Towards the Integration of Visual and Data:

Building Information Modelling (BIM) Evaluation for Historic Documentation

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Glossary

Building Information Modelling (BIM): A method of utilizing a particular type of "sophisticated" Computer-Aided Design (CAD) software with a certain degree of intelligence.

BIM Mandate: A policy established by a government body or an agency involving the enforcement of BIM utilization for a certain type of construction projects.

Computer-Aided Design (CAD): The utilization of computer-based tools to support the designing process. BIM software is one type of CAD software.

Historic documentation: Based on (ICOMOS, 1990), "compiling all available past and present records (written, graphic, photographic, and the like) about a historic resource."

Five shared purposes: Five overlapping purposes between Building Information Modelling (BIM) and historic documentation.

Historic Documentation BIM (HDBIM): The title of the proposed framework in this thesis - including a set of protocols and application guidelines to support the planning and implementation of BIM approach in historic documentation.

Identification: One of the initial phases in historic preservation which involves the process of pinpoint potentially significant historic monuments.

International Foundation Class (IFC): A file format that allows enhanced file accessibility and applicability throughout all IFC-certified software.

Intervention: A preservation action that results in changes in historic buildings.

Non-visual data: Text-based information with limited or no representation visually.

Point cloud: A product of laser scan or LiDAR system, consisting of an array of points in 3D space.

Historic Recordation/Recording: Based on (ICOMOS, 1990), "the activity of producing precise and reliable technical records of historic resources that meet the Historic Resource Conservation standards."

Schedule: A tabulated list of building elements with their associated parameter and information including dimension, material, and more.

Visual data: A type of information that is represented or associated with a visual object.

Introduction

Background

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

Historic documentation is one particular process in preservation workflow and is significant in supporting the process of safeguarding buildings. It has specific guidelines depending on the territory where the building is located, but all of them share five primary purposes: providing a visual representation, creating an information management system, allowing collaboration between experts, supporting decision-making, and providing archives for future uses. In the most common practice today, the general workflow starts with information gathering, followed by research and developing the drawing. They are usually generated separately, with different experts working on other files. Arguably, this workflow contains some disconnection between the essential documents and among the experts working on the project.

To allow a more comprehensive documentation for preservation, I will evaluate another approach utilizing Building Information Modelling (BIM) in this thesis. BIM is currently growing in significance as more countries have established BIM mandates - which could influence preservation practice as one of the sectors in the construction industry. Tracing back to BIM's development history, the developers had made an apparent effort to allow a data-containing model, prioritizing the 3D model as a tool not only for a digital representation, but also as a tool to develop and transfer information. While BIM could be considered newer technology, arguably, the preliminary procedure in BIM for existing buildings is similar to the traditional workflow that preservationists typically use. The main difference is that BIM allows a more comprehensive information management system, whereas the traditional method arguably disconnects the visual representation of the building from the data management.

Research Rationale

To understand BIM's utility for historic documentation, this thesis will evaluate whether a common BIM approach can comply with the current historic documentation requirement and to also determine its current challenges. This thesis also argues that existing BIM standards are not sufficient and considerably hard to implement for historic documentation purposes. Improvements and alterations from existing protocols are required, with specific guidelines for application and evaluation to determine its feasibility and applicability, all of which will be proposed in this thesis.

Research Statements

1. How is historic documentation defined, and how significant is it in historic preservation workflow?
2. What are the requirements for historic documentation at international, federal, and local levels?
3. How Building Information Modelling (BIM) is defined, and does it possess the potential to support historic documentation?
4. What framework and protocol are available in BIM, particularly for preservation projects, and are there any ways to improve the existing protocols?
5. How to improve the BIM protocol for historic documentation purposes? What are the criteria, and what is the methodology?

Goals

1. Understanding the current state of knowledge of Building Information Modelling (BIM).
2. Understanding the potential and limitations of BIM for historic documentation.
3. Proposing criteria to plan and evaluate BIM for historic documentation.
4. Determining a set of guidelines and protocols of BIM for historic documentation for guide owners, preservationists, designers, and other stakeholders during the project development.
5. Evaluating the feasibility and applicability of the proposed guidelines and protocols.

Structure and Methodology

For the purpose of fulfilling the goals determined above, this thesis is divided into five chapters. The thesis begins with introduction to this project, outlining the background information, the rationale behind the thesis, raising some research questions this thesis aims to answer and the goals, as well as the structure and methodology of this thesis. The first chapter provides knowledge regarding the theoretical background of this thesis, informed mostly by literature reviews, with some additional information obtained from interviews with experts and practitioners. It will be structured with the purpose of analyzing the relationship between what preservation needs (historic documentation) and what technology offers (Building Information Modelling/BIM).

The second chapter is titled "BIM for Historic Documentation," involving the evaluation of BIM approach in response to the documentation requirements, informed by interviews, literature reviews, and software analyses. The second half of this chapter also provides the additional findings from interviews with practitioners, exploring the workflow and tool difference between different types of interviewee: non-BIM users, hybrid BIM users, and full BIM users. Lastly, the consideration behind BIM utilization based on these sources will be discussed, along with some challenges in utilizing BIM in the field of preservation.

The third chapter starts with the evaluation of the existing BIM protocol, from new building protocol to the historic building protocol, aiming to determine the requirement for improvements. It continues with analyzing two case studies conducted within the BIM environment: adaptive reuse (TWA Hotel) and stabilization (Clara Barton Home). The case studies will provide a precedent and insight on how previous preservation projects standardize BIM application.

The Historic Documentation BIM (HDBIM) protocol will be developed in the fourth chapter. The criteria of evaluation will be suggested based on the evaluation in chapter 1 and 2, as well as the workflow phase, based on the interview with practitioners mentioned in chapter 2. It will also include the recommended approach to plan the protocol application, including the factors to consider before implementing a certain level of protocol. Lastly, to evaluate the feasibility and applicability of HDBIM, real-life projects discussed on chapter 3 will be used as a sample for evaluation. I will evaluate how the proposed protocol applies to different types of preservation projects, resulting in future recommendations. The last chapter will contain the overall conclusion of this thesis, as well as recommendations for different stakeholders, including researchers, BIM developers, and historic preservationists.

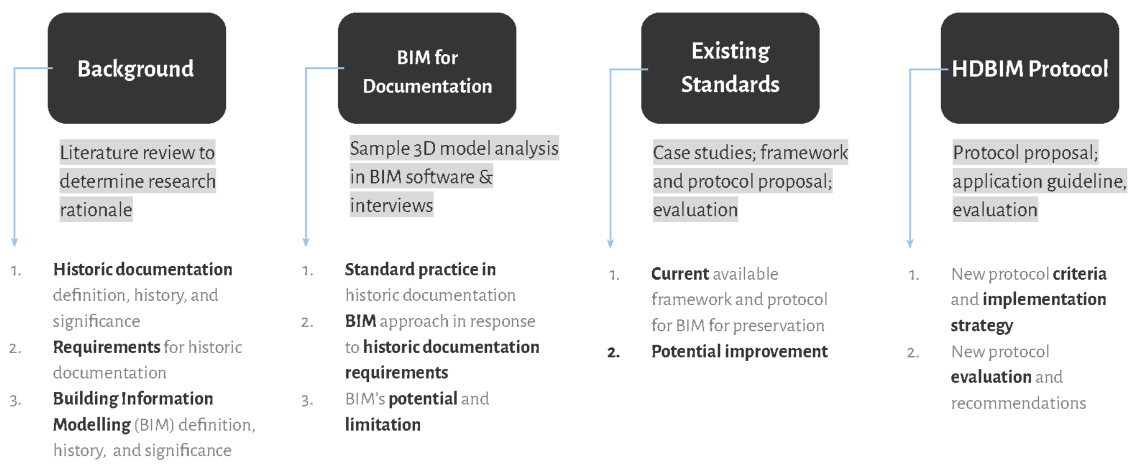

Figure 1. Thesis structure table diagram

Chapter 1: Background

What Preservation Needs - Historic Documentation

Regulatory Framework

At international level, the requirement of 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 (HABS/HAER standard). It determines that each state should have its own historic preservation office, of which one of the primary functions is to complete an inventory of significant sites (U.S. Department of the Interior National Park Service, 2016).

The term "historic preservation" might be defined differently based on the territories, therefore the National Historic Preservation Act determines its scope in the United States. It 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). In both of the regulations above, documentation is always mentioned right before action. It indicates that while it is one process in preservation measures, the knowledge inventory it provides informs further decision-making on the building treatment.

Documentation Within An Integrated Safeguarding Process

To ensure clarity of this study, this section will start by discussing how documentation is defined, as well as how it correlates to other processes in preservation. Recording and documentation are often mentioned concurrently in the case of historic preservation, which might blur the dividing line between those two. For instance, the guideline issued by The International Council on Monuments and Sites (ICOMOS) titled *Guidelines for the Recording of Heritage Buildings* covers protocols for both recording and documenting, despite the title. Based on (ICOMOS, 1990), the difference between those two processes is that recording is "*the activity of producing precise and reliable technical records of historic resources that meet the Historic Resource Conservation standards,*" whereas documentation "*consists of compiling all available past and present records (written, graphic, photographic, and the like) about a historic resource*."

In other words, recording refers to the process on-field in capturing the existing conditions of the building, and documentation refers to the collection of available documents regarding the object, including present "records," which is the result of the recording process. The term documentation is considered more appropriate in this thesis's context, considering that this study mainly evaluates and provides recommendations for the process of utilizing the past and existing documents of a historic building to develop data-containing models in Building Information Modelling (BIM). Naturally, the recording process still influences this study topic. However, it is not the primary focus, as this process has an entirely different set of tools and methods, such as Light Detection and Ranging (LIDAR), Terrestrial Laser Scanners (TLS), and Photogrammetry, which could be distinguished into a completely different research topic.

I would argue that documentation, along with other historic preservation processes, is an integral tool for safeguarding culturally and historically significant monuments. 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 action (intervention and education), which is one of the latest stages in historic preservation. The compilation of information would provide knowledge resources for future projects, allowing continuous preservation practices.

As indicated in the previous section, identification and evaluation are the earliest stages of historic preservation, and the following resources stipulate how early documentation assists in safeguarding significant monuments. ICOMOS determined that one of the primary purposes of documentation is to establish the building's value and significance (ICOMOS, 1990), which are evaluated throughout the designation process. According to the NHPA, the designation is "*the identification and registration of property for protection that meets criteria established*" (U.S. Department of the Interior National Park Service, 2016), indicating it is one of the initial phases in preservation. Additionally, (Stylandis, 2020) supports this argument by stating that, "*by documenting cultural heritage, we are assessing the values and significance of the heritage itself across the different epochs,*" and further referring to documentation as a "*forerunner of conservation*."

The materials contained in the document, including the assessed value and significance, act as a knowledge resource that would support the decision-making processes, including restoration, conservation, and intervention[1]. Based on (Worthing and Counsell, 1999), the records in the historic documentation enable partial or full restoration of a historic building in the event of its damage or destruction. The document allows access to authentic information on a certain building condition that is considered significant and needs to be protected, supporting the purpose of conservation. This argument is further supported by (Stylandis, 2020), who referenced, "*documentation is the observable evidence that the conservators stand in to validate motive, interpretation and finally the actions to take place in the building*."

In the case of intervention, the available historic document informs the extent to which the changes that happened to the building are appropriate and the possible effect the proposed alteration might have on historic building fabric (Worthing and Counsell, 1999). The documents have the ability to assist decisions made by responsible authorities such as the New York City Landmark Preservation Commission (LPC) while determining whether the proposed changes are pertinent to the character and the style of the designated buildings (Landmark Preservation Commission, 2021).

Additionally, by capturing the modifications over time, as (Stylandis, 2020) suggested, *"the entire collection of records, written and graphic are taken up during the investigation and treatment of the building,"* would allow experts to identify in which period certain decisions were made. As a result, historic documentation provides an archival record of what has been preserved, changed, or lost (Arayici et al., 2017). The chronological evolution of the building captured in the document can support the future establishment of a period of significance and which elements constitute it - allowing reversible alterations if necessary. This wide array of information contained in historic documentation is not only able to support the present decision-making process, but also provides the opportunity to transfer knowledge about the importance of the historic building to future generations and communicate its significance to the wider public (Stylandis, 2020).

While documentation is one particular process in historic preservation, its significance in supporting the entire process of safeguarding culturally and significantly valuable buildings from identification to decision-making and archival, determines how essential this step is for historic preservation. In the next section, the guideline of historic documentation issued by several authorized preservation institutions will be evaluated to understand the requirement and workflow that needs to be fulfilled in this process.

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1 In the context of this chapter, restoration refers to the process of returning the building to a certain condition, conservation refers to the process of taking care of a building to protect its significance, and intervention refers to an action that results in changes in buildings (Stylandis, 2020)

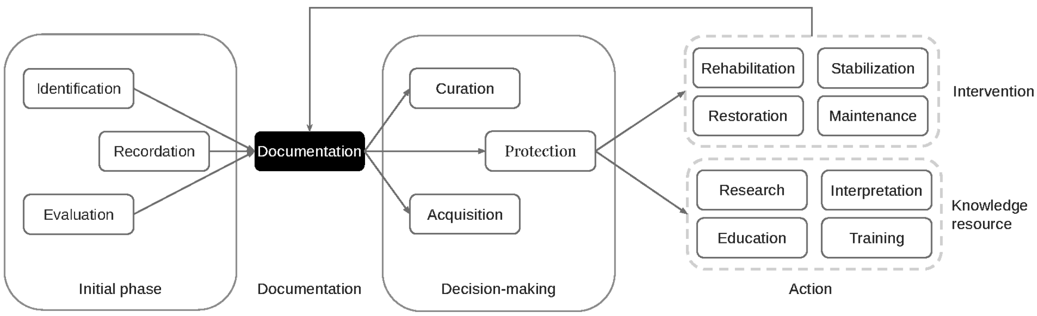

Figure 2. Historic Preservation workflow diagram based on National Historic Preservation Act, showing documentation as one particular process bridging the initial phase (identification) with decision making and action phases.

Documentation Purposes

The previous section has mentioned the significance of documentation in safeguarding important buildings and the preservation action it supports. Naturally, this results in the importance of documentation guidelines, which have been released by different authorities based on territory. Each document has specific purposes, although some of them are more generic than the other. In this section, those purposes will be evaluated from sample guidelines issued by institutions responsible for historic preservation at different geographical levels: international, federal, state, and local.

At international level, The United Nations Educational, Scientific and Cultural Organization (UNESCO) requires several documents prepared by state parties to support the safeguarding effort, two of which will be evaluated in this section as samples. The first document is the World Heritage nomination dossier, prepared for officially applying a property for World Heritage status with the following requirements (UNESCO, 2011).

The nomination dossier needs to:

1. *Clearly define the proposed boundaries of the property;*
2. *Describe the property;*
3. *Outline its history;*
4. *Demonstrate its significance and why it is thought to demonstrate potential Outstanding Universal Value;*
5. *Show how it can satisfy one or more criterias;*
6. *Explain its state of conservation and how it is documented and monitored;*
7. *Set out how in the long term its potential Outstanding Universal Value will be sustained through legal protection and management of attributes that convey its value, and who will be involved in that process, and*
8. *Demonstrate how its value will be presented or interpreted to visitors and others.*

The three primary purposes of historic documentation are directly indicated by evaluating the above requirements. The first one is a visual representation, as indicated by requirements 1 and 8, mentioning how the dossier needs to showcase the clear boundary of the property and determine how the property's value can be visually demonstrated to the public.

The second purpose is information management, referring to requirements number 2, 3, 4, and 6, which outline the needs to provide information on the property, its history, its significance, and the state of conservation. The third purpose is to support collaboration, as mentioned in requirements 6 and 7, referring to how the dossier needs to determine how conservation is documented and monitored and who will be involved in the legal protection and management - indicating different stakeholders that will participate in the process.

A periodic report is a document submitted every six years by state parties to UNESCO, informing the actions taken to the properties and the state of conservation. The reporting and monitoring guideline issued by UNESCO determine the primary purposes of this document as follows (UNESCO, 2013).

1. *To provide an assessment of the application of the World Heritage Convention by the State Party;*
2. *To provide an assessment as to whether the Outstanding Universal Value of the properties inscribed on the World Heritage List is being maintained over time;*
3. *To provide updated information about the World Heritage properties to record the changing circumstances and state of conservation of the properties;*
4. *To provide a mechanism for regional cooperation and exchange of information and experiences between States Parties concerning the implementation of the Convention and World Heritage conservation.*

This guideline also mentions the purpose of historic documentation as an information management system, as the report needs to provide updated information on the property to illustrate the changing environment and the state of conservation. The document's purpose to support collaborative efforts is also indicated by requirement 4, determining the need to specify the methods of cooperation and information sharing between state parties. Additionally, this guideline indicates that supporting decision-making is also one of the purposes of historic documentation, as mentioned in requirements 1 and 2, as the assessment of the World Heritage Convention application and the maintenance of Outstanding Universal Value will inform future judgment regarding the property.

At federal level, two document samples will be evaluated, including the Historic Structure Report (HSR) administered by the United States Department of the Interior National Parks Service and the Historic American Building Survey (HABS) issued by the Library of Congress (LoC). HSR is a document recommended to be prepared by designated building owners. Its primary purpose is determined in the following list (New York City Landmark Preservation Commission, 2019).

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*

Based on the list above, HSR also indicates historic documentation purposes as visual representation, pointed out by numbers 7 and 10, as they mention HSR provides an interpretation tool for the property and captures the as-built condition after conservation of intervention takes place. Documentation's purpose for information management is also 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 documentation purpose in supporting decision-making, evidently indicated in number 1 and implicitly indicated by numbers 2, 3, and 6, mentioning how HSR acts as a planning tool for different types of conservation and intervention on the building, from the design, budgeting, scheduling, and dividing works. In addition to those four purposes already mentioned in the previous type of documents, the list above also informs the documentation'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.

HABS documentation is one of the first historic preservation programs established by the United States federal government. It contains standardized measured drawings of historically and architecturally significant buildings to illustrate and explain their significance. The purpose of this document is determined in the HABS Guideline issued by the United States Department of the Interior, as follows (US Department of the Interior National Park Service, 2008).

HABS drawings typically serve multiple purposes.

1. *Provide a simple documentary record of a building in a standardized format, placed in the public domain at the Library of Congress, where it is made available to the general public and specialized researchers.*
2. *Used as illustrations in scholarly and popular publications.*
3. *Used for interpretive purposes at historic sites.*
4. *Base architectural drawings for facilities management purposes, as well as for renovation and restoration projects.*
5. *Where a significant historic resource is faced with an adverse impact, such as demolition or substantial alteration, HABS documentation can serve a mitigative role.*

The purposes listed above further support the arguments of historic documentation purposes determined in other documents, including visual representations indicated by numbers 1, 2, 3, and 4, as they highlight HABS utility as a record of the building's physical fabric in the form of architectural drawings which could support publication and interpretation purposes. The information management utility of documentation is also pointed out by number 1, as documentary records could come in other formats beyond visual, such as text. Historic documentation's purpose in assisting decision-making is indicated by numbers 4 and 5, mentioning HABS's function in supporting facility management, renovation, restoration, and even reconstruction works following the demolition. Lastly, as determined by numbers 1, 4, and 5, historical documentation also acts as an archival record for future uses, as in the case of HABS, it is made available to the general public.

Lastly, the documentation for nomination and permit established by New York City (NYC) Landmark Preservation Commission (LPC) will provide the sample at local level. Both of these documents intend to "help preserve the City's landmark properties by regulating changes made to these buildings and sites by ensuring that planned changes are appropriate to the character and style of the building." The LPC permit application documents have several purposes, including the list below (Landmarks Preservation Commission, 2021).

1. *Pinpoint areas of proposed work*
2. *Illustrate the information on missing or altered architectural features*
3. *Assess the deteriorated conditions*
4. *Provide written specifications on methods of repair or replacement*
5. *Provide comparative drawings between existing conditions and proposed work*
6. *Determine material and color specifications of the existing condition and proposed work*

In support of the purposes indicated by the previous documents, the above list further highlights the purpose of visual representation, indicated by numbers 1, 2, and 5, stating that the document should visually locate the areas of work, illustrate the missing or changed building features, and compare existing and proposed physical fabric. Numbers 3, 4, and 6 support the argument of documentation as a tool for information management, as it contains written specifications, condition assessments, and material and color specifications of the building, which also include different types of information that must be conveyed for the permit.

Collectively, documents evaluated in this section share five primary purposes, including providing a visual representation, creating an information management system, allowing collaboration between experts, supporting decision-making, and providing archives for future uses (New York City Landmark Preservation Commission, 2019) (National Parks Service, n.d.) (Historic American Building Survey, 1990) (UNESCO, 2011). The purposes determined in this section, referred to as "five shared purposes," will later be analyzed corresponding to BIM features to discover the extent of the tool's performance in accomplishing the standard and in which aspect this tool could further benefit the historic documentation needs. The overview of the evaluation conducted in this section is outlined in the table below.

