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DIGITAL HISTORIC STRUCTURE REPORT (DHSR): A BUILDING INFORMATION MODELLING (BIM) UTILIZATION STRATEGY IN HISTORIC PRESERVATION

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ABSTRACT:

To allow a more comprehensive, adaptable, and accessible Historic Structure Report (HSR), an approach to transform HSR to Digital HSR (DHSR) utilizing Building Information Modelling (BIM) will be evaluated in this paper. HSR is the type of historic documentation ruled by the National Park Service (NPS), a U.S. Department of the Interior bureau. It is directed to owners of historic buildings to help with decisions on the structure and provide an information resource for future uses. BIM’s ability to enhance the current HSR process by closing the disconnection between visual and information could suggest its potential utility in complementing or even substituting physical HSR. This research will be conducted in two approaches to support the proposal for a standard application of DHSR. The first approach is by analyzing the current guideline of HSR, which will include the evaluation of the NPS’s “Preservation Brief.” The second approach is to evaluate the BIM features, potential, and challenges for Digital HSR by analyzing the software as a user. The result of this study would be a proposed protocol of the DHSR, as an application guideline.

1. INTRODUCTION

1.1 What Historic Preservation Needs: Documentation

Historic documentation records the building’s history and its existing tangible and intangible information. Based on (ICOMOS, 1990), the primary purpose of an on-site recording is to determine the value and significance and to evaluate its materials, structure, and pathology, which would allow for a better opportunity to safeguard the important monument (Stylianidis, 2020) (Worthing & Counsell, 1999).

The standard of historic documentation is regulated in certain territories. In the United States, the National Park Service, a bureau of the U.S. Department of the Interior, provides guidelines known as "Preservation Briefs" for developing Historic Structure Reports (HSR). The guideline is directed to owners of historic buildings to help with decisions on the structure and provide information resource for future uses (Slaton, 2004). HSRs contain not only visual and written information on both the past and current conditions of a building, but also serve as a record of the changes that happened over time. Thus, the document is living as it may acquire edits and additions as the building continues to change or alter over time.

1.2 What Technology Offers: Building Information Modelling (BIM)

Building Information Modelling (BIM) is a broad term typically used to describe a method of utilizing a particular type of Computer-Aided Design (CAD) software. Some commonly utilized BIM software include Autodesk Revit, Graphisoft ArchiCAD, Grasshopper plugin for Rhinoceros, Bentley Architecture, and many others.

Tracing back BIM’s development history, the developers made an apparent effort to create a data-containing model, prioritizing the 3-D model as a tool not only for visual representation but also to develop and transfer knowledge (Autodesk, 2002). One significant shift BIM initiated is a way to perceive the importance of information in the built environment. It highlights the relationship between visuals and different data types and redefines how information is conveyed through a digital representation of the building. Building elements in BIM models are often regarded as *intelligent*, as each contain a set of data, understanding its characters and relationship with others (Eastman, C. et al., 2008) (Kymmel, W., 2008).

Another characteristic of BIM software is its ability to accommodate collaboration among experts in one shared model. Within the past few years, online collaborative platforms have been developed to further support this purpose.

1.3 Research Objective

In the most common practices today, an HSR is made under the direction of the building owner, who will commission several experts to produce a report in the form of a physical book. The information is segregated into three formats: measured drawings, photographs, and written descriptions. Even though the entire process of developing this document is conducted collaboratively, those three different formats are generated separately with different experts working on different files. In some cases, additional notes could be provided on the measured drawing or photograph, but the amount of text able to be embedded into images is usually limited.

Arguably, the typical HSR workflow contains some disconnection between the essential documents and among the experts working on the project. In addition, the nature of this document, which keeps growing along with the changes and alterations in the building, makes the physical report bulky and less practical – suggesting the potential necessity to transform the format into a digital version.

To allow a more comprehensive, adaptable, and accessible HSR, another approach utilizing BIM will be evaluated in this paper. While BIM was initially designed to model new buildings, its ability to enhance the current historic documentation process by closing the disconnection between visual and information could suggest BIM's potential utility in complementing or even substituting the current physical HSR into Digital HSR (DHSR).

