that the highest-profile heritage assets should be the first for HBIM implementation because of the cost and time-saving potential. The remaining interviewees responded by claiming that a non-complex, low profile heritage asset should be trialled to develop an understanding of HBIM’s potential and develop knowledge and skillset. Both responses have valid points supporting their arguments.

VI. Lessons learnt

The following points summarise the lessons learnt in the findings of the semi-structured interviews with DEPW personnel:

- Lack of knowledge regarding BIM and HBIM may prove a barrier to adopting new technology;
- Funding and time constraints seem to be the main concerns within the department for maintaining heritage assets;
- A shared collaboration platform would greatly increase the efficiency of accessing asset information;
- DEPW welcomes new technology that can assist the heritage asset management process;
- Determining the optimal heritage asset for the feasibility case study is necessary to demonstrate HBIM’s application;
- Starting at a lower level of HBIM maturity may increase the feasibility of implementation.

5. Preliminary guidance for implementing HBIM

This section provides guidance for implementing various data capture and modelling techniques for managing heritage assets. This guidance is designed to assist DEPW in taking the first steps for using BIM for managing heritage assets. The guidance is based on the research findings on the organisation’s current practices, the fundamental HBIM principles presented in the review of academic literature, and the existing industry best practices.

Within the industry, the main obstacles to the adoption of HBIM are funding and time constraints. Although there is evidence that HBIM has long-term benefits related to cost and time management, the initial resources required to implement HBIM act as a deterrent for many departments. Therefore, the guidance developed within this project aims to assist with the initial implementation of HBIM for managing heritage assets by consolidating all information relevant to HBIM and developing four levels of maturity. The purpose of the guidance is to explain how HBIM can be used on a case-by-case basis depending on the complexity of a heritage asset. In a perfect scenario with unlimited resources, the highest level of HBIM would be applied to all heritage assets. However, each asset needs to be reviewed and analysed, and one of the four levels of HBIM needs to be selected accordingly. Factors such as the asset’s criticality and ongoing maintenance costs need to be considered.

The guidance is developed based on the four levels of HBIM implementation. The levels range from Level 1, the lowest level of HBIM implementation, to Level 4, the highest current HBIM implementation possible. The key criterion defining each level is the level of detail of the final HBIM model produced. Figure 8 shows the features of each level of HBIM. The levels of HBIM are detailed in the following subsections.

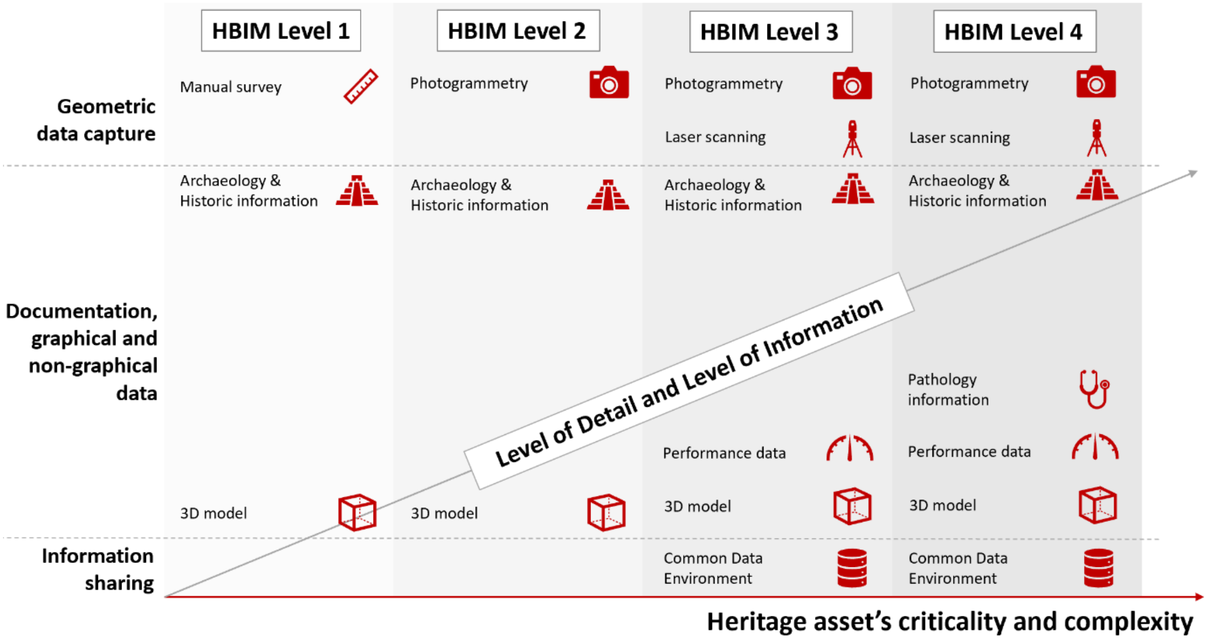

Figure 8. HBIM levels and features

5.1 HBIM Level 1

HBIM Level 1 characteristics:

- It is the lowest level of HBIM implementation that features entry-level technology to begin the process of updating existing heritage management practices with updated BIM software and technologies.
- It marks the initial steps towards moving to a basic level of HBIM collaboration.
- It features the collection of available historical and archaeological information but does not investigate further.
- It features the development of a 3D model; however, the use of high-end technology is not feasible, so manual surveys and photographs may be used as supporting evidence to manually produce a model.
- The level of detail within the 3D model is low, and only the main aspects and proportions of the heritage asset are featured to make it recognisable.
- The heritage assets most suitable for Level 1 of HBIM are those that are non-iconic and do not produce enough economic impact to validate a high level of HBIM.