Level	**Organization**	**Document title**	**General purposes**
International	UNESCO	World Heritage nomination dossier	Visual representation, information management, collaboration,
		Periodic report	Information management, collaboration, decision-making
Federal	NPS	Historic Structure Report (HSR)	Visual representation, information management, collaboration, decision-making, archive for future uses
	LoC	Historic American Building Survey (HABS)	Visual representation, information management, decision-making, archive for future uses
Local	LPC	Permit application	Visual representation, information management

Table 1. List of historic document titles utilized to evaluate documentation purposes.

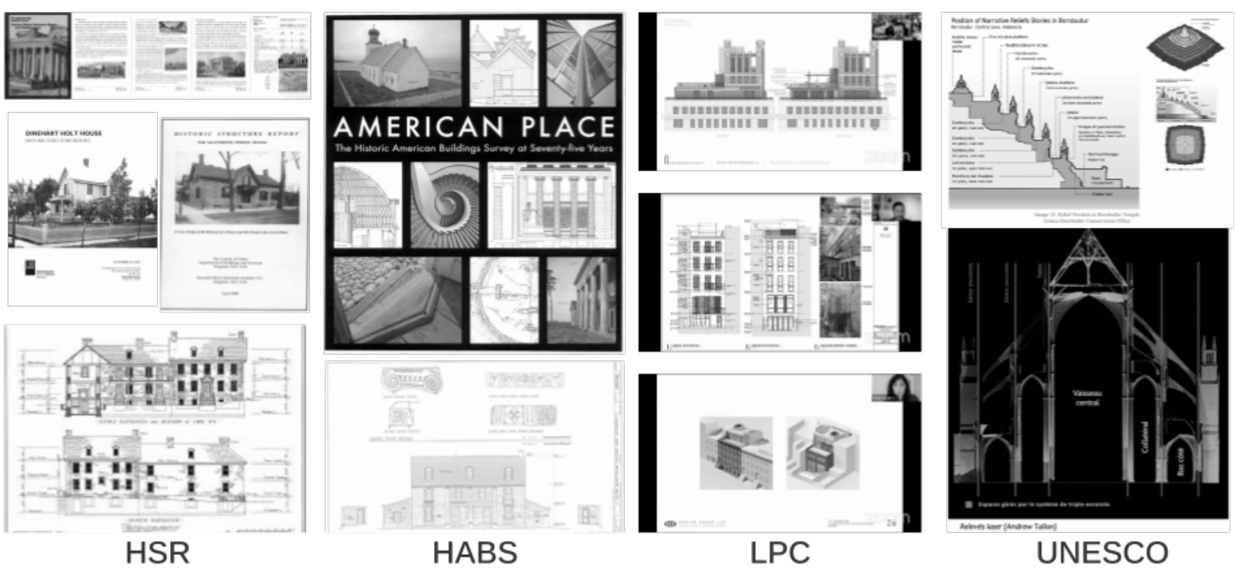

Figure 3. (From left to right) Examples of the Historic Structure Report (HSR), Historic American Building Survey (HABS) report, Landmark Preservation Commission (LPC) permit documents, and UNESCO reporting and monitoring documents.

What Technology Offers - Building Information Modelling (BIM)

More than a Tool

> *BIM is defined in many different ways and tends to mean different things to different people. In one extreme, BIM is purely a technical enabler in the form of sophisticated software, and at the other extreme, it offers a philosophical framework that offers a paradigm shift within the construction sector. In effect, BIM is both of these extremes and everything that comes in between them* (Khosrowshahi, 2017).

People in the field often confuse Building Information Modelling (BIM) with BIM software. Many experts argue that BIM actually refers to the process, approach, or methodology enabled by technological advancement. In other words, they define BIM as the action of utilizing the tool instead of defining the tool itself.

Some BIM software developers support this argument by mentioning that "*Building Information Modeling is Autodesk's strategy for the application of information technology to the building industry,*" (Autodesk, 2002) and "*it (BIM) is a highly collaborative process that allows architects, engineers, real estate developers, contractors, manufacturers, and other construction professionals to plan, design, and construct a structure or building within one 3D model*" (Trimble, 2022). Those two definitions refer to BIM as an application strategy and a process instead of merely a software they developed.

Some of the BIM Guide Books written by experts also further enhance this definition. Based on (Associate General Contractors, 2006) in The Contractors' Guide to BIM, Edition 1, they refer to BIM as "*the development and use of a technology to simulate the construction and operation of a facility from which views and data appropriate to various user needs can be extracted and analyzed*." They elaborate how BIM is not the technology itself, but more about utilizing the technology and exploring the development process involved. In the National Building Information Modelling Standard issued by the (National Institute of Building Science, 2007), "*A Building Information Model, or BIM utilizes cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information [...]*" determines their definition of BIM as a way to use advanced tools for specific purposes.

Furthermore, BIM is defined as the use of technology; other terms that experts often use in defining BIM are process, approach, and method. One interesting explanation is provided in the BIM Handbook written by (Eastman et al., 2008) as follows.

> *It is important to keep in mind that BIM is not just a technology change, but also a process change. By enabling a building to be represented by intelligent objects that carry detailed information about themselves and also understand their relationship with other objects in the building model, BIM not only changes how building drawings and visualizations are created, but also dramatically alters all of the key processes involved in putting a building together.*

The invention of BIM in the AEC (Architecture, Engineering, Construction) industry has been changing the processes involved within the workflow, indicating that the shift in methods follows the technological evolution in the process. Additionally, (London et al., 2008) also defined BIM as an "*IT-enabled approach to managing design data in the AEC/FM industry,*" pinpointing the relationship between "approach" and the technical enabler or "IT." Another expert determining BIM as a method includes (Stagg, 2011), who defined BIM as "*A method to describe a project and its spaces, structures, components and materials with their essential information and properties.*"

Alternatively, as mentioned above, some experts refer to BIM as the tool or the technology itself. For instance, as further mentioned in the BIM Handbook (Eastman et al., 2008), BIM is "*A modeling technology and associated set of processes to produce, communicate, and analyze building models.*" While it is not as common, this definition gives another perspective of BIM as the tool being used (BIM as a noun), contrary to other arguments that illustrate BIM in correlation to how it is used as a tool (BIM as a verb). As additional support for this definition, (Kymmel, 2011) mentioned BIM as "*A tool, process and/or product that develops virtual intelligent models linked to other construction management tools [...].*" One thing to note is that while both of these arguments perceive BIM as an object, they follow the definition with a "process," similar to other definitions made by previous experts.

In conclusion, there is a wide array of definitions for BIM, as experts have different ways of defining this terminology. While some arguments consider otherwise, corresponding to this thesis, I will refer to "BIM" as the way to utilize the tool and "BIM software" as the tool being utilized.

Development History

Tracing back through BIM's development history, there were some efforts to allow the 3D model as a tool not only for a visual representation, but also to develop and transfer information. This signifies one of the goals to integrate different types of data in one product. Based on (Autodesk 2002), the initiative began from the early utilization of PC-based CAD in the 1960s, which replaced the manual hand-drawing methods initially used by architects and engineers. The first attempt to develop a computer-generated graphic tool is believed to be conducted by Dr. Patrick J. Hanratty in 1961, titled DAC (Design Automated by Computer), which faced multiple failures due to the unpopular programming language (Charott, 2017).

A few years later, in 1963, Ivan Sutherland from MIT Lincoln Labs developed the first Computer-Aided Design (CAD), Sketchpad, which pioneered a more advanced human-computer interaction in the field of design (Sutherland, 2003). It is argued that one of the success factors behind CAD software that allowed its continuous utilization was caused by the relatively easy-to-implement interface. It is similar to the previous drawing methods architects used, which involve layering the drawings on top of each other to establish hierarchy - a feature provided by CAD software (Autodesk, 2002).

Arguably, the first underlying principle of the modern BIM prototype was initiated in the United States by Carnegie-Mellon professor Charles Eastman who described a working prototype called Building Description System (BDS) in his paper published in 1975 (Eastman, 1975). This concept pioneered the idea of a sortable database presented in a graphical format with orthographic and perspective views (Bergin, 2011). Following this invention, by the 1980s, there was a shift in how information was communicated through digital drawing. ArchiCAD and Vectorworks were developed during the period and are considered the two earliest parametric software available for personal use. The electronic file formats that were originally developed to provide graphic representation, at this time, started to convey information about the building directly, for example, through hatches.

The first object-based CAD was initiated in the 1990s when building elements such as doors, windows, and walls began to contain non-graphical specifications in a logical organization (Autodesk, 2002). In 2000, Autodesk Revit was developed. It is believed that the first "Building Information Modelling" term was first used in a pilot project in the early 2000s (Volk et al., 2014). A more systematic list of BIM development from the earliest stage of CAD can be found below (Charott, 2017).

1957 – Pronto, first commercial computer-aided machining (CAM) software
1963 – Sketchpad, CAD with graphical user interface
1975 – Building Description System (BDS)
1977 – Graphical Language for Interactive Design (GLIDE)
1982–2D CAD
1984 – Radar CH
1985 – Vectorworks
1986 – Really Universal Computer-Aided Production System (RUCAPS)
1987 – ArchiCAD
1988 – Pro/ENGINEER
1992 – Building Information Model as official term
1993 – Building Design Advisor
1994 – miniCAD
1995 – International Foundation Class (IFC) file format
1997 – ArchiCAD's Teamwork
1999 – Onuma
2000 – Revit
2001 – NavisWorks
2002 – Autodesk buys Revit
2003 – Generative Components
2004 – Revit 6 update
2006 – Digital Project
2007 – Autodesk buys NavisWorks
2008 – Parametricist Manifesto
2012 – formit

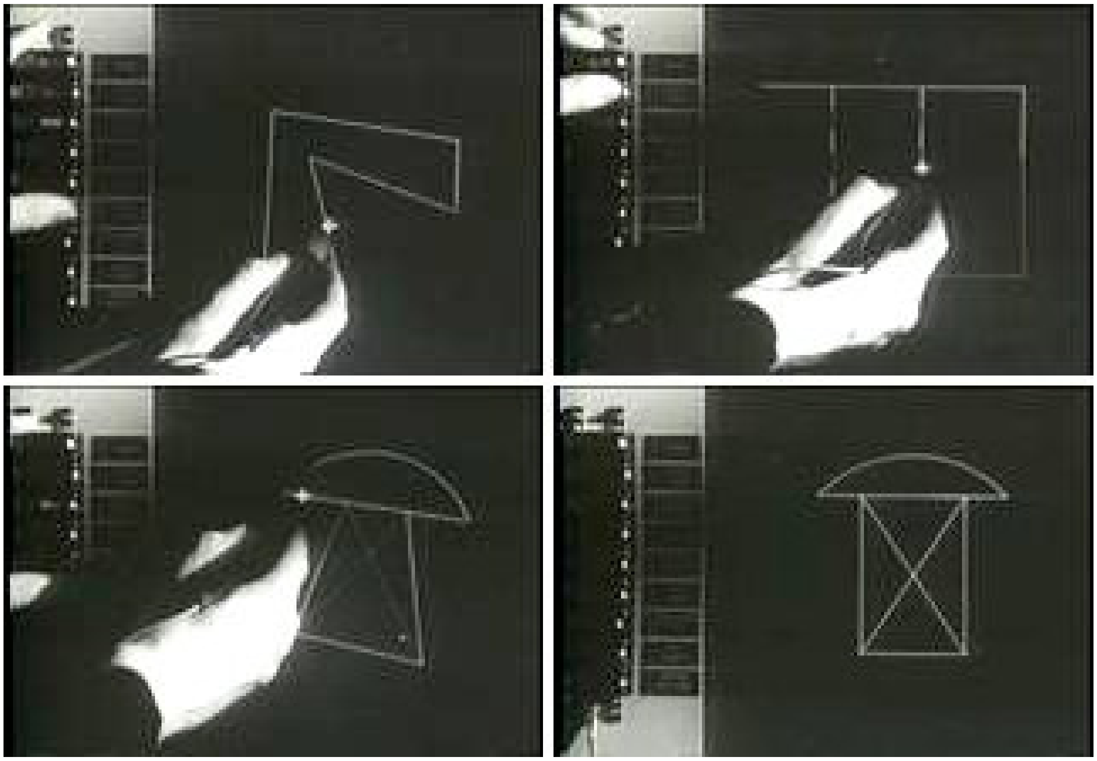

Figure 4. Ivan Sutherland demonstrating Sketchpad, initially released in 1963 and featured in Alan Kay: Doing with Images Makes Symbols Pt 1 in 1987 (University Video Communications, 1987).

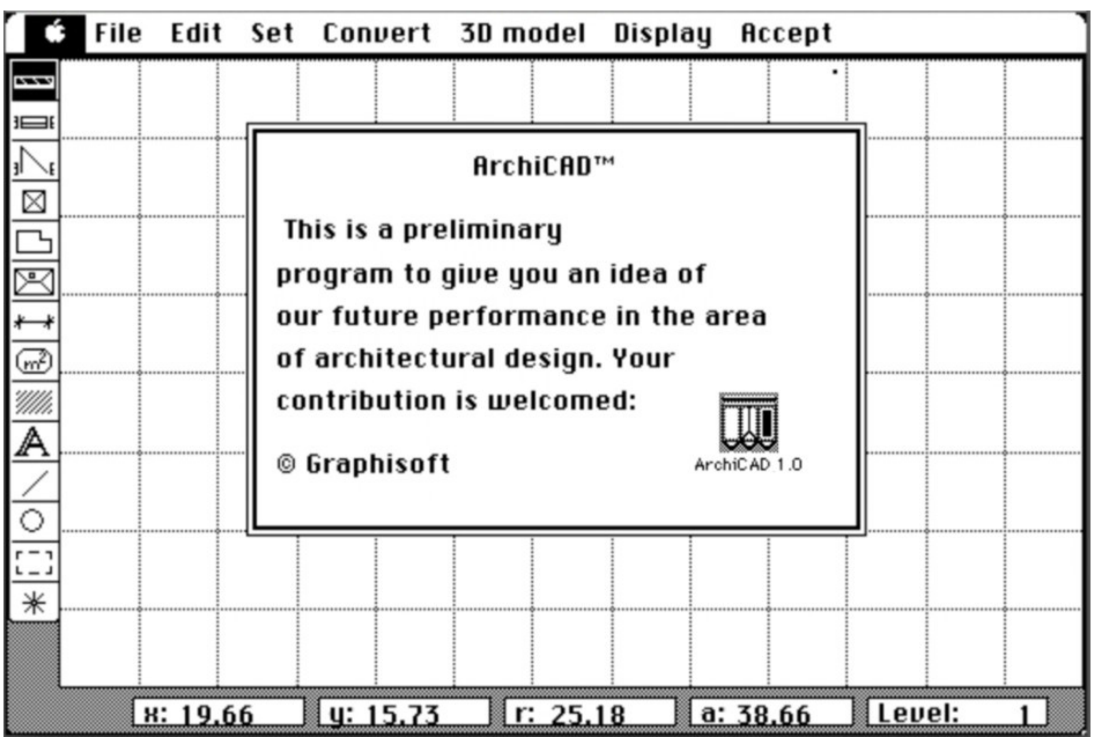

Figure 5. ArchiCAD Version 1 interface on Apple Macintosh (PAZAcademy, n.d.)

The successful technology transition during the development of digital drawing software was supported by the fact that the workflow involved in the new tool still overlapped with the traditional tools commonly used in the field. As mentioned earlier, the layer utility in CAD software provides a familiar interface to practitioners as it supports the purpose of traditional drawings and enhances the workflow and sustainability of the document. This provides a precedent for a new technology development, where it is encouraged to fulfill the purposes of traditional tools previously utilized on the field and offer familiar feelings to the users to support the transition. Additional features introduced by the new technology must also be significant enough to further appeal to the progression.

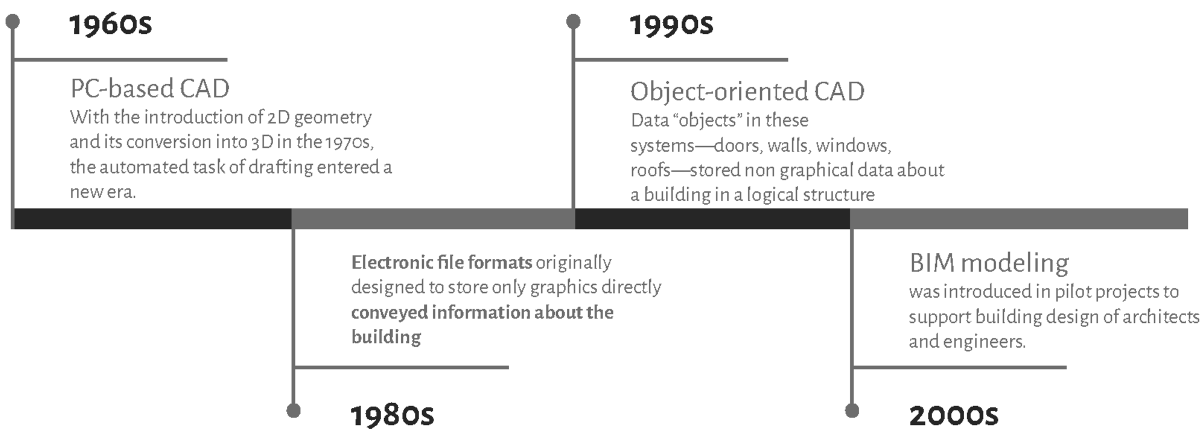

Figure 6. Building Information Modelling (BIM) development history shows the continuous effort to develop a way to convey information in the model or drawing.

The Growing Significance

BIM keeps evolving and its role in supporting the Architecture, Engineering, and Construction (AEC) industry keeps growing - necessitates a continuous research regarding its development and evolution. It has been found out that 53.7% practitioners are actively enacting an effort to increase the efficiency and productivity of their job by experimenting with new technology, such as drones, augmented reality, and intelligent tools including BIM, to improve the operation in their office and to solve challenges raised in the job site (JBKnowledge, 2021).

The BIM's growing significance is also supported by the emergence of BIM mandates established by several countries. Finland, in 2007, then Norway, in 2010, mandated the requirement for design software to pass Industry Foundation Class (IFC) Certification. While it does not necessarily enforce BIM software to the construction sector, IFC is a format that allows the file to be distributed across different software - allowing better sharing and collaboration, which is one of the core approaches of BIM (Singh, 2011).

The United Kingdom, although it might not exactly be the pioneer of the BIM mandate, provides a precedent for a clear national strategy for enforcing BIM utilization (Lorek, 2018). Motivated by the fact that BIM supported the decreasing construction cost in this country by 15% to 20%, nearly 900 million pounds between 2009 to 2015, the United Kingdom enforced all taxpayer-funded construction to implement BIM Level 2[2], starting from April 2016. This decision was made to reach a further 20% decrease in construction procurement costs (Singh, 2017). Considering that it is required to be BIM Level 2 compliant to be able to participate in any government project, this regulation expedites the tool utilization throughout the country, which immediately increased from 48% to 54% just after a year of the rule implementation (NBS, 2016). In 2019, the statistic showed that 69% of practitioners know BIM and are a user of the software, which was a steady increase from 62% in 2017 (NBS, 2019).

France followed the BIM mandate establishment in April 2017, along with the official French standardization roadmap, which supports the strategy to digitize the construction industry in that country. Based on (Daskalova, 2017), the main objective of this regulation is to improve the quality of exchanged data, improve the deadline, increase the effectiveness of data sharing, decrease errors and conflicts, and decrease project costs. Germany has been assigning a task group called Digital Building Platform to support national BIM strategy development, but the mandates were not established until the end of 2020. It is now required for all transportation projects in Germany to use BIM (Lorek, 2018).

Although there is an argument that the United States was where the first idea of BIM was invented, this country does not have a strict nationwide requirement for BIM utilization. This is most likely caused by the fact that, unlike the UK, the US does not have a central government body responsible for procuring all infrastructure projects (Goodman, 2019).

2 Based on the UK Government Construction Client Group Strategy Paper established in 2011, there are three levels of BIM maturity, as follows (Building Information Modelling Strategy Party, 2011).
Level 0: Unmanaged CAD, distributed with paper or electronic paper, with no collaboration
Level 1: Managed CAD in 2D or 3D format with partial collaboration in Common Data Environment (CDE)
Level 2: Managed 3D environment held in separate 'BIM(M)' tools with attached data. Higher level of collaboration with all stakeholders owning their own 3D CAD models. Information is exchanged through the same data format, allowing the creation of federated models.
Level 3: Fully open process and data integration enabled by IFC/IFD (Industry Foundation Classes/International Framework for Dictionaries). Managed by a collaborative model server.

However, several local authorities have established BIM mandates in their territory, starting from the case in Wisconsin, which was the first state to establish the requirement to use BIM on publicly funded projects with a budget higher than $5 million (Drewry, 2010). Another example is the Los Angeles Community College District (LACCD) which obliged taxpayer-funded sustainable building projects to utilize BIM starting in 2018 (Slowey, 2018).