Although research has been conducted in BIM for historical buildings, many of them focus on workflow enhancement for visual representation purposes. Previous research on BIM's utility in information management systems, especially in historic documentation, is not as common, making this evaluation of BIM for DHSR valuable in the field.

1.4 Methodology

To understand BIM's potential for DHSR, this paper will evaluate whether common BIM approach can comply with the current HSR requirement; what additional features it provides, and the challenges. Some documents including HSR guideline issued by National Parks Service and sample HSRs including Eagle Creek Overlook Shelter and Historic Commissary Building will be reviewed to determine the documentation requirement and how HSR were produced traditionally. A sample BIM model will be developed to identify the potential and limitation of utilizing BIM to fulfil the aforementioned guideline. The model will portray Avery Library, a historic New York building designed in 1890 by McKim, Mead & White.

2. LITERATURE REVIEW

2.1 Historic Documentation: Integrated Safeguarding Tool

At an international level, establishing a collective cultural heritage inventory is ruled under the UNESCO World Heritage Convention 1972. It suggests that the inventory should be collected in a suitable form, regularly brought up to date, and should be in the form of maps and "fullest possible documentation covering the cultural and natural properties in question." (UNESCO, 1972) This requirement is followed with a guide for action, including a suggestion on planning the intervention (protection, conservation, and rehabilitation) and education (presentation) of historic monuments.

UNESCO is not the first authority to suggest the importance of historic documentation. A few years before the convention took place, the United States of America had established the National Historic Preservation Act (NHPA 1966). This act declares the requirement of documenting historic structures to standards issued by the Secretary of the Interior (U.S. Department of the Interior National Park Service, 2016). The NHPA also determines historic preservation scope in the United States, which includes "[...] identification, evaluation, recordation, documentation, curation, acquisition, protection, management, rehabilitation, restoration, stabilization, maintenance, research, interpretation, conservation, and education and training regarding the foregoing activities or any combination of the foregoing activities," (U.S. Department of the Interior. National Park Service, 2016).

Both regulations above indicate that while documentation is one process in preservation measures, the knowledge inventory it provides informs further decision-making on the building treatment. Some, if not all, processes in historic preservation are supported by the knowledge archived as a result of documentation. Naturally, this also works the other way around - as documentation involves compiling all available resources, it also receives input from other processes, including the intervention action, which is one of the latest stages in historic preservation. Furthermore, the wide array of information contained in historic documentation also provides the opportunity to transfer knowledge to wider public and future generation (Stylandis, 2020).

2.2 Historic Structure Report: Purpose, Workflow, and Standard Practice

The significance of documentation in safeguarding important buildings results in the necessity of documentation guidelines. Different authorities release these guidelines based on territory. At the federal level in The United States, The US Department of the Interior National Parks Service administers Historic Structure Report (HSR). An HSR provides documentary, graphic, and physical information of a building's history and existing condition. It is an essential guide for all changes to a historic property and a record for future researchers. The report allows additional content when more information is acquired, or the building is altered. Its primary purpose is determined in the following list.

> *"The completed historic structure report is of value in many ways. It provides:*
> 1. *Primary planning document for decision-making about preservation, rehabilitation, restoration, or reconstruction treatments*
> 2. *Documentation to help establish significant dates or periods of construction*
> 3. *Guidance for budget and schedule planning for work on the historic structure*
> 4. *The basis for the design of recommended work*
> 5. *Compilation of key information on the historic structure's history, significance, and existing condition*
> 6. *Summary of information known and conditions observed during the survey*
> 7. *Readily accessible reference document for owners, managers, staff, committees, and professionals working on or using the historic structure*
> 8. *Tool for interpretation of the structure based on historical and physical evidence*
> 9. *Bibliography of archival documentation relevant to the structure*
> 10. *Resources for further research and investigation*
> 11. *Records of completed work."* (Slaton, 2004)