5.2 HBIM Level 2

HBIM Level 2 characteristics:

- It may either be built upon from the previous level or implemented outright.
- It features all technology used in Level 1 including historical and archaeological information. However, the main difference between the two levels is the development of a highly accurate

3D model that allows for more options for communication within the model regarding non-geometric data.

- The PCD set is most likely to be captured through photogrammetry, and the modelling process is done manually; complex objects are modelled separately from the base model.
- The level of detail is rated at a medium level as it can communicate the layout of the asset effectively but does not include time-consuming intricacies and complex sections.
- The heritage assets most suitable for Level 2 are similar to Level 1 but either may have planned maintenance that needs to be organised efficiently or the asset may provide enough funding to warrant HBIM Level 2.

5.3 HBIM Level 3

HBIM Level 3 characteristics:

- It is the recommended level of implementation for heritage assets. Although the outright implementation of Level 3 is unlikely, building upon previous levels to achieve Level 3 is feasible.
- It contains all geometric and non-geometric information from previous levels and similar modelling processes of PCD.
- Laser scanning is more suitable within Level 3 as it is used for more complex heritage assets that require detailed PCD sets.
- A high level of detail for the BIM model is recommended to use the full potential of the laser scanned PCD.
- The most significant difference between Levels 3 and 2 is the establishment of a centralised CDE which drastically contributes toward collaboration among stakeholders.
- All files are within the selected format, and the HBIM model is the single source of information.
- The heritage assets suitable for Level 3 feature complex objects that require ongoing maintenance or are more iconic and thus could benefit from HBIM.

5.4 HBIM Level 4

HBIM Level 4 characteristics:

- It is the highest level of HBIM implementation.
- It features advanced technology methods to capture information and innovative software to communicate information.
- A 3D model of the asset is produced using laser scanning or photogrammetry to create PCD.
- The produced model incorporates all information of the heritage asset and features a high level of detail and level of information, including intricate parametric objects.
- It uses investigation methods to capture information and data regarding the structural and material pathology of the building. All available information regarding the history and archaeology of the building is captured; if the information is unknown or missing, investigations to retrieve data are undertaken.
- All relevant performance data is captured regarding the building’s performance and systems.
- All information and data retrieved are linked to a single CDE for all stakeholders to access and monitor the heritage asset.
- All operation and maintenance works are organised through the HBIM model.
- It should be utilised for iconic heritage assets that are cornerstones of communities and require new systems to manage the maintenance and preservation of the asset.

6. Conclusion

The research project aimed to develop preliminary guidance for implementing data capture and modelling techniques for managing heritage assets for DEPW. The guidance would allow the organisation to enhance the lifecycle asset management of heritage assets as it is tailored to the unique preservation and restoration requirements of heritage assets.

To achieve the research goal, four case studies were reviewed to identify possible challenges, the feasibility of implementation, and the overall effectiveness of HBIM. These case studies were chosen due to the successful application of BIM and because the heritage assets are in the same or a similar class of heritage listings as the ones managed by DEPW. Additionally, semi-structured interviews were conducted to gather an understanding of the current heritage asset management system and the organisation's readiness for implementation. The interview findings indicate that the DEPW is overall welcoming of the adoption of new technology that can improve the heritage asset management practices. Currently, there is a lack of knowledge concerning the amount of information available for a heritage asset, such as the performance data, geometric data, and so on. Moreover, there is no collaboration among stakeholders in the asset management system. The responses also indicate that there is a lack of knowledge about the application of BIM overall. The DEPW would require training and specific roles within the department for the skillset and knowledge to maintain an HBIM model. Depending on the level of HBIM to be implemented, investigations may be required to collect unknown or missing information about the heritage asset. After analysing the research findings, four HBIM guideline levels were developed featuring various data capture and modelling techniques.

The report is designed to serve as a starting point to creating a strategic guideline for HBIM implementation in DEPW; however, a much more detailed investigation is required to identify the specific changes to workflows and policies and procedures required for the successful adoption of HBIM by the organisation. DEPW would greatly benefit from further research into HBIM implementation in the organisation. A much deeper investigation into the work practices is required to develop a comprehensive strategy for the successful implementation of HBIM and to fully realise its benefits. A more comprehensive study could be conducted using more interviews with DEPW staff from a wider range of areas within the organisation. The guidelines produced could form a more detailed asset information management strategy for the DEPW portfolio of heritage assets. Moreover, developing back-built digital models of any DEPW's heritage asset proves the benefits and applications of HBIM through a cost-benefit analysis.

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8. Appendix A. Interview protocol

This section provides the interview questions as prepared for the semi-structured interviews. Not all interviewees were asked all questions, dependent on their role. The questions served as a guide to prompt discussion.

Table A1. DEPW interview questions

Theme	Interview questions
General	• What is your current role in DEPW? • How much input over heritage assets?
BIM application	• How familiar are you with BIM's applications? • Does the heritage management team have any experience with BIM? To what extent? • Do you think there is any lack of collaboration between stakeholders currently? • Would you say heritage management welcomes or needs new methodologies for asset management of heritage facilities?
DEPW current practices	• What are the current systems for heritage asset management? • Is most asset information available digitally? Or is paper documentation most available?
Assets management challenges	• What are some of the main factors currently challenging the asset management? • Cost? Time? Lack of information or collaboration? • Is the current system sustainable for the future?
Information sharing	• How is all the information currently linked? • Is there a platform for all stakeholders or departments to collaborate/share information? • Which stakeholders are actively involved in asset management?
HBIM	• On a scale 1-10, how would you rate the complexity of the heritage assets? Any complex features of the asset that would be difficult to model? • If a 3D model of the asset were developed, what would you see the main benefits? • What do you want to get out of HBIM? • Is the cost and resources required for implementing HBIM going to be an issue? • Why has not HBIM already been proposed or implemented?