Despite the fact that, in the case of the US and some other countries like Germany, the regulations are only deployed for very specific projects (with a particular type of project and/or a certain amount of budget), there is some growing realization regarding the potential necessity of BIM. Furthermore, in 2021, JBKnowledge, which had conducted surveys with thousands of construction workers in the US, stated, "*for five years, The ConTech Report has cautioned that BIM is not a fad; moreover, a mandate (like the public sector mandate in the UK) could be imminent in the future*," (JBKnowledge, 2021).

This idea is not only limited to the US - it is applicable all over the world. The increasing number of mandates established by countries has encouraged local construction workers to transition to a BIM environment. Considering the collaborative nature of the AEC industry and the growing competitor, the increasing number of BIM users might further motivate other practitioners in the field to adapt to the new emerging working environment. Naturally, it is also imperative to anticipate the growing significance of BIM utilization in historic buildings as one part of the construction industry in general.

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Chapter 2: BIM for Historic Documentation

BIM for Historic Documentation

Purpose, Methodology, and Limitations

Continuing the discussion from the previous section regarding technology transition, it is essential to analyze whether BIM has the ability to fulfill the basic needs of documentation before understanding the additional potential benefits it provides. 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 documentation needs. Instead, this chapter aims to analyze the BIM approaches commonly used by the practitioners in the field, and compare it to what historic documentation requires, to understand the potential and limitations.

In the previous section, it has been determined that five shared purposes of historic documentation include providing a visual representation of the property, creating an information management system, allowing collaboration between experts, supporting decision-making, and providing archives for future uses. To discover all the ways in which BIM could benefit preservation in response to the needs of historic documentation, the purposes of BIM will be evaluated based on the collection of BIM definitions coined by experts, which then will be clarified with user analysis. It is imperative to note that the evaluation below is conducted by the writer, 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.

Based on the preservation action it leads, historic documentation can be divided into two[3]: document for intervention planning[4], and document providing knowledge resource for education[5]. This thesis will evaluate both purposes in general, but future research is strongly recommended to gain a more specific evaluation on each type of document, responding to their individual needs.

3 Some document such as National Parks Service's Historic Structure report (HSR) could lead both preservation actions mentioned

4 For instance, Landmark Preservation Comission's Permit Application document

5 For instance, Library of Conress's Historic American Building Survey (HABS) document

Five Shared Features

1. Visual Representation

BIM software provides a visual representation of the building in the form of digital drawings and models that acts as a basis to support different stages of the project, including design, implementation, and evaluation. This is explained by the (British Standard Institution, 2019), defining BIM as "*Use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions.*" BIM visually represents not only the physical condition of the building, but also its functional characteristics, as indicated by (RIBA, 2012), who pointed out that "*Building Information Modelling is a digital representation of physical and functional characteristics of a facility.*" Additionally, the (National Institute of Building Sciences, 2007) indicated that the representation made in BIM software is computable, referring to the tool's ability in calculating an array of different systems.

Depending on the purpose of historic documentation, there are several different requirements and expectations in visually representing the building. Generally, documents providing knowledge resources for future projects in the form of archival, such as the Historic American Buildings Survey (HABS) document, require a more comprehensive and very specific content in the drawing. As the main purpose 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 material. This type of document 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 documentation guideline was initially made for hand drawing format, there are some specific rules that still apply for digital representation. Some of the hatches are advised to not use the "*predefined hatch patterns for surfaces (such as brick coursing or roof shingles in elevation, or herringbone brick paving in plan),*" (New York City Landmark Preservation Commission, 2020). It is imperative to measure and draw the material pattern individually to represent the actual condition of the building. In terms of different construction periods, typically it is indicated by a different rotation of poché pattern in floor plan drawings. The guideline of this type of documentation requires flexibility in the software to comply, as the approach suggests it is not very common in digital drawing practice.

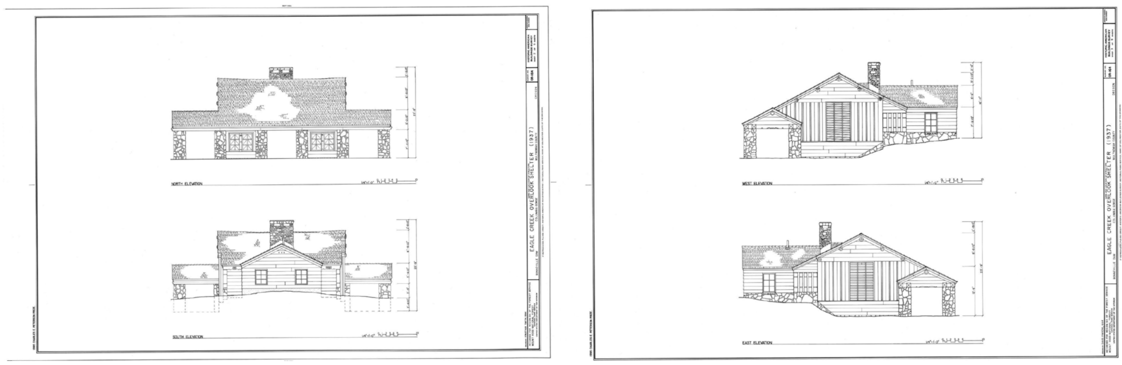


Figure 7. HABS drawing of Eagle Creek Overlook Shelter, 1937, made in CAD. It indicates the use of custom material pattern on the roof and wall in elevations, avoiding "predefined hatch" from the software (Historic Preservation Northwest, 2015)

BIM software like Autodesk Revit did not specifically get developed for modeling historic buildings, let alone documentation, but it is possible to attain the requirement. Considering the initial intention of BIM to facilitate new building design, some of the 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 CAD software like Rhinoceros, AutoCAD, or SketchUp, modeling the building element is more straightforward - as it only represents the building visually, contrary to BIM that offers information embedded on each element. Revit's workflow starts with determining the element type, or family, to assign a set of parameters and information to that element, which is then followed by modeling the actual shape. Due to this, 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 - posing a challenge in modeling an intricate architectural decoration.

Currently, there are at least two possible approaches in Revit in modeling the way material patterns actually look like in real life. The first method is to model each brick as one element, which has higher accuracy but would result in a very long list of schedules - and longer time spent on it as well. The second 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 information. It is possible to fulfill the guideline, but the approach is very dependent on the project and the building, and might have a different workflow compared to the other CAD software.

With that said, the 3D format in BIM allows a better approach in visualizing the building, especially in informing the

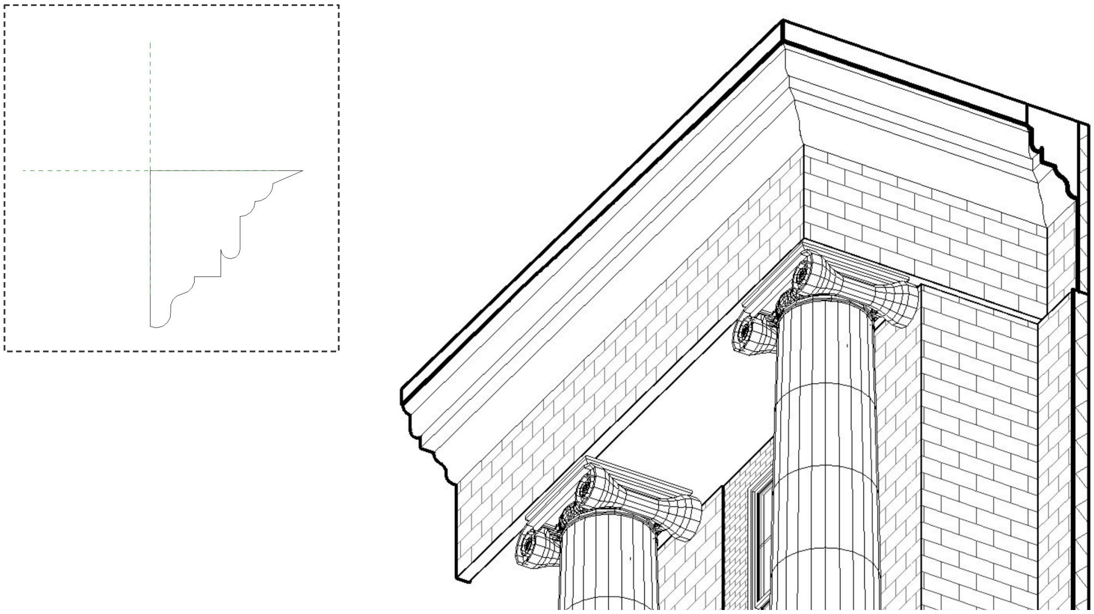


Figure 8. Modeling cornice in BIM requires a process to model the section of the molding in the "wall sweep" family. While this process is not common in other CAD software and might be more time consuming, once the family is established, the user can put the cornice element in any wall surface automatically.

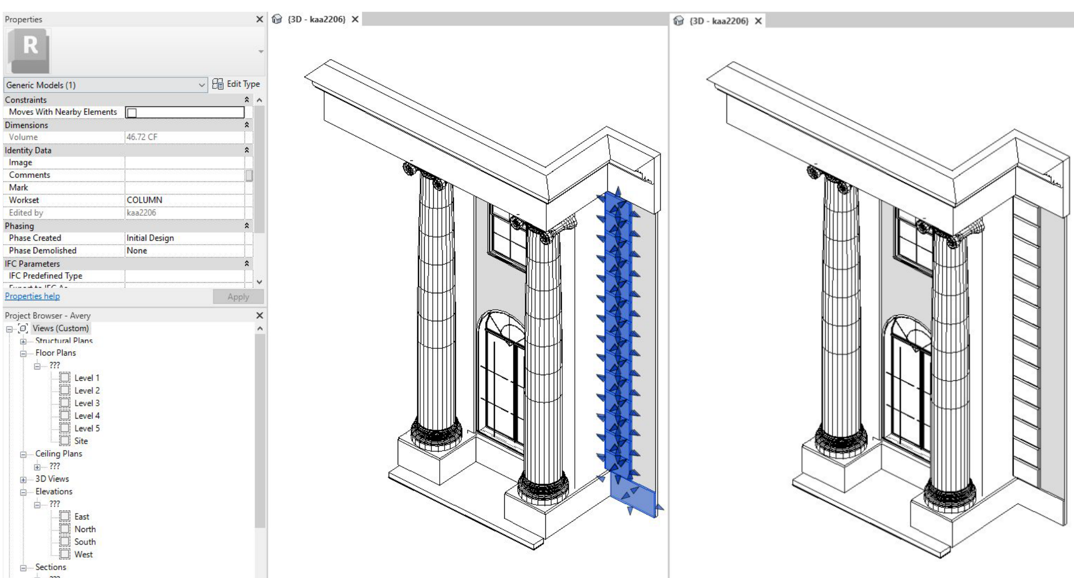


Figure 9. One of the approaches to modeling the correct material pattern (instead of using a predefined hatch pattern) is by using a model-in-place tool on top of the wall as the target plane (highlighted in blue).

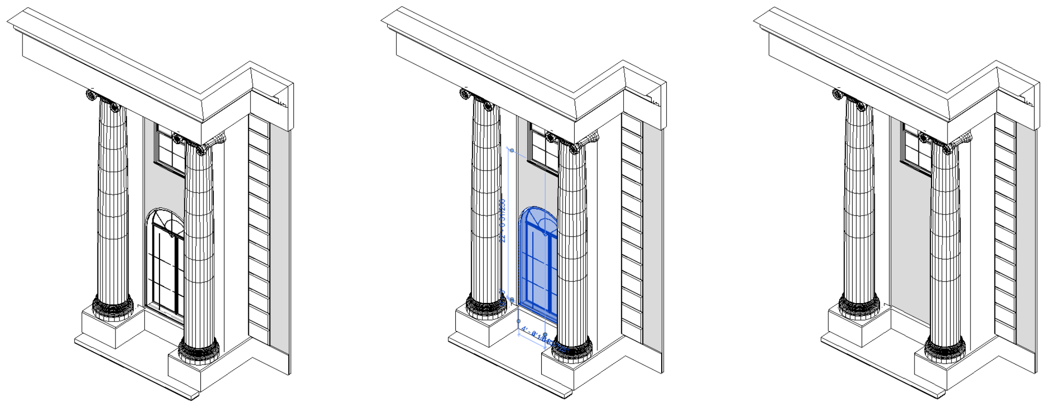


Figure 10. As BIM's element has characteristic and a certain amount of intelligence, deleting the window in BIM will leave the wall intact, unlike other CAD software that will leave the hole to the wall. This is because the deleted element (window) understands its relationship with the other element (wall).

more accurate physical form[6]. Some buildings might have a particular form that cannot get captured as clearly in 2D format[7], hence 3D visualization would inform a better spatial understanding for future uses.

Additionally, models made in BIM environments are "intelligent." This means that each element generated in the software has the ability to understand its characteristics and its relationship with other elements in the building (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 the element has "character." For instance, in other tools, to model a window, we need to manually create a hole on the wall, then place the window. In BIM, the software understands holes are always necessary to model a window - so the user is only required to determine the window's location, and the following process gets automated.

Alternately, historic documentation made for decision making for intervention has a set of different visual representation rules compared to knowledge resource documents. Unlike HABS, this type of document does not have highly standardized rules, but it requires specific visual information to be captured in the drawing. Landmark Preservation Commission's permit application, for example, typically asks for drawings showcasing the existing condition of the building and the proposed alteration. As this document's main purpose is to obtain permission to change the physical or functional fabric of the building, the content for this document should support the decision-making process for this purpose.

6 This in particular is further supported by the 3D scanning technology which is importable to the BIM environment - allowing the point cloud as a reference to examine the model's accuracy.

7 For instance, organic form, walls with extruded surface, niche, and many others.

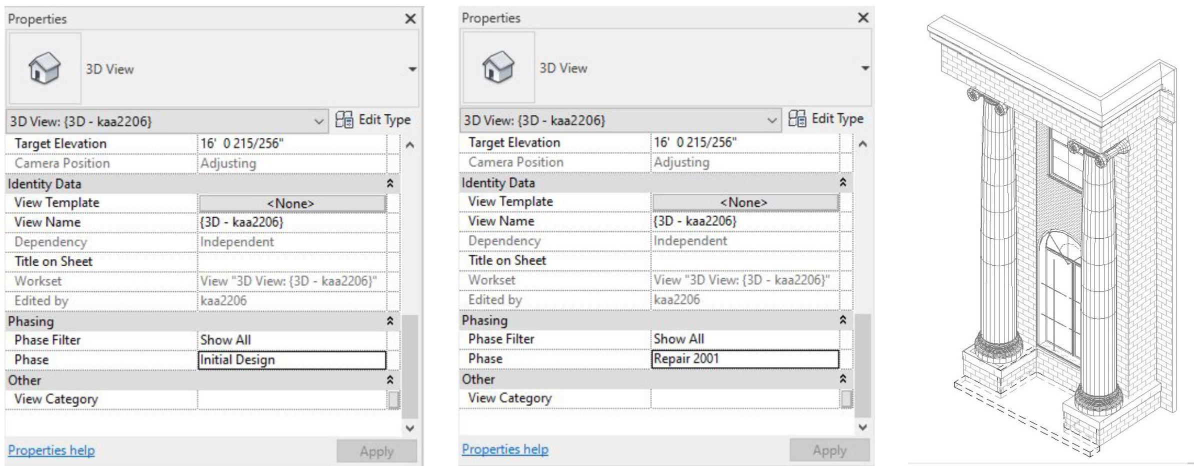


Figure 11. Phasing in BIM indicated on the property bar (left and middle image), and represented as a dash line on the 3D model (right image).

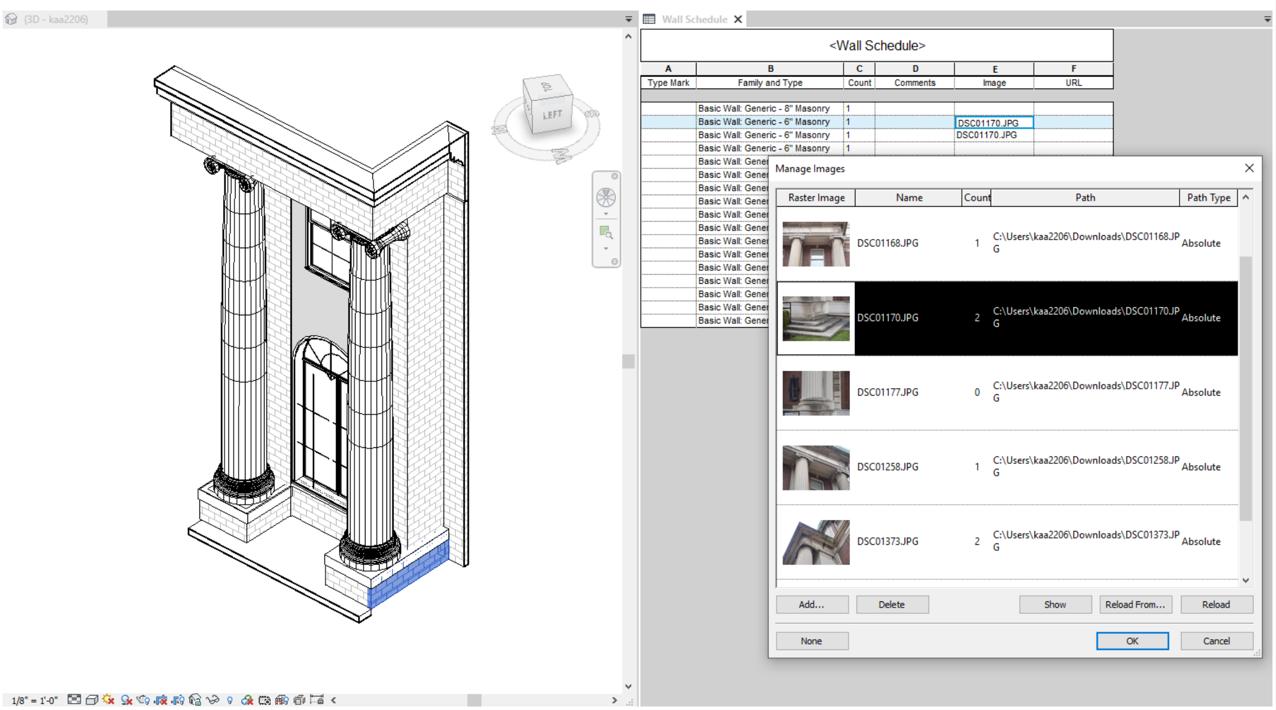


Figure 12. Linking existing condition photographs to a certain building element in BIM - all of which are linked throughout the schedule.

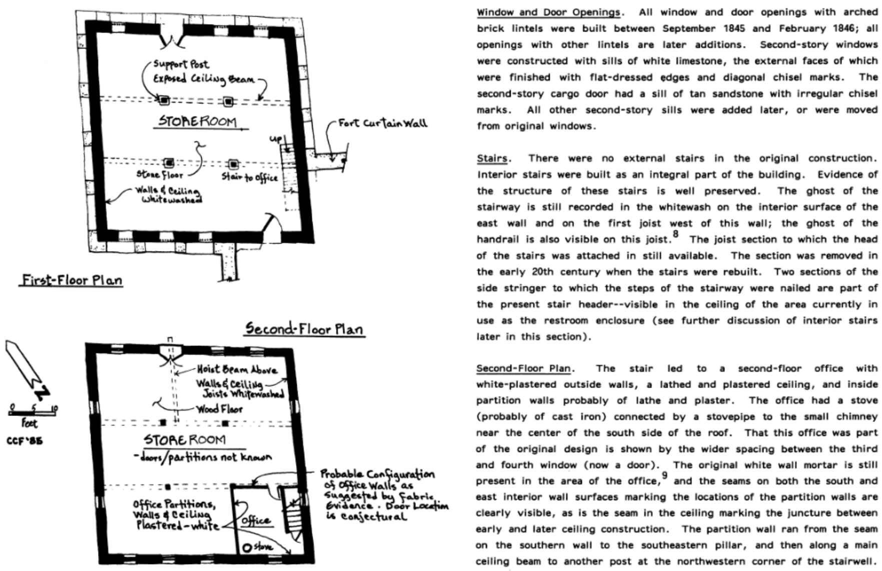
The phasing utility in BIM software like Revit highly benefits this requirement. Initially made to represent different stages of new construction development, this tool allows layering different building phases, including the initial design, existing condition, and the proposed alteration. In some cases, a historic photograph might be required to support the proposed intervention, which also could benefit from Revit's feature for linking external images to a certain element. This will be helpful to inform a missing element, for example. One of the things that BIM still lacks is the ability to freely annotate deterioration for condition assessment. As mentioned above, drawing and modeling in BIM is not as straightforward as other design software, hence it still possesses some limitations in drawing a certain condition of the building. Despite that, it is possible to provide deterioration information on each building element in the comment part in the property bar, which later could be sorted and organized in schedule - which might be beneficial depending on the scenario.