Based on the list above, HSR indicates its purposes as visual representation, pointed out by requirement numbers 7 and 10, as they mention HSR provides an interpretation tool for the property and captures the as-built condition after conservation or intervention takes place. Documentation's purpose for information management is determined in numbers 4, 5, 8, and 9 on the list, directly mentioning the HSR's utilization in compiling and summarizing the known information of the past and existing conditions of the building, as well as in providing a knowledge resource for further research, providing the information and the bibliography of the corresponding archives. It also indicates that documentation supports collaboration among experts, mentioned in number 2 and 6, elaborating HSR acts as a guide for different experts involved during the construction, including owners, managers, staff, committees, and professionals. The HSR guidelines also determine the purpose in supporting decision-making, evidently indicated in number 1 and implicitly indicated by numbers 2, 3, and 6, mentioning HSR acts as a planning tool for different types of conservation and intervention on the building, from the design, budgeting, scheduling, and dividing works. The list above also informs the document’s benefit in accommodating archives for future uses, as pointed out by numbers 6, 8, and 9, not only for further construction works, but also serves as knowledge resources and links the information to their sources.

In the most common practice today, the content of an HSR is adjusted to meet the project’s requirements. This typically considers the property's significance, condition, intended use, and available funding. The HSR preparation involves multidisciplinary tasks, with the building owner or manager commissioning preservation specialists consisting of experts from different fields. There are at least nine work phases during HSR development, in which the content and the involved expert's role are outlined in the table 1 below. The report typically contains information in multiple formats, including texts, photographs, annotated sketch drawings, and measured CAD drawings - produced by the appropriate specialists from the HSR team members. This team is led by a principal author responsible for coordinating and integrating the information generated by the various disciplines (Slaton, D., 2004).

Work Phase	Format	Information	Actor
Preliminary walk through	Annotated sketch drawings, photographs	User concern, deterioration, recent repairs	Site manager, building staff
Historical research	Text, existing drawings, photographs	History, original construction, modification, and occupancy	Historians, architectural historians
Existing condition survey	Text, annotated sketch drawings, CAD drawings, photographs	Existing materials, finishes, structure, MEP, and security systems	Architects, structural, mechanical, and electrical engineers, materials scientists
Measured drawings and record photography	Existing drawings, existing photographs	Supplementing information for historical research and existing condition survey	Architects, photographers
Material investigation and testing	Text, annotated sketch drawings, CAD drawings, photographs	Testing, field monitoring, and lab testing results about the building materials, components, and systems.	Architects, structural, mechanical, and electrical engineers, materials scientists
Evaluation of significance	Text	Historical, architectural, engineering, and cultural significance	Historians, architectural historians, key HSR members
Selection of treatment approach	Text, annotated sketch drawings, CAD drawings	Alternatives of the recommended treatments	Architects, structural, mechanical, and electrical engineers, historian, key HSR team members
Development of work recommendation	Text, annotated sketch drawings, CAD drawings	Procedures for the recommended work	Architects, structural, mechanical, and electrical engineers, key HSR team members

Table 1. HSR work phases, format, content, and the involved specialists based on “The Preparation and Use of Historic Structure Reports” by Slaton Deborah (2004), re-arranged and organized by author.

3. EVALUATION

HSR's purposes include providing a visual representation of the property, creating an information management system, allowing collaboration among experts, supporting decision-making, and providing archives for future uses. While there are several other features BIM can conduct, it is essential to analyze whether BIM has the ability to fulfill the basic needs of HSR before understanding the additional potential benefits it provides. This will be evaluated based on the collection of BIM definitions coined by experts, which will then be clarified with software analysis. It is imperative to note that the evaluation is conducted by the author, as a BIM user, supported by literature reviews and interviews. While there is an array of BIM software available, the analysis is conducted in the Autodesk Revit environment.

Considering the rapid pace of technology advancement, the approaches evaluated might change over time; hence this section is not indicative of all methods available in BIM in tackling the HSR needs. Instead, this chapter aims to analyze the BIM approaches commonly used by the practitioners in the field, and compare it to what HSR guideline requires, to understand its potentials and limitations.

3.1 Visual Representation

BIM software provides a computable visual representation of the physical and functional characterization of a building in the form of digital models that acts as a basis to support different stages of the project, including design, implementation, and evaluation (British Standard Institution, 2019) (RIBA, 2012) (National Institute of Building Sciences, 2007).

In HSR, several different requirements and expectations exist in visually representing the building. Generally, as HSR follows the Secretary of the Interior's Standards and Guidelines for Architectural and Engineering Documentation (HABS/HAER standard), it requires comprehensive and very specific content. As one of the main purposes of this document is to provide base drawings for future projects and research, the drawings must have a higher level of accuracy, specifically in dimension and visual representation. HABS/HAER standard is very standardized in terms of formatting, with very specific methods of presenting the dimension, drawing the material hatches, and even indicating different periods of time when certain elements are added.

Although the HABS/HAER standard was initially made for hand drawing format, some specific rules still apply for digital drawings. It is advised not to use the “*predefined hatch patterns for surfaces (such as brick coursing or roof shingles in elevation, or herringbone brick paving in plan)*” (U.S. Department of the Interior National Park Service, 2020). It is imperative to measure and draw the material pattern individually to represent the actual condition of the building. The guideline requires flexibility in the software to comply, as the approach suggested is not very common in digital drawing practice.

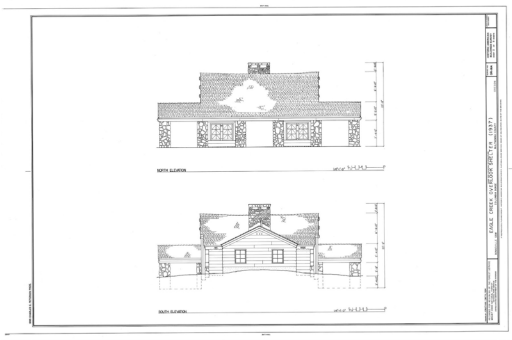


Figure 1. HABS drawing of Eagle Creek Overlook Shelter, 1937, made in CAD. It indicates the use of custom material pattern on the roof and wall in elevations, avoiding “predefined hatch” from the software (Historic Preservation Northwest, 2015)

BIM software was not specifically developed for modeling historic buildings, let alone HSR, but it is possible to attain the requirement. Considering the initial intention of BIM to facilitate new building design, some methods require more effort. Particularly, fulfilling requirements to visually represent the exact pattern of materials like bricks, shingles, and paving would be more time-consuming. In other Computer-Aided Design (CAD) software, modeling the building element is more straightforward - as it only represents the building visually, unlike BIM, which has parameters and information embedded in each element. Revit’s workflow starts with determining the element type, or family, to assign a set of information to that element, which is then followed by modeling the actual shape (figure 2). Due to this reason, each wall surface with the same material is typically considered as one element, as the entire wall shares the same “information.” Modeling in BIM is also less organic, requiring multiple steps to produce a certain form and tend to result in a more rigid geometry - hence modeling an intricate architectural decoration is also a challenge.

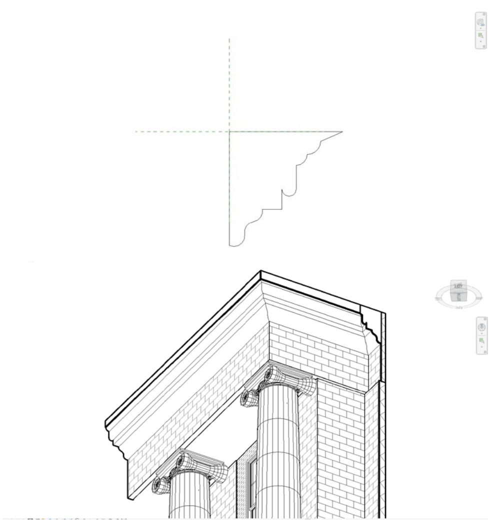


Figure 2. Modeling cornice in BIM requires a process to model the section of the molding in “wall sweep” family.

Currently, there are several approaches in Revit in modeling the way material pattern look like in real life. One of the methods is to model each brick as one element, which has higher accuracy and information but would result in a very long list of schedules – and a highly time consuming process. Another method is to model-in-place the material, following their actual arrangement using the wall surface as a work plane - avoiding a very long list of schedules - but the entire wall will share the same property containing the same parameters and information (figure 3). It is possible to fulfill the guideline, but the approach is very dependent on the project, with considerably different workflow compared to the other CAD software.