2. Information Management System

As pointed out in the development history section, one of the primary intents of BIM development is to allow information to be more effectively conveyed through the building model, as also pointed out by (Stagg, 2011), stating that in BIM, "*The model is a container for the information.*" It responds to the need for historic documentation in providing an information management system for the property. As one of the developers (Autodesk, 2002) explained, "*Building Information Modeling (BIM) is the holistic process of creating and managing information for a built asset,*" highlighting that the purpose of BIM is not only to create or contain information, but also to manage it in the form of schedule. The collection of information that has been organized and reorganized in the model acts as a knowledge resource for the stakeholders for decision making and maintenance throughout the building's life-cycle (Associate General Contractor, 2006) (National Institute of Building Science, 2007)

Historic documentation contains a wide array of information indicating the building's significance. For instance, in Historic Structure Report (HSR), the information typically include the 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 most valuable capabilities that makes the difference between BIM and other CAD software is the ability to manage information. The illustration above showcases a particular construction 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 in 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 that are 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 13. Construction chronology as shown in Historic Commissary Building's Historic Structure Report (HSR) with separate information regarding the building elements on that development phase (Frazier, 1987).

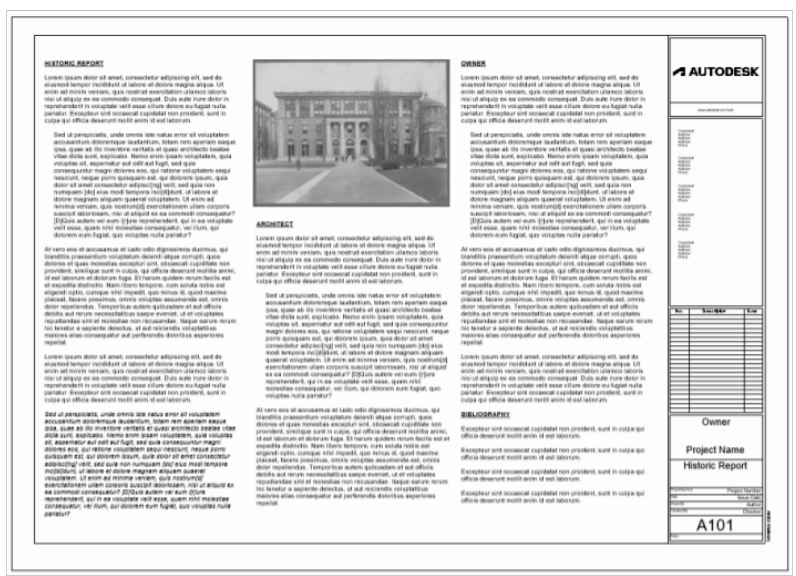


Figure 14. Although not a common practice, drafting text on sheets in Revit allows stakeholders to type non-visual data on the working file - allowing synchronization and better collaboration. This approach also allows linking drawings, images, and PDF files to the sheet.

Visually representable historic information as this example could be conveyed and managed more effectively in the BIM environment. The phasing tool, as already mentioned in the visual representation part, allows each construction phase to be modeled 3-Dimensionally into layers. The parameters and information about the building element, on that one particular phase, can be embedded directly to the drawing using the comment section in the property bar. These features come in handy when the building's physical fabric has an array of significant chronology and alterations - especially if each phase and each element has important 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.

That being said, BIM still has limitations in delivering non-visual text-based paragraphs. Sheets in Revit allows text drafting, but it does not offer any special features in comparison with typical writing software such as Microsoft Word - if anything, writing in BIM is more complicated considering the less familiar interface to draft texts. Once more, it is possible, and considering the more comprehensive collaborative platform BIM introduces, 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 bibliography in Historic Structure Report. However, for further reasons, at this moment this feature is only available for generic annotation families, and not the typical text families commonly used for typing.

3. Support Decision-Making

The data conveyed in the model helps inform the decision made for the properties. Based on (Computer Integrated Construction research group, 2010), "*Building information model is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle.*" The information provided by this tool benefits strategy-making on the building throughout its entire life span. Furthermore, Trimble, one of the BIM software developers, also stated that "*this data (generated in BIM) allows governments, municipalities, and property managers to make informed decisions based on information derived from the model– even after the building is constructed*," (Lorek, 2022) determining an array of different stakeholders and decision-makers that could benefit from the data available in BIM models.

Document like the Landmark Preservation Commission (LPC) permit application is prepared to support the decision on the intervention appropriateness in response to the building's physical character and significance. As mentioned in the visual representation section, one of the requirements is to show the comparisons between existing conditions and the proposed design to determine visual appropriateness; hence the 3D format of BIM, along with the phasing feature, is highly beneficial for that purpose. 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 in allowing simulation pre-establishment further assists the decision-making process. BIM software has some features that allow coordination between elements to avoid clashes among different systems (Eastman, 2008) in addition to the ability to utilize the external tool in the form of a 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 material specification, such as R-value, material durability, and others, require on-site testing because the predefined data in BIM might not be available for historic materials.

4. Support Collaboration

Another purpose of historic documentation is to support collaborative work between experts and stakeholders. BIM has been widely developed to accommodate this particular requirement, as some developers released a fully-collaborative platform where workers from different fields could work together in a shared model. As early as 2006, Autodesk listed among BIM characteristics that "*they create and operate on digital databases for collaboration.*" However, interestingly, it was not until 2015 that the developer released BIM360 for the purpose of a more efficient collaborative work. This could indicate that allowing collaborations has been one of the goals of BIM software development, even if it was mentioned the particular software for this purpose has not been released yet. The way experts such as (Computer Integrated Construction research group, 2010) (RIBA, 2012), and (British Standard Institution, 2019) defined BIM as a "*shared digital representation,*" further supports the idea that BIM has been designed to allow accessibility among users.

In today's practice of historic documentation, different groups of experts work together to develop a comprehensive report, containing historic reports, drawings, and photographs. They work in different document formats and files which then will be transferred through email or other communication tools. In some cases a release should be signed for copyright purposes[8]. This type of workflow is defined as BIM maturity level 0 by UK Government Construction Client Group Strategy Paper, which consists of fewer collaboration and manual file exchange with paper of digital paper format. While the traditional approach works just fine, it 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 through two different ways: collaborate within the network and in the cloud (online platform). The first option will turn the active file as a central model, where other users can synchronize every period of time to update the changes made. Typically a BIM manager will assign each member to synchronize the file in

8 Based on interviews with non-BIM users and hybrid BIM users (users who only use BIM in less than half of their practice workflow) practitioners.

Figure 15. Two ways of collaborating in Autodesk Revit.

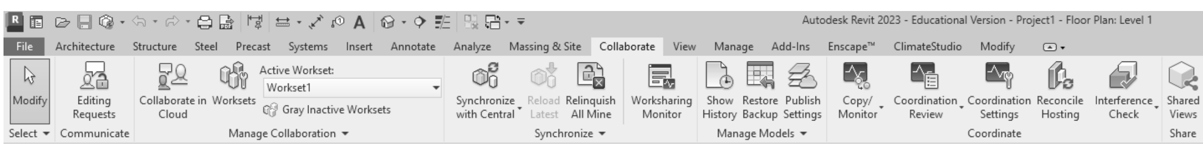


Figure 16. To update the changes, users are able to synchronize with the central model within a certain time interval.

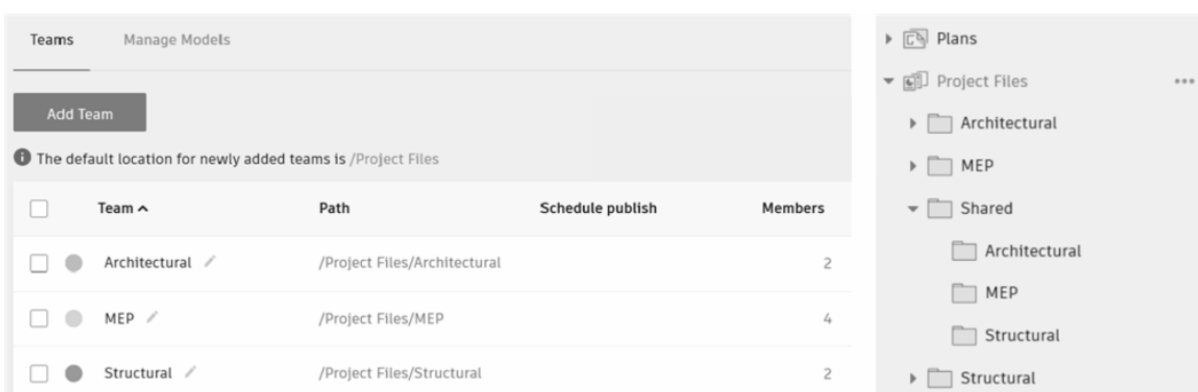


Figure 17. In a BIM collaborative platform such as BIM360, the document is developed and managed based on the involved stakeholder groups.

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 a better flexibility in terms of location, as long as each party owns an account to hold a certain accessibility to the file - which requires higher cost, as users need to purchase a subscription for this purpose. 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, then when the file is ready they will release a package for other stakeholders to confirm and import to their file. The stakeholder groups typically involve engineers and architects, but there is also a possibility to work collaboratively with historians, photographers, and other experts, depending on the file format the team aims to develop.

5. Durable Archive

The information contained in the model supports the decision-making during the construction and beyond throughout the building life-cycle, as indicated by the experts' statements mentioned above. Furthermore, the data stored in the BIM model might allow further use, beyond the lifespan. This informs that the model created in BIM software along with the information embedded in each of the elements provides a sustainable knowledge resource in the form of the digital archive. Continuing the BIM characteristics discussion provided by (Autodesk, 2002), on how "*they (BIM) capture and preserve information for reuse by additional industry-specific applications,*" referring to the ability to reuse the data made and organized in BIM software for future utilization.

There is an on-going discussion and the emerging awareness of the importance of digital archive - not only due to the potential risks of physical archive, but also in consideration of the benefit of a more organized and accessible knowledge resource. Digitization of archives is getting even more common in today's practice, where archivists typically scan and store the document in the form of electronic paper or PDF. This file format informs the 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 a platform-neutral file format named International Foundation Class (IFC) that allows an enhanced file accessibility and applicability throughout all IFC-certified software. The users in need of the data can directly work with the file as a base model and immediately implement the project without the need of replicating the content. It is not impossible that this format will constitute the future approach of historic documentation digital archive. That being said, at this moment, there is an issue with a large IFC file size in comparison to PDF - necessitating the need of bigger digital storage capacity. Another possibility is using online cloud provided by some BIM developers, waiving the need of a large capacity hard drive, but the high cost expenditure to access the cloud itself poses another challenge.

BIM Approach vs Traditional Approach

Purpose, Methodology, and Limitations

To support the evaluation conducted on the first half of this chapter, this section aims to additionally address the state of knowledge and practices of historic documentation and the way Building Information Modelling (BIM) is utilized for this purpose. The qualitative information was gathered through interviews with three categories of preservation practitioners: non-BIM users, hybrid BIM users, and full BIM users. Non-BIM users are practitioners in the field that have been working in historic preservation without utilizing any BIM software or approaches. Hybrid BIM users are practitioners that utilize different software in different stages of their workflow, with BIM being utilized in less than half of the entire process. Lastly, full BIM users refer to the practitioners that mostly use BIM during the project workflow with BIM being used more than the half amount within the entire process.

I interviewed two non-BIM users, one hybrid BIM user, and four full BIM users. Considering the limited number of sources I could connect with, this section does not intend to determine the overall practice of historic documentation and BIM. To allow a more direct analysis, I have summarized the interview response as it is, therefore, some of them might include subjective opinions. Having more conversation with a broader audience might change the result of this analysis, but this section aims to evaluate the application conducted by a small segment of preservation practitioners and analyze the BIM potential and challenges in historic documentation based on their experience.

This section will include comparisons of their workflow, determined by four stages: on-site, pre-documentation, documentation, and post-documentation; and their approach to fulfilling historic documentation requirements. Additionally, an analysis of the recommended project types requiring BIM application will be provided. The collection of their opinion regarding BIM challenges and potentials, which then encourage or discourage BIM utilization will be discussed at the end.

Workflow

The table below summarized the different historic documentation steps practiced by each user category. The interview result indicates that all users share at least four stages workflow: on-site, which is the initial survey as a baseline of documentation implementation; pre-documentation, which is the process of existing material gathering and verification; documentation, which is a criteria application process utilizing relevant tools; and post-documentation, which is the next step after documentation process is finished.

Non-BIM Users		**Hybrid BIM Users**		**Full BIM Users**	
On-field	Traditional ways are utilized, including photographing, drawing, and making holes in walls to discover how something is built. The interviewee(s) might hire engineers to do non-destructive testing to see hidden objects.	On-field	In some cases, the firm might hire a surveyor who will deliver the CAD model of the existing condition. In other cases, laser scanning will be used.	On-field	Most of the interviewee reported the survey utilizes a laser scanner. In some cases, the scanning was done by an architecture firm, in other cases, they needed to outsource the tool and service.
Pre-Documentation	The existing drawings (if available) will be used with verification at the beginning to ensure the accuracy of the information.	Pre-Documentation	The existing drawing (if available) used as a foundation to confirm the field measurement.	Pre-Documentation	Existing drawings (if available) are utilized as a tool to confirm several parts of the building that were not captured by laser scans - but the basis of the model itself is the point cloud.
Documentation	CAD and Vectorworks are utilized to draw the existing condition. The working method involved mixed media and tools. In some cases, the digital drawing will be overlayed with hand drawings.	Documentation	The existing condition model is built in Revit, but architectural molding will be drawn in AutoCAD. Additionally, design study is conducted in Rhinoceros. The working method involved mixed media and tools.	Documentation	The point cloud gets run through Autodesk Recap which lets the file to be easily linkable in Revit. Faro Scene speeds out the point cloud registration process. The point cloud will be imported to Revit where people model the building elements. The working method involved mixed tools, but all of them support the final format which is made in BIM.
Post-documentation	The decision-making and budget calculation mostly relies on the architect's experience and the connection to the contractor.	Post-documentation	The finished model will be communicated to the contractor, who will produce their own drawings. Later, they will have to submit it back to the architect to ensure accuracy. The BIM model becomes the tool for the contractor to deal with conflict resolution and also to address system integration with high-level detail.	Post-documentation	After the model in Revit is finished, it will be brought out to Bluebeam, which will produce the final drawings. Sometimes it still needs to be brought back to Revit for verification. Depending on the project, sometimes only the extracted rectified images from point clouds are required.

Table 2. A comparison diagram illustrating different workflows conducted by non-BIM users, hybrid BIM users, and full BIM users.

Tool Utilization

This section is intended to explore the way different kinds of tools could support the approach to fulfill historic documentation requirements. The table below will compare the different methods each user category conducted to fulfill the requirements of collaboration between experts, information management, and archive for future uses.

Utility	Non-BIM Users	Hybrid BIM Users	Full BIM Users
Visual Representation	CAD and Vectorworks are utilized to draw the existing condition. The working method involved mixed media and tools. In some cases, the digital drawing will be overlayed with hand drawings.	The existing condition model is built in Revit, but in case of architectural molding on the building, it will be drawn in AutoCAD. Additionally, design study is conducted in Rhinoceros. The working method involved mixed media and tools.	The point cloud will be imported to Revit where people model the building elements. The working method involved mixed tools, but all of them support the final format which is made in BIM. Depending on the project, sometimes only the extracted rectified images from point clouds are required.
Collaboration	The way collaboration in this user category works starts with the document being sent to the engineer, which in some cases, they will use as a basis of their drawings. A release will be signed to allow one party to utilize the other party's drawings. This will give them the responsibility for data accuracy; hence the drawing should be verified beforehand.	In the case of this user category, the contractor will build their model separately from the architect. It could be a completely individual model or the architect's model will be used as a base drawing. A release should be signed if the other party decided to use somebody else's drawing. One of the interviewees recently transitioned to an online collaborative platform - BIM360, which helped with remote work and collaboration with partners. However, the cost of this tool and the cloud space is very high.	Online collaborative platform - BIM360 is utilized for collaboration, where the users can work in the cloud and observe the update in real time. The stakeholders gained a certain level of access to the model. The BIM protocol determined the accessibility and the update's time interval.
Information	Information is embedded as a note on the plan and elevation and will be shown in its actual dimension and detailed in the section.	The information about each element (structure, system, etc.) is embedded. The schedule provides a more organized and accessible information management.	The data is embedded into elements and organized as a schedule, allowing less manual labor for information management. The elements listed in the schedule are also linkable throughout, where the user can select it and the model will inform which element the information is from.
Post-documentation	In case future projects require the finished drawing, the interviewee would require a legal process to release their responsibility related to the drawings. The next firm will be able to save the cost for documentation; hence the release is necessary.	The client takes the model for the record but they do not typically use it for facility management. It might become an "investment," as it indicates the existing condition of the building - denying the requirement to create a new model in future projects.	Larger institutional buildings have their maintenance teams, and in some cases, they want the model because it could help their work. Institutions are using it a lot more as they find it helpful especially when there are updates in the building system, and the model could help them keep track of the changes.
Archive	Before all work was done on computers, the physical draft of the manual drawings were archived. Digital drawings and correspondence are stored on our computers and on back up discs. Over time though some written information becomes gibberish. I have not seen this happen with drawings, but digital data is not permanent.	In some cases, BIM360's cloud storage is utilized for archival. The document will be kept, in theory, forever. Technically, projects have different contractual obligations on that, in most cases the document is required to be stored from 5-10 years.	In some cases, BIM360's cloud storage is utilized for archival. Regular check is needed to avoid an error in the saved model. In other cases, the file is stored in the firm's internal drive every major milestone, and the software version gets updated within a certain period of time.

Table 3. A comparison diagram illustrating different tool utilization applied by non-BIM, hybrid BIM, and full BIM users.

BIM Challenges

The collection of opinions regarding the challenges to implement BIM indicates the reason some people are discouraged to make the technology transition. It also could act as a recommendation which informs future development of aspects of BIM that could be potentially improved for historic documentation.

Non-BIM Users		**Hybrid BIM Users**		**Full BIM Users**	
Time	In many cases, the plan, section, and elevation drawings are already adequate. 3D modeling is very time intensive.	Time	The learning curve slows down the typical working timeline. The changes in tools require workers to keep learning, so the work cannot be done at the same pace.	Visualize deteriorations	Something that still needs to be improved is visualizing the cracks and deterioration, as well as the ability to organize and calculate them.
Comparison to other tools	3D CAD could provide spatial modeling if necessary.	Setting up an entirely new system for the office	Setting up a new system and standard with BIM is also considered a lot of work.	Workflow issue	People are still developing ways to survey and directly translate it to BIM. There is still a challenge in intersecting laser scanned point clouds to the BIM model.
Data irreliability	The performance specification of materials (fire resistance, energy efficiency, etc.), especially for historic materials might not be accurate. The testing results conducted by factories might be different from real life because there is a human factor during the construction.	Changes in visualization style	The representational style of the architecture firm changed after they utilized BIM. The graphic cannot be controlled as fluidly as in other CAD software.	Skillset	Arguably preservation architects do not commonly use BIM until very recently, hence there is a problem in the skillset differences between preservationists and new construction architects.
Less on-site experience	There is a preference to directly touch and feel the texture of the existing building instead of observing it through computer screens	Skillset	A lot of training is needed, even for people that are already familiar with the tool. The fluency level might be not adequate.		
Less "lively" drawing	Computer-generated models are considered less "lively" in comparison to hand drawings.	"Too" robust	Revit needs so much effort to build the model and embed the information. It is less likely to be used for "sketching."		

Table 4. A collection of BIM challenges provided by non-BIM users, hybrid BIM users, and full BIM users.

Recommended Projects

There are multiple considerations behind the decision of BIM utilization based on these practitioners, summarized in the following list.

1. **Project scale**: a large institutional building that requires scheduled monitoring might benefit more from BIM in comparison to a smaller privately owned building.
2. **Building owner**: related to consideration number 1, the institutional-owned building typically has a mainte-

nance team, hence BIM utilization might be more valuable for them.

3. **Building status**: designated building typically has a set of existing drawings that could support BIM application. Additionally, the finished model could contain new information that benefits future intervention.
4. **Type of alteration**: when a spatial alteration occurs, many systems inside the building change and require a more robust tool to plan and calculate. If the interventions happened at a surface level or on a smaller scale, BIM might not be required.
5. **Stakeholder involved:** the more experts work on the same project, the more BIM is valuable, as it provides the opportunity to enhance collaboration.

Conclusion

This section discussed to what extent BIM is able or unable to support historic documentation, and whether this tool provides additional features that are still lacking in traditional tools. The evaluation was formulated based on my analysis as the software user supported by discussions with practitioners in the preservation field. In conclusion, the following are BIM's values in supporting historic documentation.

1. The 3-dimensional format of BIM allows a better visual understanding of a certain type of building, particularly structure that is not clearly represented in plan, section, and elevation. This includes buildings with irregular extrusion and niche, curved surface, among others. Besides the fact that it helps us comprehend the building form, it also provides the opportunity to accurately measure and utilize the correct dimension 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 inform chronological order and the information associated with it, it compares between certain phases or intervention proposals, and embeds important information (as well as external files) 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 between different stakeholders working on the project by enabling synchronization among models. It allows a more efficient teamwork by providing a shared-access platform where every stakeholder 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.

The list above does not indicate in any sense that BIM is the most ideal approach in documentation. This tool also has some challenges, as follows.