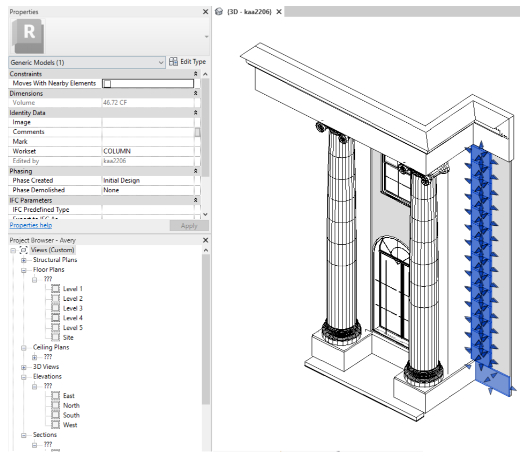


Figure 3. One of the approaches to modeling the correct material pattern (instead of a predefined hatch pattern) is using the model-in-place tool (highlighted in blue).

That said, the 3D format in BIM informs the more accurate physical form compared to the typical 2D drawing format required by HABS/HAER. Some buildings might have a particular form that cannot get captured as clearly in 2D; hence 3D visualization would inform a better spatial understanding for future uses. Additionally, models made in BIM environments are “intelligent” (figure 4). This means that each element generated in the software could understand its characteristics and relationship with other building elements (Eastman, 2008). This allows a more enhanced workflow once the model is established - it requires less time and effort to make edits and changes to the model, because each of the element has its own “character.”

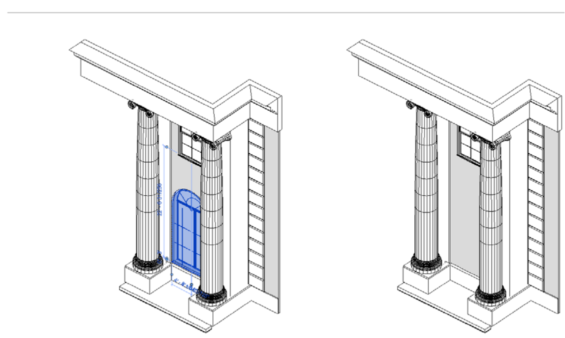


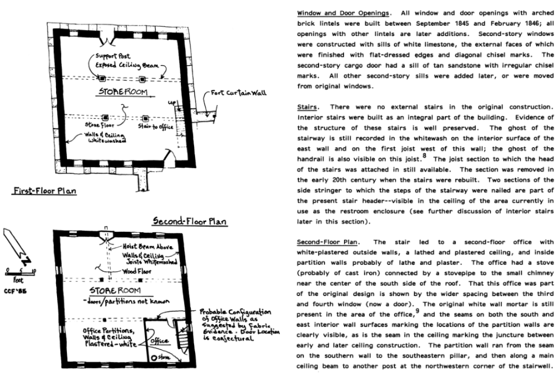
Figure 4. As BIM's element has characteristic and a certain amount of intelligence, deleting window in BIM will leave the wall intact, unlike other CAD software that will leave a hole.

3.2 Information Management System

HSR contains a wide array of information indicating the building's significance. The information typically includes visually representable data (such as the material information, the description of a certain building element, the historic construction chronology, and many more) and non-visual data (such as background information regarding the owner, architect, building's relationship with a certain important history, and many more).

One of the primary intents of BIM development is to allow information to be more effectively conveyed through the building model (Autodesk 2002), which responds to the need for HSR to provide an information management system for the property. Additionally, the collection of information that has been organized and reorganized in the model acts as a knowledge resource for future projects (Associate General Contractor, 2006) (National Institute of Building Science, 2007).

One of the potential approaches of BIM for DHSR is showcasing visually representable historic information. The example below (figure 5) represents a particular intervention phase of the Historic Commissary Building with information about the building element shown in the image. The images and the paragraphs, although they describe the same building elements, are conveyed on two different pages, with annotations in the image pointing out the relationship between the illustration and the written information. This approach denies a direct attribution between two kinds of information supposedly associated with each other.



Window and Door Openings. All window and door openings with arched brick lintels were built between September 1845 and February 1846; all openings with other lintels are later additions. Second-story windows were constructed with sills of white limestone, the external faces of which were finished with flat-dressed edges and diagonal chisel marks. The second-story cargo door had a sill of tan sandstone with irregular chisel marks. All other second-story sills were added later, or were moved from original windows.