1. The logic behind BIM is considerably new, requiring additional training and time to set up a starting point to establish the model. The shift in 3-D modeling workflow might be needed at the beginning of the modeling process. 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 the way it behaves in relation to the other elements, which might slow down the workflow in some cases.
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, 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 in this particular tool.
6. Pre-defined patterns and material specifications in BIM are not always applicable to historic buildings.

Arguably, the challenges above are mostly time-sensitive, and they will be potentially resolved in the near future, whether by the BIM developers or the increasing familiarity with the tool.

Following the discussion regarding the way technology evolves and develops, one important note to mention is that while BIM could be considered newer technology than other tools, by comparing the workflow between the practitioners, it is indicative that the preliminary procedure in BIM for preservation is very similar to the traditional workflow that preservationists are used to. It starts with either field measurement or laser scanning to obtain the necessary information about the physical fabric of the building. This process is typically conducted parallel with additional information gathering from archives.

The main difference is that BIM allows a more comprehensive information management system, unlike the traditional method that arguably disconnects the visual representation of the building from the data management. In BIM, the drawing from the survey is processed together with the additional information on the building, which is then represented inside a 3D model - as a container. This allows a more efficient knowledge transfer, as elements in BIM are connected to each other with a clear relationship. Although, there is a concern on the less efficient workflow for typing in BIM, particularly for non-verbal information. At this time, traditional typing tools might be more advantageous in supplementing the BIM model in case comprehensive written information is necessary.

Besides the advantage of information management, BIM also allows a more efficient collaboration between designers and experts by providing a shared-access platform where every stakeholder can work together. This in particular is valuable for documentation supporting intervention planning. Existing condition model informs an array of knowledge that is valuable for future decisions, assisting historic appropriateness evaluation by comparing different phases of the building, linking photographs to the model, and conducting simulation to prevent issues and unnecessary costs during the construction.

In practice, documents for intervention planning might be more frequently developed by architects and preservationists, in comparison to documents for knowledge resources. This is due to the fact that only a particular historic building requires a comprehensive report such as HABS and HSR, but most intervention on monuments would require a permit application for changes. Collectively, considering that BIM could facilitate most purposes of traditional historic documentation, there is a possibility of an increased number of preservation projects conducted in the BIM environment in the future. I concluded that based on the evaluation of the value BIM provides for documentation, its utilization is worth implementing in the field for a certain type of projects. This necessitates the availability of protocol and standard in determining the level of development in BIM for historic documentation, which presently is not widely discussed.

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Chapter 3: Evaluation of Existing Standards

Existing Protocols

It is imperative to recognize and evaluate existing protocols in Building Information Modelling (BIM) and historic documentation as a precedent to understand the state of knowledge and practice of BIM standardization and whether any improvement is required. Following the establishment of the UK Government BIM Strategy in 2013, Construction Industry Council (CIC) published one of the earliest BIM protocols, providing an array of guidelines, including Level of Development (LOD) in BIM and protocol phases (Jordan-Palomar et al., 2018). LOD is defined as a guideline to help specify the model content, both graphic and information, within a certain project development phase (Construction Industry Council, 2015). The BIM model is typically expected to develop over time to reach greater detail following the design phase (US General Service Administration, 2022).

Numeric indicator is used in LOD to determine the increasing detail, starting from 100, which is conceptual model, 200 is approximate geometry, 300 and 400 are precise geometry, and 500 is as-built model (US General Service Administration, 2022). In 2020, CIC Hong Kong published the second version of BIM standard, where the LOD is split into two: LOD-G (graphic) and LOD-I (information), which indicates the recognition of different contents in BIM that require separate protocols to guide the implementation efficiently (Construction Industry Council, 2020). Furthermore, "The Approved Use Guide'' by Real Estate department of the U.S. General Services Administration (GSA) specify protocols in each level of LOD based on "model contents," as shown on the illustration below, indicating the necessity to take into account that BIM consists of an array of utilities which cannot be generalized into one protocol.

Model Content	LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
3D Model-based Coordination	Site level coordination	Major large object coordination	General object-level coordination	Design certainty coordination	N/A
4D Scheduling	Total project construction duration. Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	N/A
Cost Estimation	Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content	Estimated cost based on measurement of the generic element (i.e. generic interior wall)	Estimated cost based on measurement of specific assembly (i.e. specific wall type)	Committed purchase price of specific assembly at buyout	Record cost
Program Compliance	Gross departmental areas	Specific room requirements	FF&ampE, casework, utility connections		
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled and/or locally purchased materials	Specific manufacturer selections	Purchase documentation
Analysis/Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Precise simulation based on the specific manufacturer and detailed system components	Commissioning and recording of measured performance

Table 5. Level of Development (LOD) Protocol for BIM (U.S. General Service Administration, 2022).

The aforementioned guidelines are initially developed for new construction, resulting in protocols that have less applicability to existing building project, let alone historic preservation. However, some heritage BIM (HBIM) protocols have been proposed in the past. The Conference on Training Architectural Conservation (COTAC) in 2014 invented BIM for the Heritage Life Cyclical Principle, which adapts the construction phase determined by CIC to accommodate historic preservation project. In 2018, BIMLegacy was proposed, further developing COTAC's diagram with more specific BIM approach. It suggested what LOD is recommended for each phases in COTAC's diagram - with additional protocols to guide the implementation (Jordan-Palomar et al., 2018).

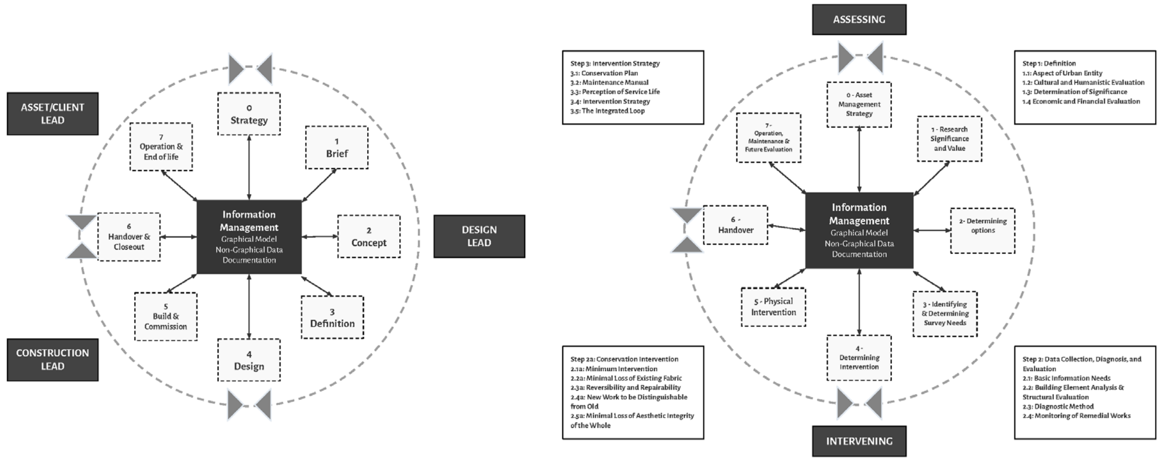

Figure 18. CIC BIM phase diagram (left) (Beale and Construction Industry Council (CIC), 2013), COTAC's suggestion on BIM for the Heritage Life Cyclical Principle, following CIC's format with some adjustments in response to historic preservation needs (right) (Maxwell, 2014) Diagrams are re-drawn by Kemuning Adiputri.

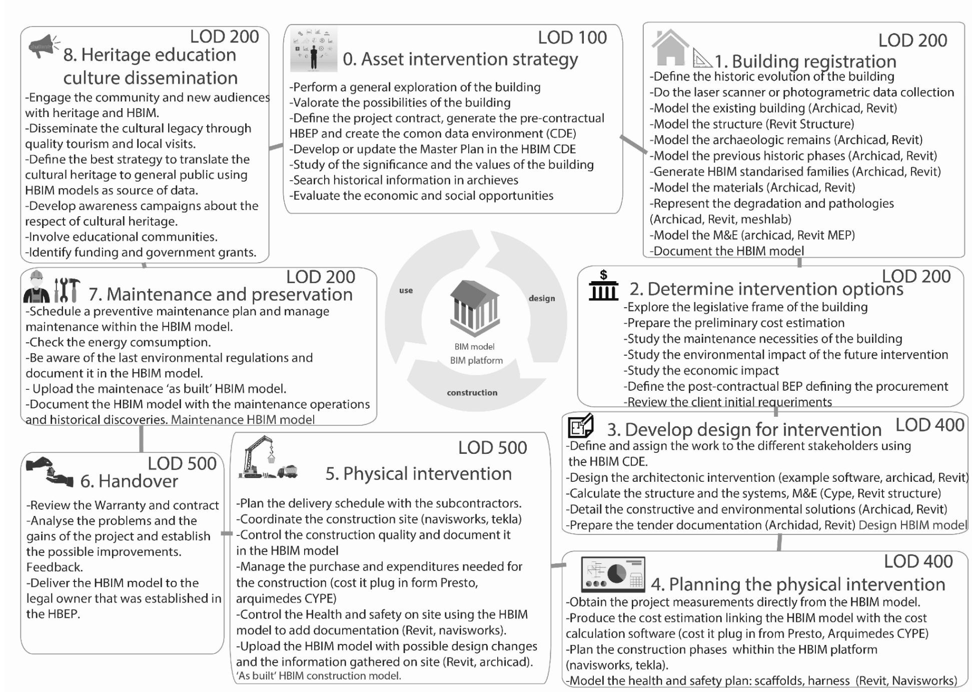

Figure 19. BIM Legacy for existing building, specifying the LOD and additional protocol for each phases in COTAC's diagram (Jordan-Palomar, et al., 2018).

These previous BIM guidelines inform the importance of dividing the protocols based on BIM's utility and project phases, recognizing that a more specific standard is necessary for better implementation. The idea of LOD in protocols provides a precedent on standardizing BIM modeling, but might not be immediately applicable for historic preservation purposes. Utilizing new building criteria of evaluation might not be the best approach because the content in that protocol did not fully take existing building into consideration.

Another approach of standardizing documentation can be seen within HABS drawing guidelines, as seen in the following diagram. Although this framework is not specifically tailored for BIM, it provides one example of using different levels, similarly to LOD, as a parameter outlining the expected details in all required formats (measured drawings, photography, written data, and other media). In this case, level 1 requires the highest details, and level 3 requires the lowest. It also acknowledges that some criteria of evaluations (content, quality, material, and presentation) are needed to provide a more detailed protocol supporting all requirements.

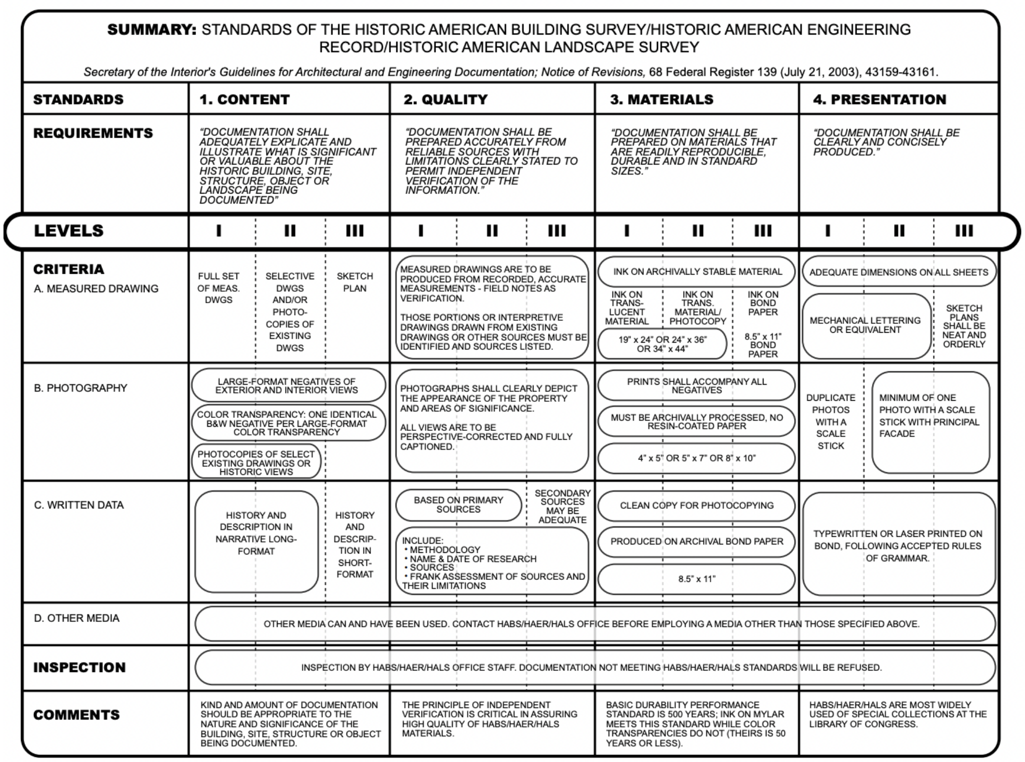

Figure 20. HABS drawing guideline, Adapted from Robert J. Kapsch's 1990 diagram first published in "HABS/HAER: A User's Guide," APT Bulletin, Vol. 22, No. 1/2, Cultural Resource Recording (1990). Redrawn and updated by Susan Bopp.

By taking into account the existing formal protocols that have been discussed in this section, I will continue evaluating case studies to discover past standardization approaches in real-life preservation projects. The case studies include the TWA Hotel Project by Beyer Blinder Belle (adaptive-reuse project) and Clara Barton Home (restoration and stabilization project), which both possess very different characteristics - the building style, size, function, project goal, and other; recognizing the very unique nature of preservation projects.

Past Standard in TWA Flight Hotel (Beyer Blinder Belle)

Site Introduction

The TWA Flight Hotel project is an adaptive reuse restoration of the historic Eero Saarinen design flight terminal located at John F. Kennedy (JFK) Airport in Queens, New York City. Initially completed in 1962-1963 as a flagship terminal for Trans World Airline (TWA), the building was always intentionally made to be an iconic structure - something designed to be beheld and wondered at.

The interior consists of organic curved walls with no 90-degree angle. It was meant to celebrate movement - both the visual movement by not having any kind of hard lines and air travel movement, which was considered exciting during that time. One of the iconic features is the main hall, with vaulted space and a sunken lounge where people wait for boarding time. The sizable expansive window shows the aircraft landing and taking off - providing a theatrical performance to the passengers as the spectators.

In 2001, Trans World Airlines filed for bankruptcy and was acquired by American Airlines. The type of plane in service by this terminal was growing - the TWA Terminal was considered too small and needed to catch up with modern airline travel. One of the issues was having adequate security procurement as required. The terminal was shut down and was utterly obsolete until the TWA Hotel project launched. The building was empty for 20 years.

The site itself is under the jurisdiction of the port authority of New Jersey. Considering the valuable land this terminal is located - within JFK Airport - in 2014, the proposal for commercial hotel use was requested. Several different agencies were involved in the project, with Beyer Blinder Belle (BBB) acting as the executive architect and preservation architect.

Project Overview

Figure 21-22. TWA Hotel aerial view (top) and the relationship between existing building and new building (bottom) (TWA Hotel, n.d.)

The TWA Hotel Project involved the restoration and adaptive reuse of the main terminal and a massive campaign of new construction. The Eero Saarinen terminal is located in the middle of the project site, and on either side of it, flanking the wings of the terminal, is a seven-story hotel structure. A conference center was also added underground. Due to the proximity to the airport, the building is considered not only a hotel, but also a business destination housing conferences, weddings, and other events. The hotel consists of 512 rooms, all of which are located in two new structures. The flight center is utilized as a hotel lobby, facilitating the primary point of entry and for programmatic elements such as bar, kitchen, and lobby assembly spaces.

As this building is located on land run by a State Agency, which is the port authority of New Jersey, it does not fall under the preview of the Landmark Preservation Commission (LPC). However, considering its significance, there was an agreement to ensure preservation practices are put into place in any development of this project. This resulted in the requirement to maintain particular view sheds, including the view from the sunken lounge. There was also a building height regulation ruled by the Federal Aviation Administration (FAA), increasing the restriction this project faced during its development.

BIM Protocol

The decision behind BIM utilization is motivated by the scale of the project and the almost equal proportion of purely ground-up new construction versus restoration preservation. In this project, in particular, the existing building is not orthogonal, and the nature of the construction was experiential - hence why the traditional 2D drawings were very hard to read. The availability of a 3D model was critical for the project's documentation and design phases, especially in coordinating with different building systems, such as Mechanical, Electrical, and Plumbing (MEP).

1. <u>Visual representation</u>

The structure's fundamentals are organic, but it is not necessarily ornate like other museum projects. Despite that, during the initial project development in 2015-2016, the BIM software utilized, Autodesk Revit, did not efficiently support modeling organic form. It was challenging to model the existing condition of the building, particularly the shell of the roof and the expressive structural columns.

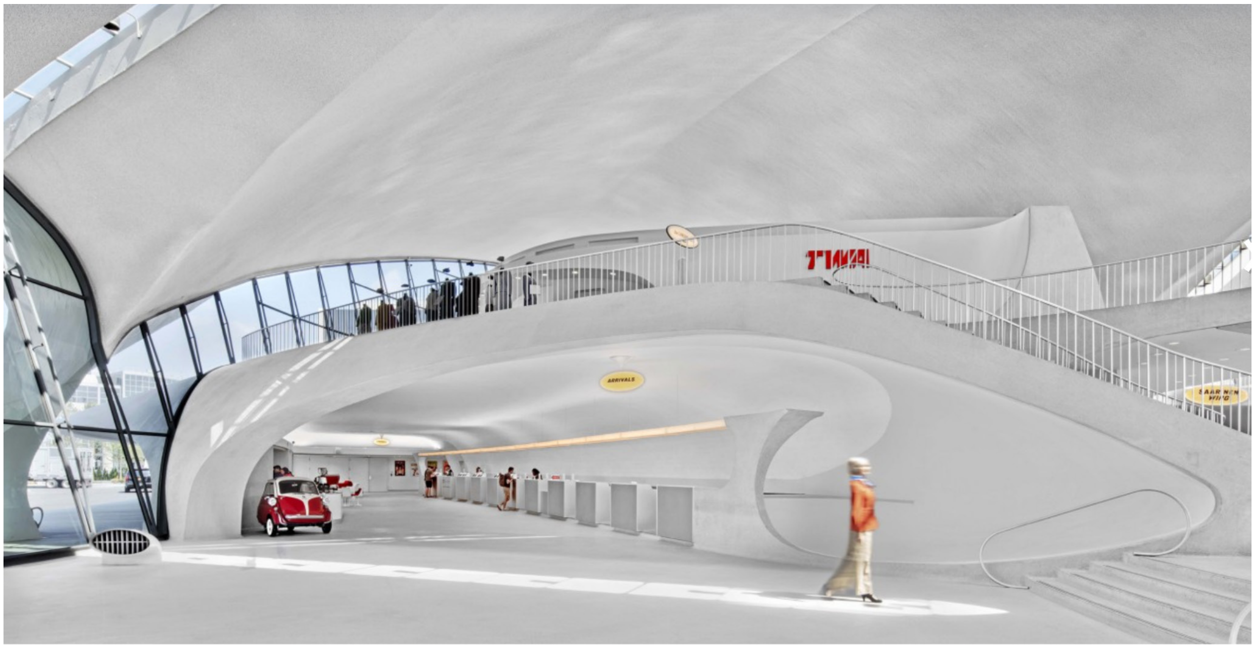

Figure 23. TWA Hotel rendered interior design showing the organic shell of the roof and expressive structure (Beyer Blinder Belle, n.d.)

Considering the necessity and the challenge, Level of Detail (LoD) 300 was utilized as the visual representation standard. Similarly to many other large-scale BIM projects, the specific LoD was written contractually, accompanied by an excel table as an execution plan. It determined the specific expectations, how the level of detail requirement was applied, and how the LoD developed throughout the project - the model started with less detail to more detail. There were also two different levels of details utilized for existing condition modeling and for the design and project development phase.

The accuracy of the model is standardized by having a median level. While it is common for existing buildings to have small bents on the walls, floors, and other elements, capturing minor tilts does not necessarily help communicate the design - and it also requires more effort. Therefore, if the threshold from the median level determined at the beginning is small, having an utterly co-planar model allows an easier development phase. If there is a significant threshold, for instance, the floor is sagging far more than the median level; this information would be necessary to be incorporated into the documentation process.

2. Information management system

Regarding materiality and assembly, the information from the existing drawing supports the on-site probes conducted to the building and vice-versa. While some existing drawings told the type of assembly this building utilized, at the beginning of this project, the building elements, such as walls, floors, and others, were documented as generic elements. The materiality was applied later in the model once the exact materials were confirmed through sample probes. This is to avoid misinterpretation, as the drawings and the existing condition might sometimes show different materials. The availability of existing drawings, though, decreased the number of necessary probes, as the investigation was only conducted to confirm the information on the drawing.

Even though some materials are obviously concrete in the TWA Hotel project, including the material information at the beginning of 3D modeling was considered less effective as there might be another editing process required during the project development. Especially in the case where only some parts of the materials are visible, instead of starting with an inconsistent information management system, the architects decided to start entirely with generic elements to avoid redundant workflow.

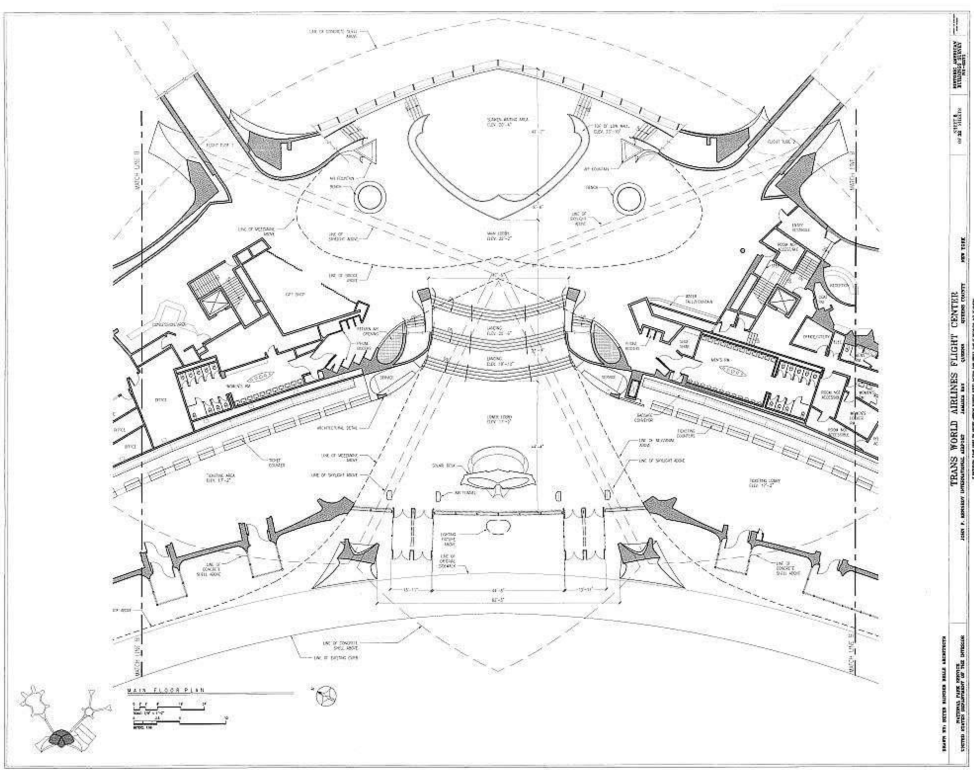

Figure 24. TWA Flight Terminal existing drawing (Historic American Building Survey, 2019).

In the case of traditional assembly or types of assembly that are not "typical" was encountered, developing a new set in Revit is necessary. Embedding the material specification in that particular process is one kind of information management the architect did in this project. Additional information, such as when some geometry has a certain relationship with another, was included in the comment portion in the material property. When some elements are more significant than others, that information would be written as annotation in 2D drawings. Even though Revit can be more parametric[9] in conveying this type of information, in TWA Hotel Project's case, those functionalities were not utilized. However, in life safety plans, for example, there was a process of calling information from room parameters and synthesizing the graphic in the plan, which involved the parametric script run by the team.

Linking to external sources is a common way of communicating in BIM environments. Usually, excel sheets including an array of information, sometimes in the form of a finished schedule, would be linked to Revit to inform the parameter of a particular element. This process was conducted in the TWA Hotel project in the exterior documentation phase, but it was still a combination of 2D annotation and linking external sources.

3. <u>Supporting collaboration</u>

There were a number of different agencies involved in the project. On the design aspect, Beyer Blinder Belle (BBB), the executive architect and preservation architect, worked with design architect Lubrano Ciavarra. There were also several interior designers and lighting designers involved. This project also involved a structural consultant, MEP engineer, signage consultant, and many others.

During the early development of this project, an online collaboration tool such as Autodesk BIM360 hadn't been invented. To accommodate collaboration, this project was broken up into a number of different models, including the historical model, the new construction model of hotel wings and conference center, and another model for lighting, MEP, infrastructure, and landscape. The architects from different firms would work in the same environment to allow updated information whenever changes were made. The BIM manager was the responsible individual that would issue progress models periodically.

These models have different ownership as some of these models were developed by different stakeholders, all of which were determined contractually. In the case of the existing condition and new construction model, the copyright is owned by the executive architect, Beyer Blinder Belle (BBB). Whereas, for example, the MEP models were owned by the

9 Developing a set of algorithms utilizing parameters and rules to define a relationship between design intent (in this case, showing the level of significance in building elements) and design response (visual or data).

engineer as they were responsible for developing them. Though at the time, it was allowed for some people to take temporary ownership of certain areas in the model as they progressed through designs. During the design phase, different architecture firms could update the changes individually, or the executive architect could incorporate their ideas into the model.

As for the ownership of the finished model, Beyer Blinder Belle (BBB) owns the intellectual property of the drawings, but they released those documents to the client. In this case, the ownership obtained by the client does not include intellectual property. The client also received the existing condition model, which is a survey model - hence Beyer Blinder Belle (BBB) does not own its intellectual property.

4. Pre-establishment simulation

This project did not utilize tools inside BIM software for interference checking such as clash detection, which is a method to clarify whether there are building elements that conflict with each other. The reason is because during the project development, this tool was considered complicated, and less straightforward than it is today. However, different plugins for information management, like schedules and data management, were used. This project also involved rendering plugins such as Enscape. Other plugins applied include dynamo, lighting analysis, and daylight analysis. To fulfill the Leadership in Energy and Environmental Design (LEED) rating system, energy analysis and system analysis were also carried out in this project.

5. Durable archival format

The models were stored in Beyer Blinder Belle (BBB)'s internal servers and shared through the NPT system. The models were archived thoroughly during major milestones, such as the end of the design phase and the end of construction. Although the model of this project was made in Autodesk Revit 2017, which is not supported by the new versions anymore, the update process is straightforward. It allows the models to be used in the future even though a certain amount of digital work is required to re-access the file.

If an external party wants to use this project's Revit model, it requires a particular agreement to take place as it involves the intellectual property of the firm that produced it. Besides the BIM model, the point cloud from the laser scan survey might be the file type with the most reusability, as it is raw data. Considering the technology is developing so quickly, it might be easier, more economical, and more accurate to do brand-new scans and rebuild a model instead of utilizing other firms' finished Revit model.

TWA Flight Hotel

Previous Standard

Visual representation	LOD 300, a standard initially made for new building was utilized with a set of excel sheet as an execution plan. The accuracy is standardized by having a median level.
Information management system	Information from existing drawing supports the on-site probes, and vice-versa. At the beginning, the building elements are documented as generic elements. The materiality was applied once confirmed.
Collaboration	To accommodate collaboration, this project was broken up into numbers of different models. These models have different ownership all of which were determined contractually.
Pre-establishment simulation	Numerous simulation plugins utilized for information management, render, lighting, daylight, energy, etc.
Durable archival format	The models were stored in the architect's internal servers. If an external party wants to use this project's Revit model, it requires a certain agreement to take place.

Figure 25. BIM standardization in TWA Hotel project

Past Standard in Clara Barton House (Mills + Schnoering Architects)

Project Overview

Clara Barton Home is a National Parks Service designated historic property located in Maryland. It was originally a house belonging to Clara Barton, a founder of the American Red Cross, who lived in this house from 1897 until her death in 1912. It served as a home, headquarters and warehouse to the organization. The building is described "like a castle" with wood frame structure. This project involved a reconfiguration of the existing interior space and exterior facade. While still aiming to maintain and preserve the building as much as possible, there are some interventions done inside the building, such as an additional office facility for one of the tenants. On the exterior part, an additional element linked with a corridor that looked almost like a bridge was introduced.

Figure 26. Clara Barton Home from Library of Congress collection (Highsmith, C., between 1980-2006)

BIM Protocol

As this project involved an assembled team consisting of different experts including electrical, structural, and mechanical engineering, a more advanced system of coordination was required. Unlike 2D drawings produced in CAD, BIM software such as Autodesk Revit, that was utilized in this project, allows 3D modeling with an opportunity to link the model with all different trades - producing one united model. It has the ability to detect clashes and conflicting elements. For example, if one of the ducts was running through a steel beam, the architect could point out that issue after the models submitted by different consultants were linked.

BIM software also allowed embedding information to the model in this project. The walls made in the Revit environment would have the thickness, classes associated with the materials, and additional information conveyed on it. This data would allow an automatization in the production of schedule, or a list of all the walls in the building, which was helpful in supporting the project development.

1. <u>Visual representation</u>

The Level of Detail (LoD) standard was determined by considering the project's necessity and the client's requirements. Clara Barton Home has a very interesting exterior that uses wood clapboard and stone from the period of construction. Considering that this project involved providing additional elements to the exterior, it was essential to show the rendered model to the clients, to visually represent how the new addition would look in comparison with the historical elements of the building.

In the interior part, while there are some architectural ornaments left, they were not modeled as they do not reflect the historical significance of Clara Barton Home. The architectural value of the building lies on the overall form of the building. It has an interesting cylindrical - almost cone-shaped roof and a giant atrium that goes on multiple floors, with a bunch of perimeter of the rooms around the atrium. The aim during the modeling process was to capture that shape to the rendering as something believable - something that mimics the overall form without being overly-detailed. It involved the process of adding and subtracting solid-void in Autodesk Revit environment. As the project did not involve changes on the architectural ornaments, those elements were not required to be modeled in detail.

Figure 27. Interior photo of Clara Barton Home showing the giant atrium (Maryland Historical Trust, n.d.).

Figure 28. Sectional drawing of Clara Barton Home from HABS (Historic American Building Survey, n.d.).

The existing condition model was generated by an external consultant by referencing the existing drawing, in this case was made by Historic American Building Survey (HABS), which provided adequate accuracy and details. The architect then went to the site to take measurements to ensure the accuracy of the model. Sometimes the elements might not precisely line up, hence the 1-2 inches level of accuracy was determined. If the misaligned elements were off for more than 2 inches, an additional review would be required. This process would discover the potential sacrifice or trade off in the model accuracy.

2. Information management system

The information embedded into elements typically include the width, height, thickness, material, frame material, type of the element, and many other unique parameters. The comment portion in the property tab also allows additional information, including pointing out elements that are considered more significant than the other. All that information would result in a large schedule with a comprehensive list of the elements in the whole project. Another way to associate a certain type of information into the model is by graphic symbols. For example, an existing door would be pointed out by having 45 degree angle, instead of 90 degree angle typically indicating new doors.

Although there is a possibility to include information from historical reports to the element, this was not the case for this project. The architect typically would supplement the model with external reports, for instance reports about building history and the development over time, without linking it to the model.

3. Supporting collaboration

The Clara Barton House project did not utilize an online collaboration environment such as Autodesk BIM360 as the stakeholders did not expect to require intensive collaboration in the process. This project is considered small-scale, as it is only a house, hence the involved party was comfortable with independently linking the consultant's files.

The file ownership is determined contractually. For the sub-consultants such as electrical and mechanical, the initial contract already included the copyright matters, therefore waivers are not required. In the case of contract with external consultants, it would require C401 form, which is an American Institute of Architects (AIA) document. Sometimes the contractor needs to see the model for the purpose of understanding the dimensions to help with coordination. For this scenario, a waiver determining that the contractor is not allowed to use the architect's model would be filed. The waivers act as a protection measure for the data ownership.

4. Pre-establishment simulation

Architecturally, this project did not involve simulations such as thermal, or other types of building analysis, but the sub consultants such as the mechanical consultant worked with heating and cooling simulation to support their decisions.

5. Durable archival format

Whenever a certain milestone was reached, the Revit model would be archived as a detached model - separated from the central model the involved stakeholders worked on. This process would break the progress in a point of time, which then provides the ability to save and distribute it. In the case a client returns for the same project, those stored Revit files will be detached again and used as an as-built model. To avoid confusion, all elements in those models would be universally made into existing phase conditions rather than a variety of existing and new conditions like the previous project required.

The archived models would be kept for several years - architects are contractually required to save the file for at least 10 years from the point of the project final completion. This would allow the architect to be in hook for the design questions, claims, and other things requiring the model. Autodesk Revit versions typically last for four years, with one additional year for a grace period to upgrade the ongoing file versions[10]. As for the stored past files, even though updating the versions would take some time, the process is straightforward to do.

10 Based on the information from the architect involved in this project.

Clara Barton Home

Previous Standard

Visual representation	Level of detail was determined by considering the necessity and the client's requirements.
Information management system	The information embedded into elements include the dimension, material, and other parameters. Another way to associate information is by graphic symbols. The architect supplement the model with external report.
Collaboration	The architect independently linking the consultant's files. The file ownership is determined contractually.
Pre-establishment simulation	The sub consultants such as the mechanical consultant worked with heating and cooling simulation to support their decisions.
Durable archival format	Whenever a certain milestone was reached, the Revit model would be archived as a detached model. The archived models would be keeped for at least 10 years.

Figure 29. BIM standardization in Clara Barton Home project

Conclusion

The first half of this chapter discussed the inadequacies of existing protocols in BIM, specifically for historic documen tation. Many existing standards were mainly developed in response to new construction requirements, resulting in less applicability in historic preservation. This is also apparent in the case studies discussed above, for instance in TWA Hotel, where the BIM manager determined LOD 300 - which is considered as a standard developed for new buildings - to be implemented as baseline protocol for their BIM model. Some adjustments, specific to the project's needs, were established to fulfill the standards, which further showcase the challenge in implementing existing protocols for projects involving historic buildings.

In addition to that, as historic preservation includes an array of different processes, proposing specific standards for each phase would be a small yet important step to accomplish a more effective and targeted standardization of BIM utilization in the historic preservation field. Continuing the main focus of this thesis, the evaluation of previous standards in two case studies discussed in this chapter provides a precedent for the first draft of BIM protocol in historic documentation, titled Historic Documentation BIM (HDBIM), which will be further discussed in the next chapter.

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Chapter 4: Historic Documentation BIM (HDBIM) Protocol

Purpose and Methodology

By taking into account the previous chapter regarding past and existing BIM standardization, the purpose of this section is to provide a framework proposal for BIM for historic documentation, titled Historic Documentation BIM (HDBIM) protocol. This includes the guidelines to support the planning and implementation of standardizing BIM approach. In the previous chapter, it has been discussed that historic documentation can be defined into two purposes: education (knowledge resource), and intervention (design and planning). While both are highly essential on the field, these two types of documentation require a different set of protocols.

Document for knowledge resources typically has a very standardized format and would include as much information as possible, because it will be kept in a shared archive for future uses. The main value of this type of document is the accuracy[11], providing reliable information for incoming projects and research. In comparison, documentation for intervention planning typically contains information from a specific part of the building, with less standardization, because the main purpose is to assist decision makers to confirm the historic appropriateness of the changes proposed. One shared protocol for these two different purposes might be too generalized and less applicable. For this reason, the protocol proposed in this chapter will focus on assisting the historic documentation in BIM for intervention purposes - but it does not halt the possibility of this protocol supporting the development of knowledge resource documents.

The protocol consists of three levels, with 1 being the most advanced BIM implementation and 3 being the least. A guideline on the project type and the recommended protocol level will be provided at the end of this section. Five criterias of BIM utilization in the field are determined based on the five shared purposes between BIM and historic documentation. The definition of each criterion in the case of this framework is described below.

11 Accuracy in historic documentation defined as having accurate measurement and visual representation that reflects the real-life object. Accuracy is sometimes confused with precision - which is referred to as having the same/similar results (from experiments, for example) over and over again.

Visual representation: the extent of BIM in visually 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 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 - providing the opportunity to transfer information to future generations and support future uses.

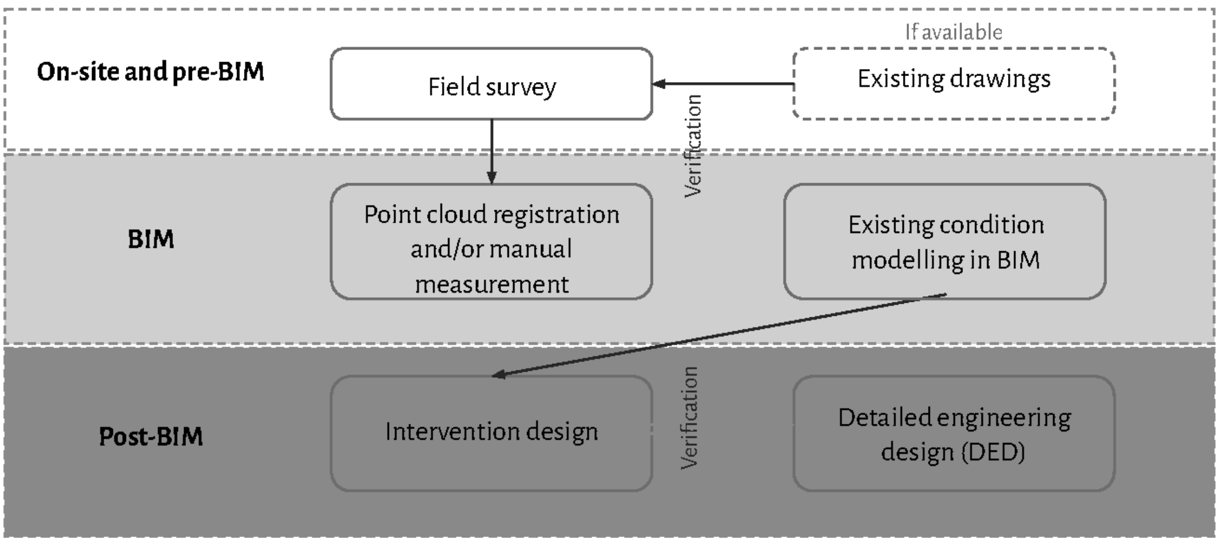

Figure 30. BIM work phases to establish protocols.

Considering the different steps, processes, and requirements in BIM workflow, as well as continuing the discussion from chapter two regarding typical documentation workflow, each of these criteria should be evaluated in four stages. These include **on-site** (the initial survey as a baseline of BIM implementation), **pre-BIM** (the process of existing material gathering and verification), **BIM** (criteria application in BIM environment), and **post-BIM** (next-step post-modelling and/or post-construction).

Proposed Historic Documentation BIM (HDBIM) Protocol

Workflow	On-field			Pre-BIM		
	Initial survey as a baseline			*Existing material gathering and verification*		
Levels	**1**	**2**	**3**	**1**	**2**	**3**
Criteria						**Prot**
Visual representation (capturing the existing condition of the building with a certain Level of Detail (LoD) and Level of Accuracy (LoA))	Manual measurement and photography	Laser scan and photography	Laser scan, photography, and manual measurement	No existing drawing available, model developed from field survey	Existing drawing collection, visually verified with photograph or field survey	Existing drawing collection, measurements are verified with laser scan or manual survey
Information management system (contains and manages different kinds of information - text, number, yes/no, etc. - embedded into the elements or model)	No on-field testing involved		Determine building material through on-field testing	No existing data available, all information gathered from field survey	Existing material and historic data collection, verified with secondary sources	Existing material and historic data collection, verified with on-field survey and/or primary sources

BIM			Post-BIM		
Criteria application in BIM environment			*Next-step post-modelling and/or post-construction*		
1	**2**	**3**	**1**	**2**	**3**
ocols					
General masses of partial/full building	Illustrate significant elements to decoration-level detail	Illustrate the entire building to decoration-level detail	Presented as 2D plan, elevation, section, and/or detail drawings with annotation and hatch texture	Presented as rendered 3D perspective drawings	Presented as a walkthrough of 3D-rendered space utilizing tools such as virtual reality, video, etc.
Information on the material and/or historic data stated in comments OR conveyed on the introduction page	Each element contains information on the material and/or historical data - stated on the property bar	Each element contains information on the material and/or historical data - linked to external sources and folders on the property bar	Compile all information from each element into schedule		

Workflow	**On-field** *Initial survey as a baseline*			**Pre-BIM** *Existing material gathering and verification*		
Levels	**1**	**2**	**3**	**1**	**2**	**3**
Supporting collaboration (allow a certain level of accessibility, editability, and utility for different stakeholders)	Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility					

BIM			Post-BIM		
Criteria application in BIM environment			*Next-step post-modelling and/or post-construction*		
1	**2**	**3**	**1**	**2**	**3**
BIM model exported into CAD, PDF, or other format - shared among involved parties through emails or other data-sharing platform	Detached BIM working file shared among involved parties through email or other data-sharing platform	All/some involved parties working in a shared BIM model (online/offline)	BIM model exported into CAD, PDF, or other digital formats - shared with owners or other parties (based on the contract) for future maintenance, repair, etc.	Detached BIM model shared with owners or other parties (based on the contract) for future maintenance, repair, etc.	Finished model stored in the cloud provided by BIM developers - with accessibility provided for the owner, facility manager, or other parties (based on the contract) for future uses

Workflow	On-field *Initial survey as a baseline*			Pre-BIM *Existing material gathering and verification*		
Levels	**1**	**2**	**3**	**1**	**2**	**3**
Pre-establishment simulation (supporting decision-making by allowing pre-construction analysis, utilizing tools incorporated in the BIM software and/or plugins from external software)	No on-field testing involved	Generate sample of material specification through on-field testing	Generate material specification through on-field testing	Utilizing existing material specification without verification	Utilizing existing material specification partially (with sample) verified with on-field survey	Material specification entirely generated from on-field survey
Durable archive format (allow more sustainable data for archival purposes - provide the opportunity to transfer information to future generations and support future uses)	Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation					

BIM			Post-BIM		
Criteria application in BIM environment			*Next-step post-modelling and/or post-construction*		
1	**2**	**3**	**1**	**2**	**3**
No simulation involved	Evaluate the relationship between systems without plugins, for instance: clash detection (interference checking)	Run a certain kind of simulation (for instance, energy, moisture, etc.) utilizing plugins that connect the BIM model to external software	Decision made with a consideration to the simulation results		
Record the existing condition of the building and the intervention design - no as-built drawing	Record the existing condition of the building and the intervention design including the as-built drawing	Record existing condition, intervention design, as-built condition, and record changes happened to the building over-time	Detached BIM model saved in architecture firm's internal drive, version updated every four years	Finished model stored in the cloud provided by BIM developers (for instance, BIM360) for future utility	Detached BIM model shared in an open-access platform for knowledge resource and future uses

Application Guideline

	Project Scale (Smaller → Bigger)			Building Ownership (Private → Institution)			Building Status (→ Higher lv. designation)			Alteration (Surface → Spatial)			Number of Stakeholders (Fewer → Greater)		
Visual representation (VR)							1	2	3	3	2	1			
Info. management system (IMS)				1	2	3	1	2	3	1	2	3	1	2	3
Supporting collaboration (SC)	1	2	3							1	2	3	1	2	3
Pre-establishment simulation (PES)	1	2	3							1	2	3	1	2	3
Durable archival format (DAF)				1	2	3	1	2	3						

Figure 31. BIM for historic documentation protocol application guideline

To determine the HDBIM protocol level for a project, the illustration above suggests the levels and the consideration factors to help with the project planning. There are some blocks that are filled with black and white because not all considerations affect all criterias. For example, the project size might not directly correlate with the level of visual representation the model needs to achieve, but it certainly does affect the level of collaboration. Another example is the alteration. If it happens at surface level, the higher visual representation level is suggested because it means the model will be produced in more detail to the architectural decoration level. Whereas spatial alteration might benefit more from lower level visual representation with less detail, considering the project efficiency.