Stairs. There were no external stairs in the original construction. Interior stairs were built as an integral part of the building. Evidence of the structure of these stairs is well preserved. The ghost of the stairway is still recorded in the whitewash on the interior surface of the east wall and on the first joist west of this wall; the ghost of the handrail is also visible on this joist.[8] The joist section to which the head of the stairs was attached in still available. The section was removed in the early 20th century when the stairs were rebuilt. Two sections of the side stringer to which the steps of the stairway were nailed are part of the present stair header--visible in the ceiling of the area currently in use as the restroom enclosure (see further discussion of interior stairs later in this section).

Second-Floor Plan. The stair led to a second-floor office with white-plastered outside walls, a lathed and plastered ceiling, and inside partition walls probably of lathe and plaster. The office had a stove (probably of cast iron) connected by a stovepipe to the small chimney near the center of the south side of the roof. That this office was part of the original design is shown by the wider spacing between the third and fourth window (now a door). The original white wall mortar is still present in the area of the office,[9] and the seams on both the south and east interior wall surfaces marking the locations of the partition walls are clearly visible, as is the seam in the ceiling marking the juncture between early and later ceiling construction. The partition wall ran from the seam on the southern wall to the southeastern pillar, and then along a main ceiling beam to another post at the northwestern corner of the stairwell.

Figure 5. Construction chronology as shown in Historic Commissary Building's Historic Structure Report (HSR) with separate information regarding the building elements in one development phase (Frazier, et al., 1987).

Visually representable historic information as this example could be conveyed and managed more effectively in the BIM environment. The phasing tool, which was originally made to show different construction phases in new buildings, allows each intervention to be modeled 3-Dimensionally into layers (figure 6). The parameters and information about the building element on that particular phase can be directly embedded in the model using the comment section. These features come in handy when the building's physical fabric has an array of significant chronology and alterations - especially if each phase and element has important parameters and information to convey. With the traditional approach, this scenario might result in hundreds of pages of report, but in BIM, this information is packed into one model. The schedule utility also allows the data to be easily organized, sorted, and browsed when needed.

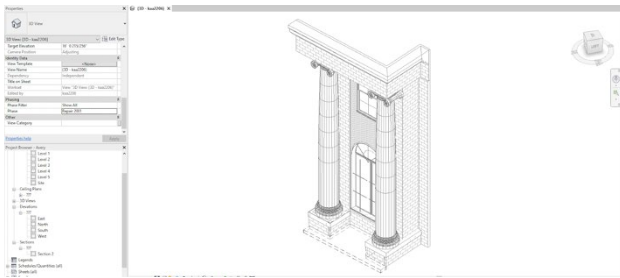


Figure 6. Phasing in BIM with different construction phases represented in dashed line.

BIM still poses some limitations in delivering non-visual written paragraphs. As mentioned earlier, visual representation is needed as a container for the information, which non-visual information typically does not have. Sheets in Revit allows text drafting, but it does not offer any special features compared with typical writing software such as Microsoft Word - if anything, writing in BIM is more complicated considering the less familiar interface to draft texts. Considering the more comprehensive collaborative platform BIM introduces, it is possible that the typing tool in BIM might get more uses in the future. Another potential is linking a certain text with hyperlinks, which could act similarly to the bibliography in HSR.

3.3 Support Decision-Making

The data conveyed in the model helps inform the decision made for the properties. The information contained in BIM benefits an array of stakeholders during strategy-making on the building throughout its entire life span (Messner, et al., 2019).

One main goal of HSR is to provide treatment alternatives and work recommendations based on the building requirement in response to the building's physical character and significance. As mentioned earlier, the phasing tool in BIM can potentially compare existing conditions and the proposed design, informing the decision regarding visual appropriateness. Deteriorations on the building can be documented by overlaying notes and legends on top of 2D drawings. Furthermore, there is some emerging research to model, calculate, and manage a different kind of building failure in 3D format, which would further benefit the historic preservation projects.