The more detailed recommendation in determining the protocol levels are suggested below.

1. The project scale
   The bigger the project scale, the higher level of protocol in "supporting collaboration" and "pre-establishment simulation" criteria is recommended.
2. The building ownership
   Institution-owned buildings require a higher level of protocol compared to privately-owned buildings, particularly in "information management system" and "durable archival format" criteria. The reason is because buildings owned by institutions typically would benefit from the knowledge resource stored as an information management system, especially in supporting future projects, research, maintenance, and many other purposes.
3. Building status
   In today's practice, national monuments require a more comprehensive document outlining the historical significance, both in visual format and written format. Therefore, higher level of designation - whether it is federal, states, or locally designated - necessitates higher level of protocol in criteria "visual representation," "information management system," and "durable archival format."
4. Type of alteration
   Developing documentation for supporting spatial alteration projects would benefit from lower level of "visual representation," to enhance the modeling efficiency, but higher level of "information management system," "supporting collaboration," and "pre-establishment simulation."
5. The number of stakeholders:
   The bigger the involved party size, the higher "information management system," "supporting collaboration," and "pre-establishment simulation" levels are recommended. This type of project will have multiple experts working together, requiring a more comprehensive collaboration mechanism and IT-enabled decision support.

It is imperative to keep in mind that all projects are unique, therefore, this guideline has a certain degree of flexibility. Additional considerations must be taken into account before deciding on the level of protocol which would guide the BIM utilization during the documentation phase of the project. As mentioned earlier in this chapter, the HDBIM protocol is ideally suited for documents for intervention planning instead of for knowledge resource and education, as the later type of document would require a whole different set of protocol and guidelines. However, some of the criterias, protocols, and the suggested levels might be applicable for a certain knowledge resource project.

Protocol Evaluation

HDBIM proposes an approach in determining a set of protocols to implement, specifically for historic documentation purposes, including the criteria of evaluation, work phases, and application guidelines - all of which are fabricated from the research conducted throughout this thesis. It is important to note though, that the protocol itself still needs to be evaluated to determine its feasibility and practicality towards actual projects.

First approach involves pragmatic evaluation, analyzing to what extent the protocols in HDBIM reflects the actual need and requirements of real-life projects. This approach will be conducted by comparing the proposed protocol and the standards used previously in the same cases discussed in chapter 3: TWA Hotel and Clara Barton Home. Although those projects had been completed by the time this thesis was written, I will approach the evaluation process by reimagining the initial protocol planning, consecutively following the application guideline provided. As mentioned earlier, these two projects possess different characteristics. Therefore, this section will evaluate how the proposed protocol applies to those variables. Additional case studies with diverse characteristics[12] might be necessary to further inform how comprehensive the protocols are and how to improve them.

The result of this analysis will show the similarities and differences between standards, of which a qualitative analysis will further inform whether a certain revisions are needed for HDBIM. Some recommendations to consider for the first protocol iteration will be fabricated as the end result of this approach. As all intervention projects are unique, specific adjustments are expected to accommodate the different requirements, but HDBIM aims to improve its protocols to include more project characteristics.

After the iteration takes place and the protocols are ready to be established for practice, additional analysis involving applicative evaluation is recommended periodically. This should be conducted by having several stakeholders to inform and evaluate the application of HDBIM in their specific projects within a certain time frame, including how it responds to the advancing BIM technology as well as the shift in documentation practice. This would inform further necessary improvements, allowing the protocols to grow together with the technology.

12 Characteristics include project scale, owner, stakeholder, type of intervention, and more.

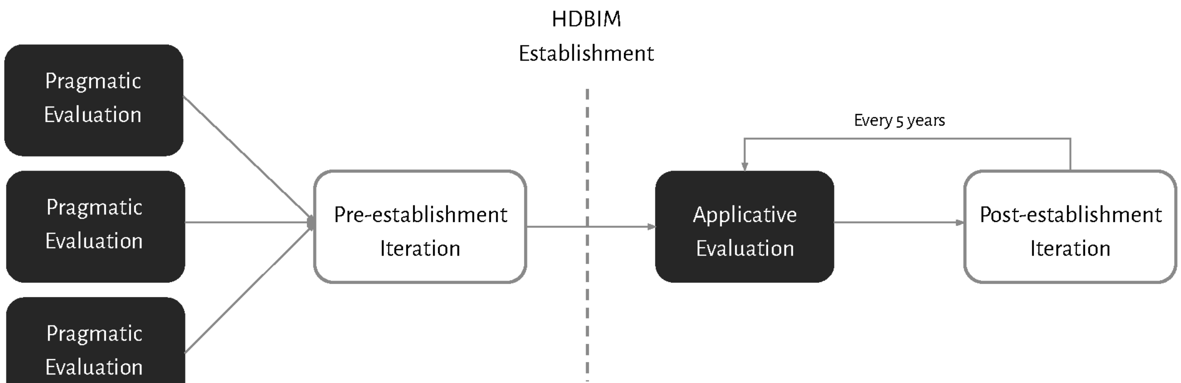

Figure 32. HDBIM protocol evaluation scheme.

Proposed Application 1: TWA Hotel Project (Beyer Blinder Belle)

Project Scale: Level 2-3 SC and PES	The project involved existing terminal with two additional structure on its wings, and new basement. The project is relatively big in scale.
Building Ownership: Level 3 IMS and DAF	The site itself is under the jurisdiction of the port authority of New Jersey. It does not fall under the preview of LPC. However, there was an agreement to ensure preservation practices are put into place.
Building Status: Level 2-3 VR, IMS, and DAF	The main building had been made a New York City designated landmark in 1994, and subsequently was added to the National Register of Historic Places in 2005.
Alteration: Level 1-2 VR, level 2-3 IMS, SC, PES, and DAF	TWA Hotel Project involved the restoration and adaptive reuse of the main terminal and a massive campaign of new construction. The structure's fundamental is organic, but it is not necessarily ornate like other museum projects. The intervention is spatial.
Numbers of Stakeholders: Level 2-3 IMS, SC, and PES	There were a number of different agencies involved in the project, starting with numerous architecture firms, interior designer, lighting designer, structural consultant, MEP engineer, signage consultant, and many others.

Figure 33. Proposed protocol levels in TWA Hotel Project

The TWA Hotel project involved the restoration of Eero Saarinen's Trans World Airline (TWA) Terminal in the middle of the site, in addition to new structure development at either wing of the terminal and new basement for business purposes. The new additions consist of a seven-story building with 512 hotel rooms, and the basement hosts 45 meeting rooms and one 7000 square-foot meeting hall. The total size of this project is 392.000 square feet. This building is considerably on a larger scale, consisting of three multi-story building masses in addition to underground space, resulting in the recommendation of level 2-3 protocols in "supporting collaboration" and "pre-establishment simulation" criteria.

Regarding building ownership, the site itself is under the jurisdiction of Port Authority New Jersey. However, the recommendation to preserve the building comes from an agreement with New York City (NYC) Landmark Preservation Committee (LPC)[13]. This project is conducted on an institution-owned land; therefore, protocol level 3 is recommended for an "information management system" and "durable archival format."

The main building, TWA Flight Terminal, designed by Eero Saarinen, was designated as a New York City landmark in 1994 and added to the National Register of Historic Places (NR) in 2005. The building being listed in the NR program does not necessarily translate it as a National Historic Landmark (NHL). Still, it is considered significant to the nation and worthy of preservation (National Parks Service, 2022). Due to this reason, levels 2-3 of "visual representation," "information management system," and "durable archival format" is recommended to be implemented.

This project involved a restoration of the main terminal and a spatial intervention in the form of new buildings. Additionally, considering the existing building's characteristics as a modern building with less ornament, level 1 of "visual representation" is considered adequate. However, as this project has a considerable amount of additional structure and function, it triggers the suggestion of levels 2-3 for "information management system," "supporting collaboration," and "pre-establishment simulation," to manage and organize important data of the project and to avoid errors.

Lastly, there was a group of experts working on this project - involving multiple architecture firms, lighting and interior designers, engineers, and many others. All stakeholders are responsible for certain levels of decisions; hence, it is imperative to implement higher levels of "information management system," "supporting collaboration," and "pre-establishment simulation." Levels 2-3 are recommended for these criterias, allowing a more comprehensive, organized, and structured teamwork with more calculated decisions and fewer missteps.

The illustration below shows the recommended levels of HDBIM protocol for the TWA Hotel project. To allow more flexibility, some criteria did not face a strict recommendation on the protocol level; rather, there are options to provide

13 Based on the interview with Beyer Blinder Belle (BBB)'s architect involved in the project.

the opportunity to decide which levels are most appropriate to implement. Considering that the protocol consists of four documentation phases, having two options on the protocol levels allows the stakeholders to implement different levels in different phases. A more detailed approach to this will be discussed below.

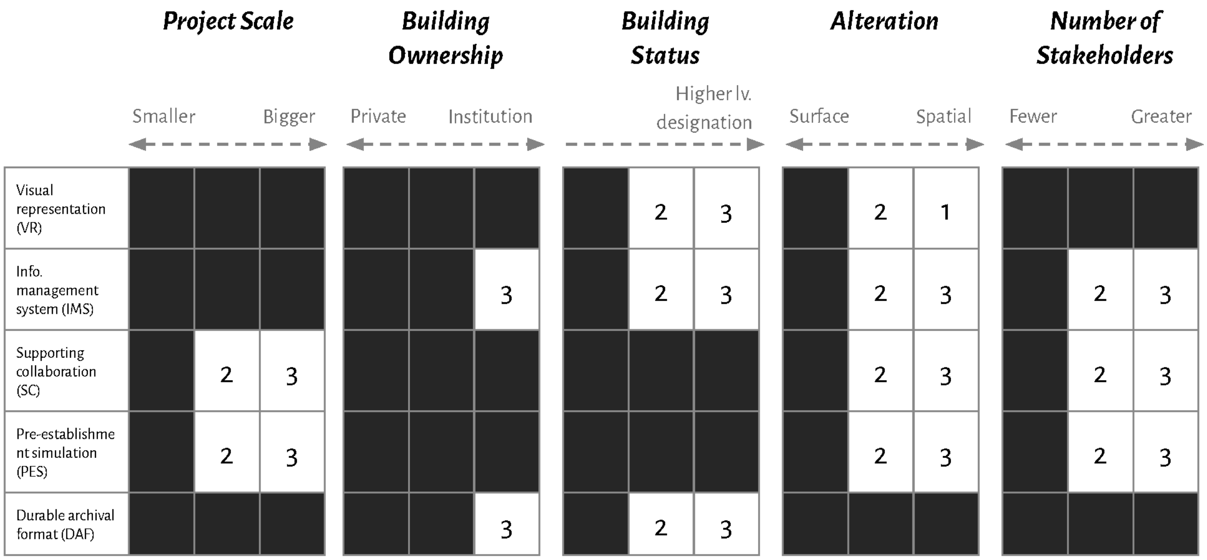

Figure 34. Proposed protocol levels in TWA Hotel project

Visual representation

Due to the "building status" and "alteration" factor, there are conflicting levels recommended for visual representation, where the first consideration suggested levels 2-3, whereas the second suggested level 1-2. In this case, the median number could be chosen to compromise different requirements; therefore, level 2 of visual representation will be utilized. Looking at the protocols, level 2 of visual representation determines the following

On-site: Laser scan and photography
Pre-BIM: Existing drawing collection, visually verified with photograph or field survey
BIM: Illustrate significant elements to decoration-level detail
Post-BIM: Presented as rendered 3D perspective drawings

Based on one of the architects who was involved in the project development, during the survey, both laser scan and existing drawings were utilized. The laser scan, which can only capture visible objects, acts as a foundation - then the data will be confirmed using existing drawings. The initial phases of this project consisted of a "*combination of point cloud data,* *supplemented with existing condition drawings*." The HDBIM protocol for visual representation using the guideline suggested in this thesis aligns with the method this firm conducted - involving a laser scan survey and existing drawing analysis, which both acted as a two-way verification method. They also mentioned Enscape, a plugin for 3D rendering, was used to support the presentation; therefore, the "post-BIM" protocol was also the standard implemented during the actual project.

The suggestion to model "significant element to decoration-level detail," might not be completely in accordance with the actual practice. The architect mentioned that LOD300 was used as a guideline for the graphic and information detail of the model. Based on CIC's guidelines, LOD300 shows accurate geometry, but it is not required to model all components on certain elements - which means the architectural details on the wall, for example, are unnecessary. The architects did not go beyond LOD300 for the modeling because TWA Terminal was built in a modern style, with few architectural details and more unique masses. The protocol might need re-evaluation to determine whether the standard to model "to decoration-level detail" is sufficient or whether a numeric indicator, for instance, "2 inches detail," would be more appropriate.

Information management system

"Building status," "alteration," and "number of stakeholder" allow a more flexible information management system protocol level, which is level 2-3. However, the fact that an institution owns the site triggered the necessity to utilize level 3 of this category. Considering that one factor strictly requires one certain level, that suggested level will be used. Level 3 of the information management system provides the following protocols.

On-site: Determine building material through on-field testing
Pre-BIM: Existing material and historic data collection, verified with on-field survey and/or primary sources
BIM: Each element contains information on the material and/or historical data - linked to external sources and folders on the property bar
Post-BIM: Compile all information from each element into schedule

During the actual project phases, the model was initially developed with generic elements, then after the material specification was confirmed, they were edited according to their correct assembly. The past drawings and on-site sample probe inform the existing material for this purpose. They also mentioned the schedule in BIM helped with organizing and managing information. The recommended HDBIM protocol above, specifically the "on-site," "pre-BIM," and "post-BIM", appear to have similarities with the standard utilized by the firm, with the suggestions to use existing drawings confirmed with on-site sample probes to determine the building material. The "BIM'' phase, however, might need re-evaluation as it says "each element" needs to contain information "linked to external sources," which appears to be too robust for this project.

Supporting collaboration

All three factors determining "supporting collaboration" criteria suggested level 2-3, including "project scale," "alteration," and "number of stakeholders." If two options are available for a category, it allows different utilization levels in different documentation phases based on the project requirements and needs. The following is one sample of recommendations.

On-site: Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility
Pre-BIM: Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility
BIM: All/some involved parties working in a shared BIM model (online/offline) (level 3)
Post-BIM: Detached BIM model shared with owners or other parties (based on the contract) for future maintenance, repair, etc. (level 2)

The architect of this project mentioned that a BIM protocol typically rules the copyright, ownership, and file accessibility, but in the case it does not, each party should sign a release. During this project, an online collaborative platform was not fully invented; therefore, the model was separated into three - developed by three groups of stakeholders. The BIM manager was responsible for overseeing the synchronization throughout the project phase. A detached BIM file was shared with the client at the end, but the firm still owns the model's intellectual property. Considering the collaboration approach conducted during the project, the suggested protocols appear to align with what they carried out. However, the protocol might need to be detailed further, as it did not include some points, for instance, about intellectual property, which turned out to be a crucial part of the process.

Pre-establishment simulation

Similarly to the previous criteria, the "project scale," "alteration," and "number of stakeholder" factors suggest flexibility in the "pre-establishment simulation" protocol, allowing the options to choose between level 2-3 to be implemented in the project. Once again, this provides the opportunity to pick different levels on different phases depending on the project's specifications. The recommendation below is one of the approaches to choosing the levels of protocols for this particular project.

On-site: Generate sample of material specification through on-field testing
Pre-BIM: Utilizing existing material specification partially (with sample) verified with on-field survey
BIM: Run a certain kind of simulation (for instance, energy, moisture, etc.) utilizing plugins that connect the BIM model to external software

Post-BIM: Decision made with a consideration to the simulation results

As already mentioned in the information management system part, sample probes were taken during the project to determine the material. The simulation conducted includes daylight, energy, lighting analysis, and others, which involve external plugins (as recommended in level 3 protocol) - but clash detection was not used due to the perceived complexity at the time this project was carried out. It is interesting to note that clash detection is much simpler today, which is also why this protocol was written in level 2, but it was not the case 10 years ago.

Durable archival format

In terms of "durable archival format" criteria, the "building status" factor allows flexibility for level 2-3 of the protocol, but the "building ownership" strictly requires level 3. Therefore, protocol level 3 will be suggested for the entire documentation workflow in this project. The protocol's details are as follows.

On-site: Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation
Pre-BIM: Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation
BIM: Record existing condition, intervention design, as-built condition, and record changes happened to the building over-time
Post-BIM: Detached BIM model shared in an open-access platform for knowledge resource and future uses

The model ownership, as ruled by AIA, has to be determined contractually within the stakeholders. One thing to note regarding the suggested protocol is that during the project implementation, an open-access platform such as BIM360 was not invented yet; therefore, the finished model was stored in the architecture firm's internal repository. The model is updated as a record after a certain milestone - a point which might be necessary to add to the protocol.