Additionally, the ability of BIM to allow simulation pre-establishment further assists the decision-making process. BIM software allows coordination between elements to avoid clashes among different systems (Eastman, 2008) and the ability to utilize the external plugin to conduct specific simulations required for a specific project. Some examples include energy simulation, moisture simulation, and many more. There is also the opportunity to link the elements to external construction management tools to enhance scheduling and budgeting, increasing the precision and accuracy of the project implementation (Kymmel, 2008). Simulations that require

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material specification, such as R-value, material durability, and others, require on-site testing because the pre-defined data in BIM might not be available for historic materials.

3.4 Support Collaboration

Another purpose of HSR is to support collaborative work between experts and stakeholders. BIM has been widely developed to accommodate this need, as some developers released a fully collaborative platform, some are accessible online, where workers from different fields could work together in a shared model.

In today's practice of HSR, different groups of experts work together to develop a comprehensive report containing historic information, drawings, and photographs. They work in different document formats, which will then be transferred through electronic mail or other communication tools. In some cases, a release should be signed for copyright purposes. The traditional approach arguably contains some disconnection between experts working on the file. The document does not get updated as quickly when certain changes have been made, denying the ability of other parties to observe in real time.

Collaboration in BIM could be achieved in two ways: within the network and in the cloud (online platform). The first option will turn the active file into a central model, where other users can synchronize every period to update the changes made. Typically, a BIM manager will assign each member to synchronize the file in a certain time interval. This approach is limited to a workspace where every user shares the same LAN or WAN network - requiring every stakeholder to work in close proximity.

Working in the online collaborative platform allows better flexibility in terms of location, as long as each party owns an account to hold certain accessibility to the file. Today, this access still requires a higher cost, as users need to purchase a subscription. In the case of online collaboration, the BIM manager will specify each user's ability to view and edit a certain document. Typically, each group of stakeholders will have one central model they synchronize to. When the file is ready, they will release a package for other stakeholders to confirm and import to their files. The stakeholder groups typically involve engineers and architects. Still, there is also a possibility to work collaboratively with historians, photographers, and other experts, depending on the file format the team aims to develop.

3.5 Durable Archive

The data stored in HSR allow further use beyond the building lifespan. It provides a sustainable knowledge resource in the form of a digital archive. There is an ongoing discussion and emerging awareness of the importance of digital archives - not only due to the possible risks of physical archives, but also considering the benefit of a more organized and accessible knowledge resource. Digitization of archives is becoming increasingly common in today's practice, where archivists typically scan and store the document in electronic paper or PDF. This file format informs future projects and other purposes as a knowledge resource and reference - but it requires the users to replicate the visual representation and the data to their own working model.

BIM introduces an International Foundation Class (IFC) platform-neutral file format, allowing enhanced file accessibility and applicability throughout all IFC-certified software. The users needing the data can directly work with the file as a base model and immediately implement the project without replicating the content. It is not impossible that this format will constitute the future DHSR as a digital archive. Although, at this moment, there is an issue with a large IFC file size compared to PDF - necessitating a bigger digital storage capacity. Another possibility is using an online cloud provided by some BIM developers, waiving the need for a large-capacity hard drive. However, the high-cost expenditure to access the cloud itself is another challenge.

4. RESULT

In conclusion, the following are the current BIM's values for DHSR.

1. The 3-dimensional format of BIM allows a better visual understanding of a certain type of building, particularly structure that is not clearly representable in plan, section, and elevation. This includes buildings with irregular extrusion and niche, curved surface, and others. It does not only help with comprehending the building form, but also provides the opportunity to obtain more accurate building measurements for future projects.
2. The model in BIM is considered "intelligent," which allows a more enhanced workflow once the system is established.
3. BIM allows a more comprehensive information management system, especially for visually representable data. It particularly has a higher benefit to informing past intervention chronology and the associated information, comparing between certain phases or intervention proposals, and embedding important information in each building element.
4. The 3-dimensional visual representation, phasing feature, clash detection, and other simulation plugins allow a more calculated decision-making process.
5. BIM enhances collaboration among stakeholders working on the project by enabling model synchronization. It allows more efficient teamwork by providing a shared-access platform where stakeholders can work together.
6. IFC file introduces a platform-neutral format, increasing the accessibility and applicability of the visual and written data contained in the model.

However, the list above does not indicate that the current BIM approach is already ideal for substituting HSR. This tool also comes with some challenges, as indicated below.

1. The logic behind BIM is considerably new, requiring additional training and more time to set up a starting point to establish the model. A shift in the modeling workflow might be required at the beginning. The learning curve among stakeholders is also another challenge.
2. The modeling process in BIM is less straightforward. Customizing a building element, pattern, and additional form that is not typical is more challenging. It demands associating the elements with a certain parameter or how it behaves in relation to the other elements, which might sometimes slow down the workflow.

3. Some features in BIM, such as the online collaborative platform, cloud storage, plugins, and even the software itself, are considerably expensive.
4. BIM is not the most efficient tool for non-visual information (although it is possible that some people might prefer typing reports using more traditional software).
5. Some existing historic documentation requirements were established before the BIM concept even emerged, resulting in less applicability of this tool.
6. Pre-defined patterns and material specifications in BIM are not always applicable to historic buildings.

One point to note is that most, if not all, challenges mentioned are time-sensitive. Potentially, they will be resolved by the BIM developers or the increasing practitioner’s skill set.

5. RECOMMENDATION: BIM PROTOCOL FOR DHSR

The purpose of this section is to provide a protocol for BIM for DHSR (table 2). Five HSR requirements introduced at the beginning of this paper will serve as a criterion of this protocol. These criteria have a particular guideline for each HSR work phase based on the HSR guideline. It is imperative to keep in mind that all buildings are unique; therefore, this guideline has a certain degree of flexibility. Additional considerations must be taken into account before applying the proposed protocols, and some adjustments are allowed to guide the DHSR development appropriately.

The definition of each criterion in the case of this protocol is described below.

Visual representation: the extent of BIM in capturing the existing condition of the building with a certain Level of Detail (LoD) and Level of Accuracy (LoA).

Information management system: the extent of approaches in BIM to contain and manage different kinds of information - text, number, float, yes/no, etc. - embedded into the elements or model.

Supporting collaboration: the extent of BIM in allowing a certain level of accessibility, editability, and utility for different stakeholders.

Pre-establishment simulation: the extent of BIM supports decision-making by allowing historic appropriateness evaluation, pre-construction analysis, utilizing tools incorporated in the BIM software and/or plugins from external software.

Durable archival format: the extent of BIM allows more sustainable data for archival purposes - provide the opportunity to transfer information to future generations and support future uses.

Work phases	Visual representation	Information management system	Supporting collaboration	Pre-establishment simulation	Durable archival format
Preliminary walk through	Existing drawing collection, on-site verification required	Existing information collection, verification required from primary or secondary sources	Stakeholders sign a contract determining copyright, ownership, and file accessibility	Plan the simulations to conduct based on the building requirement from initial research	Stakeholders sign a contract determining copyright, ownership, and file accessibility
Historical research			Relevant experts submit the historic report to principal author, as a supporting document for BIM model	-	I Visual representation and relevant information stored in IFC file format in each work phases, verified and updated throughout the DHSR development.
Existing condition survey	Laser scan, photography, and/or manual measurement as visual reference to the existing condition of the building	Determine building material, structure, and other information through on-field testing	Relevant experts illustrate the survey result in 3D format with information linked throughout the building elements	Determine material specification through on-field testing	
Measured drawings and record photography	Produce BIM model in 3D format based on the survey and existing drawings	Visually representable information including photographs linked to building elements		Produce BIM model in 3D format based on the survey and existing drawings with appropriate family	
Material investigation and testing	Utilize appropriate families based on the testing result	Appropriate family selected or manually produced with relevant parameter based on the survey result	Relevant experts inform the testing result to produce appropriate material parameters and specifications		
Evaluation of significance	Visual data and non-visual data supporting evaluation of significance		Key HSR team members determine building significance, reported as written text linked to BIM model	Verify and update the necessary simulation by considering the significance of the building	
Selection of treatment approach	Illustrate selection of treatment and work recommendation in 3D and 2D visual representation format with relevant information as notes in schedule or annotation		Key HSR team members determine selection of treatment and work recommendation, reported as 3D and 2D format with relevant information embedded	Utilize plugins to conduct simulations to support the selection of treatment approach	
Development of work recommendation				Utilize plugins to conduct simulations to support the development of work recommendation	

Table 2. BIM for DHSR protocol recommendation.

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