Workflow	**On-field** *Initial survey as a baseline*			**Pre-BIM** *Existing material gathering and verification*			**BIM** *Criteria application in BIM environment*			**Post-BIM** *Next-step post-modelling and/or post-construction*		
Levels	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Criteria	**Protocols**											
Visual representation (capturing the existing condition of the building with a certain Level of Detail (LoD) and Level of Accuracy (LoA))	Manual measurement and photography	Laser scan and photography	Laser scan, photography, and manual measurement	No existing drawing available, model developed from field survey	Existing drawing collection, visually verified with photograph or field survey	Existing drawing collection, measurements are verified with laser scan or manual survey	General masses of partial/full building	Illustrate significant elements to decoration-level detail	Illustrate the entire building to decoration-level detail	Presented as 2D plan, elevation, section, and/or detail drawings with annotation and hatch texture	Presented as rendered 3D perspective drawings	Presented as a walkthrough of 3D-rendered space utilizing tools such as virtual reality, video, etc.
Information management system (contains and manages different kinds of information - text, number, yes/no, etc. - embedded into the elements or model)	No on-field testing involved		Determine building material through on-field testing	No existing data available, all information gathered from field survey	Existing material and historic data collection, verified with secondary sources	Existing material and historic data collection, verified with on-field survey and/or primary sources	Information on the material and/or historic data stated in comments OR conveyed on the introduction page	Each element contains information on the material and/or historical data - stated on the property bar	Each element contains information on the material and/or historical data - linked to external sources and folders on the property bar	Compile all information from each element into schedule		

Table 7a. Proposed protocol levels for TWA Hotel project

Workflow	**On-field** *Initial survey as a baseline*			**Pre-BIM** *Existing material gathering and verification*			**BIM** *Criteria application in BIM environment*			**Post-BIM** *Next-step post-modelling and/or post-construction*		
Levels	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Supporting collaboration (allow a certain level of accessibility, editability, and utility for different stakeholders)	Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility						BIM model exported into CAD, PDF, or other format - shared among involved parties through emails or other data-sharing platform	Detached BIM working file shared among involved parties through email or other data-sharing platform	All/some involved parties working in a shared BIM model (online/offline)	BIM model exported into CAD, PDF, or other digital formats - shared with owners or other parties (based on the contract) for future maintenance, repair, etc.	Detached BIM model shared with owners or other parties (based on the contract) for future maintenance, repair, etc.	Finished model stored in the cloud provided by BIM developers - with accessibility provided for the owner, facility manager, or other parties (based on the contract) for future uses

Table 7b. Proposed protocol levels for TWA Hotel project

Workflow	On-field			Pre-BIM			BIM			Post-BIM		
	Initial survey as a baseline			*Existing material gathering and verification*			*Criteria application in BIM environment*			*Next-step post-modelling and/or post-construction*		
Levels	1	2	3	1	2	3	1	2	3	1	2	3
Pre-establishment simulation (supporting decision-making by allowing pre-construction analysis, utilizing tools incorporated in the BIM software and/or plugins from external software)	No on-field testing involved	Generate sample of material specification through on-field testing	Generate material specification through on-field testing	Utilizing existing material specification without verification	Utilizing existing material specification partially (with sample) verified with on-field survey	Material specification entirely generated from on-field survey	No simulation involved	Evaluate the relationship between systems without plugins, for instance: clash detection (interference checking)	Run a certain kind of simulation (for instance, energy, moisture, etc.) utilizing plugins that connect the BIM model to external software	Decision made with a consideration to the simulation results		
Durable archive format (allow more sustainable data for archival purposes - provide the opportunity to transfer information to future generations and support future uses)	Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation						Record the existing condition of the building and the intervention design - no as-built drawing	Record the existing condition of the building and the intervention design including the as-built drawing	Record existing condition, intervention design, as-built condition, and record changes happened to the building over-time	Detached BIM model saved in architecture firm's internal drive, version updated every four years	Finished model stored in the cloud provided by BIM developers (for instance, BIM360) for future utility	Detached BIM model shared in an open-access platform for knowledge resource and future uses

Table 7c. Proposed protocol levels for TWA Hotel project

Proposed Application 2: Clara Barton House (Mills + Schnoering Architects)

Clara Barton Home

Proposed Protocol Standard

Project Scale: Level 2 SC and PES	It served as a home, headquarters and warehouse to the organization. The building is described "like a castle" with wood frame structure.
Building Ownership: Level 3 IMS and DAF	The National Park Service (NPS) acquired the house from the Friends of Clara Barton in 1975.
Building Status: Level 2-3 VR, IMS, and DAF	Clara Barton House is a building located within The Clara Barton National Historic Site, was designated in 1974.
Alteration: Level 2-3 VR, level 1-2 IMS, SC, PES, and DAF	While still aiming to maintain and preserve the building as much as possible, there are some intervention inside the building, including one additional room and exterior element.
Numbers of Stakeholders: Level 1-2 IMS, SC, and PES	This project involved an assembled team consisting of different experts including electrical, structural, and mechanical engineering, but the stakeholders did not expect to require intensive collaboration in the process.

Figure 35. Proposed protocol levels for Clara Barton Home project

Clara Barton Home served as a home, headquarters, and warehouse of the organization founded by Clara Barton, American Red Cross. Although the designation of Clara Barton National Historic Site includes 9 acres (392.040 square feet) of land, the project focused on restoring the main building. That being said, the house has 36 rooms and 38 closets, with three tiers of rooms facing a central gallery. Many describe the house "castle-like," and "massive."[14] This suggests that the "project scale" of Clara Barton Home would require level 2 of "supporting collaboration" and "pre-establishment simulation."

This building, along with its site, was acquired by National Parks Service (NPS) in 1975. As it is now owned by the government agency, level 3 of "information management system" and "durable archival format" would benefit this project further by providing a more comprehensive data organization and storage for long term uses.

Continuing the discussion regarding ownership, the building and the site were designated as a National Historic Site in 1974, a year before the acquisition by NPS, suggesting a higher level of designation (federal level). Due to this reason, at least level 2-3 of "visual representation," "information management system," and "durable archival format" is recommended for this project's purpose.

The project mainly involved restoration of the existing building fabric, but it also involved adaptive reuse with an additional office room inside the building and additional elements on the exterior part of the house. The intervention was conducted mostly at the surface level, except in the office room, which would require a higher level of "visual representation," which falls into level 2-3, as it needs to inform the detail of the building into decoration level to support the project. As it only involved small spatial alterations, only level 1-2 of "information management system," "supporting collaboration," and "pre-establishment simulation" is suggested for efficiency.

Lastly, this project involved stakeholders from different backgrounds, including architects, engineers, and many others. However, with the project's characteristics, the main goals, and the owner's requests, extensive collaboration was not required during the project development. This indicates that level 1-2 of "information management system," "supporting collaboration," and "pre-establishment simulation" is considered adequate for this project.

14 From the interview with Mills + Schonering Architect involved in this project.

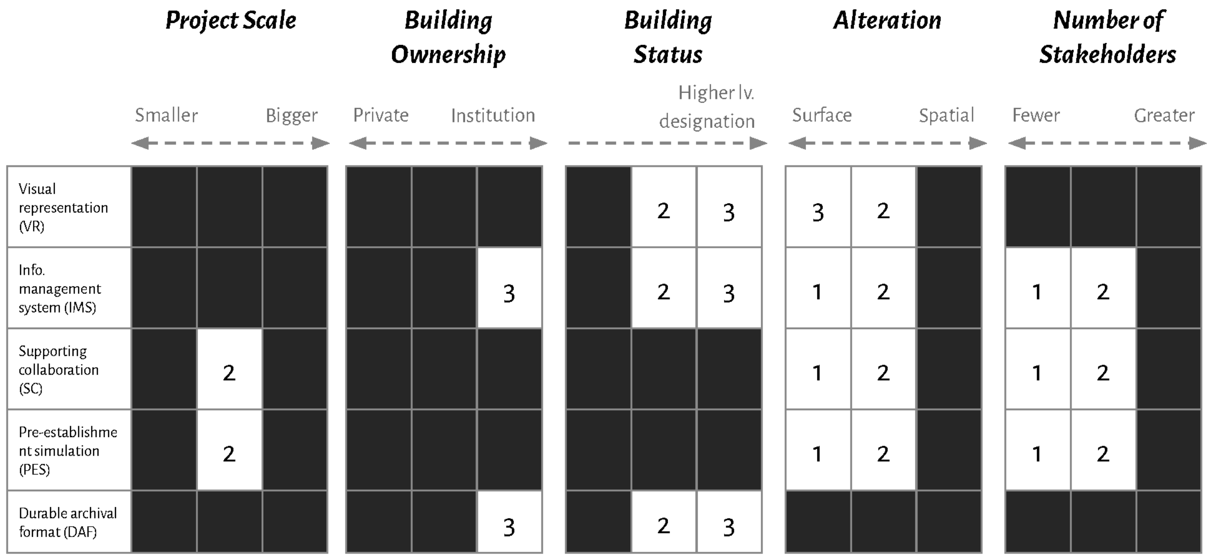

Figure 36. Proposed protocol levels for Clara Barton Home project

Visual representation

Both factors supporting the recommendation on the visual representation suggested level 2-3 protocol for this criteria. This allows stakeholders to determine which level should be implemented in which documentation phase. In the case of this project, though, after reviewing the protocol, level 3 of visual representation might be too advanced for the project requirements; therefore, all documentation phases will utilize level 2. The details of this approach are as follows.

> On-site: Laser scan and photography
> Pre-BIM: Existing drawing collection, visually verified with photograph or field survey
> BIM: Illustrate significant elements to decoration-level detail
> Post-BIM: Presented as rendered 3D perspective drawings

During the actual project, the involved architecture firm did not conduct a laser scan survey to develop the existing model. Rather, they used measurements that were obtained entirely from existing drawings. Taking into consideration the fact that Clara Barton Home is a National Historic Site means this project benefitted from comprehensive drawings from HABS. An external consultant developed the initial model, but then it got confirmed through manual measurement on-site - which is suggested as level 1 protocol instead of 2 as recommended above.

The architect confirmed that several parts of the building required greater details than the others, but they decided not to model the decoration elements, considering the BIM model's purpose. They also mentioned that the uniqueness of this building lies in its overall form instead of the decoration. The recommended HDBIM protocol, which asks for decoration-level detail on significant elements, was not implemented during the actual project, indicating the necessity of re-evaluation. Specifically, the term "decoration" might need some clarification or adjustment, as not all buildings possess traditional architectural decorations.

Information management System,

The recommended level of "information management system", is facing conflicts among different considerations - one factor strictly requires level 3, another factor suggests level 2-3, while the rest consider levels 1-2 to be adequate. This case will be further discussed in the conclusion, as it shows one of the challenges of the proposed guideline and the protocol.

For the sake of this section, though, there are three options stakeholders can choose: 1.) using the median level, which is level 2, throughout all phases; 2.) as one of the factors strictly requires level 3, level 2-3 can be used throughout all phases, allowing the opportunity to utilize level 3 for a certain phase; or 3.) level 1-3 can be used throughout the phases, depending on the project requirements. In this project, I recommend using the second option, which utilizes levels 2-3 depending on the documentation phase.

On-site: Determine building material through on-field testing (level 2)
Pre-BIM: Existing material and historic data collection, verified with secondary sources (level 2)
BIM: Each element contains information on the material and/or historical data - stated on the property bar (level 2)
Post-BIM: Compile all information from each element into schedule

The architect confirmed that schedule in BIM helped compile an array of architectural elements including the information regarding its dimension, material, type, and other unique parameters, all of which embedded and written on the property bar. The existing drawings were used to model the existing condition, including the material. They also mentioned that a site survey was conducted to verify the model's accuracy, but it was unclear whether probes were administered. The suggested protocols appear to align well with the actual project implementation, although it further suggests on-field testing to confirm the building material information.

Supporting collaboration

Although two factors allow flexible levels in "supporting collaboration" criteria by suggesting levels 1-2, the "project scale" specifically requires level 2. Therefore, utilizing level 2 of protocol throughout the documentation phase would accommodate the project's requirements better. The details of the recommended protocol are as follows.

On-site: Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility
Pre-BIM: Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility
BIM: Detached BIM working file shared among involved parties through email or other data-sharing platform
Post-BIM: Detached BIM model shared with owners or other parties (based on the contract) for future maintenance, repair, etc.

It was mentioned that an extensive collaboration was not required during the Clara Barton Home project. The architecture firm independently linked the consultant's files. An external consultant signed a waiver to determine the copyright agreement, whereas sub-consultants already had those arrangements written in their contract. The files were distributed in three formats: Revit, PDF, and CAD considering that some consultants worked with different tools.

Although the level 2 protocol only mentions "detached BIM working file," level 1 already suggests "CAD, PDF, or other formats" to be distributed among stakeholders. This might advise an additional guideline, which states when the greater level protocol is implemented, all lower-level protocols should also be put into practice. This requires further evaluation to ensure it works with other protocols.

Pre-establishment simulation

Similarly, this criteria has two factors that allow level 1-2 flexibility and one that specifically requires level 2 of the protocol. Again, in this case, following a more strict recommendation would be better to fulfill the project's requirements.

On-site: Generate sample of material specification through on-field testing
Pre-BIM: Utilizing existing material specification partially (with sample) verified with on-field survey
BIM: Evaluate the relationship between systems without plugins, for instance: clash detection (interference checking)
Post-BIM: Decision made with a consideration to the simulation results

The architect involved in this project mentioned the ability to detect clashes in BIM supported their decision to utilize this tool, specifically for projects involving multiple consultants. Architecturally, they did not conduct simulations with external plugins, but the sub-consultants, such as the engineers, used heating and cooling calculations. It is important to mention that the protocol recommended in this thesis mainly guides the documentation phases; therefore, the simulation conducted during the project implementation post-documentation is beyond what this protocol advises. The recommended protocol aligns with the practice conducted during the actual project, but it further suggests generating material specifications with partial on-field testing.

Durable archival format

In the case of "durable archival format," the "building status" factor allows options to implement level 2-3, but as the building is owned by a government agency, this triggers the requirement to apply level 3 of this criteria. The protocol for this purpose is as follows.

> On-site: Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation
> Pre-BIM: Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation
> BIM: Record the existing condition of the building and the intervention design - no as-built drawing
> Post-BIM: Detached BIM model shared in an open-access platform for knowledge resource and future uses.

The architecture firm would archive the detached BIM file when a certain milestone was reached during the project. This process would break the project down into different phases. Contractually they must store the project file for 10 years to allow design questions, claims, and other procedures. This also provides the opportunity for the firm to use the file as an as-built model when the clients return for additional projects on the same building. They mentioned that BIM360 was not used during this project, implying that an open-access platform was not utilized to distribute the finished file. However, as this project involved National Historic Site, the suggestion to share the model as a knowledge resource might benefit future projects.

Workflow	On-field			Pre-BIM			BIM			Post-BIM		
	Initial survey as a baseline			*Existing material gathering and verification*			*Criteria application in BIM environment*			*Next-step post-modelling and/or post-construction*		
Levels	1	2	3	1	2	3	1	2	3	1	2	3
Criteria	**Protocols**											
Visual representation (capturing the existing condition of the building with a certain Level of Detail (LoD) and Level of Accuracy (LoA))	Manual measurement and photography	Laser scan and photography	Laser scan, photography, and manual measurement	No existing drawing available, model developed from field survey	Existing drawing collection, visually verified with photograph or field survey	Existing drawing collection, measurements are verified with laser scan or manual survey	General masses of partial/full building	Illustrate significant elements to decoration-level detail	Illustrate the entire building to decoration-level detail	Presented as 2D plan, elevation, section, and/or detail drawings with annotation and hatch texture	Presented as rendered 3D perspective drawings	Presented as a walkthrough of 3D-rendered space utilizing tools such as virtual reality, video, etc.
Information management system (contains and manages different kinds of information - text, number, yes/no, etc. - embedded into the elements or model)	No on-field testing involved		Determine building material through on-field testing	No existing data available, all information gathered from field survey	Existing material and historic data collection, verified with secondary sources	Existing material and historic data collection, verified with on-field survey and/or primary sources	Information on the material and/or historic data stated in comments OR conveyed on the introduction page	Each element contains information on the material and/or historical data - stated on the property bar	Each element contains information on the material and/or historical data - linked to external sources and folders on the property bar	Compile all information from each element into a list generated automatically in BIM		

Table 8a. Proposed protocol levels for Clara Barton Home project

Workflow	On-field			Pre-BIM			BIM			Post-BIM		
	Initial survey as a baseline			*Existing material gathering and verification*			*Criteria application in BIM environment*			*Next-step post-modelling and/or post-construction*		
Levels	1	2	3	1	2	3	1	2	3	1	2	3
Supporting collaboration (allow a certain level of accessibility, editability, and utility for different stakeholders)	Each party signs a contract and/or release agreement determining copyright, ownership, and file accessibility						BIM model exported into CAD, PDF, or other format - shared among involved parties through emails or other data-sharing platform	Detached BIM working file shared among involved parties through email or other data-sharing platform	All/some involved parties working in a shared BIM model (online/offline)	BIM model exported into CAD, PDF, or other digital formats - shared with owners or other parties (based on the contract) for future maintenance, repair, etc.	Detached BIM model shared with owners or other parties (based on the contract) for future maintenance, repair, etc.	Finished model stored in the cloud provided by BIM developers - with accessibility provided for the owner, facility manager, or other parties (based on the contract) for future uses

Table 8b. Proposed protocol levels for Clara Barton Home project

Workflow	On-field *Initial survey as a baseline*			Pre-BIM *Existing material gathering and verification*			BIM *Criteria application in BIM environment*			Post-BIM *Next-step post-modelling and/or post-construction*		
Levels	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Pre-establishment simulation (supporting decision-making by allowing pre-construction analysis, utilizing tools incorporated in the BIM software and/or plugins from external software)	No on-field testing involved	Generate sample of material specification through on-field testing	Generate material specification through on-field testing	Utilizing existing material specification without verification	Utilizing existing material specification partially (with sample) verified with on-field survey	Material specification entirely generated from on-field survey	No simulation involved	Evaluate the relationship between systems without plugins, for instance: clash detection (interference checking)	Run a certain kind of simulation (for instance, energy, moisture, etc.) utilizing plugins that connect the BIM model to external software	Decision made with a consideration to the simulation results		
Durable archive format (allow more sustainable data for archival purposes - provide the opportunity to transfer information to future generations and support future uses)	Architecture firm and client sign a contract determining the data ownership, format, and each parties' post-construction right and obligation						Record the existing condition of the building and the intervention design - no as-built drawing	Record the existing condition of the building and the intervention design including the as-built drawing	Record existing condition, intervention design, as-built condition, and record changes happened to the building over-time	Detached BIM model saved in architecture firm's internal drive, version updated every four years	Finished model stored in the cloud provided by BIM developers (for instance, BIM360) for future utility	Detached BIM model shared in an open-access platform for knowledge resource and future uses

Table 8c. Proposed protocol levels for Clara Barton Home project

Evaluation Result

Based on the protocol evaluation of each criterion and the implementation guideline, around 80% of the proposed standard aligns with the actual protocol used by the architecture firm during the project implementation. However, there are some re-evaluation needed to enhance the applicability, as listed below.

1. Consider whether qualitative indicator such as "decoration-level detail" or quantitative indicator such as "2 inches detail" applies better for "visual representation" criteria
2. Additional guideline regarding intellectual property needs to be mentioned
3. Consider "when the greater level protocol is implemented, all lower-level protocols should also be put into practice" added to the application guideline
4. The application guideline should be either specified further in conflicting case levels or be allowed for further flexibility acknowledging the uniqueness of each project.

This HDBIM protocol and the application guideline act as a methodological suggestion and baseline for future development of BIM protocol for historic documentation. It is recommended for future research to continue analyzing and revising the standards, starting by taking into account the suggestion above.

Future Evaluation

As previously mentioned, before putting HDBIM into practice, additional pragmatic evaluation involving different kinds of documentation projects is recommended. Although two cases that were evaluated in this section already possessed different characteristics in terms of their scale, intervention type, and the number of stakeholder, the two cases might still not be adequate to decide its actual feasibility. The evaluation conducted in this chapter intends to provide precedent of the analysis for a future reference. Additionally, after the establishment of HDBIM, a periodical applicative evaluation is required to assess the protocol's relevancy to advancing BIM approach and historic documentation practice.

Chapter 5: Conclusion

Conclusion

Building Information Modelling (BIM) is growing in significance, with countries starting to establish mandates which expedite tool utilization throughout the globe. As one part of the construction industry in general, the mandates also apply to projects involving historic buildings, referred to as historic preservation in the case of the United States. Within the preservation workflow, one of the valuable steps is historic documentation, which supports the knowledge resource from the beginning to the end of safeguarding important monuments, even beyond.

By comparing the purpose of BIM and historic documentation, this thesis has determined "five shared purposes," indicating the possibility of BIM in fully or partially supporting documentation practice - informing the potential value of this research in the field of preservation, technology, and policy-making. This thesis discovered BIM's strength mainly in 3D digital representation for accurate measurement and visual understanding, managing visually-representable data, and allowing a more efficient collaboration, but it also found out some challenges in implementing BIM for documentation, including the learning curve, additional expenses, and managing text-based information. Arguably, the challenges are time-sensitive, therefore there is a potential for them to be resolved in the near future. Based on the result of this evaluation, I have concluded that the value BIM provides for documentation makes its utilization worthy of being implemented in the field for a certain type of projects, however, a specific guideline and standard are needed.

As a supporting tool for BIM mandates, or BIM projects in general, a protocol is an important guide to utilize the software, allowing a standardized output and efficient workflow. This thesis evaluated the inadequacies of existing BIM protocols which mainly consist of standards for new building, and argued that specific standards for each preservation phase would be imperative to accomplish a more targeted standardization of BIM in the historic preservation field. A new standard titled Historic Documentation BIM (HDBIM) protocol, including the application guideline, was proposed, as a first draft of BIM protocol intended specifically for historic documentation. This protocol still requires periodic feasibility and applicability evaluations to ensure its qualification. The first pragmatic evaluation was conducted, resulting in a set of recommendations for future improvements.

Recommendation

For Researchers

Historic preservation, although this field mainly engages with objects from the past, needs to keep up with technological advances, including BIM, requiring continuous research effort to go along with new approaches and tools. My research about BIM for historic documentation is an ongoing process, as BIM is still continuously developing, therefore future research is recommended specifically in testing and improving the HDBIM protocol that I have proposed. This includes conducting pragmatic evaluation with existing projects with particular characteristics and, later on, applicative evaluation with ongoing historic documentation projects.

As the protocol produced in this thesis focused only on the documentation phase, additional research regarding methods to produce specific BIM standards for other preservation phases, for instance intervention design and heritage education, would be beneficial.

For BIM Developers

The software evaluation part of this thesis has determined a few challenges in the BIM environment that preservationists are facing today, including learning curve, less straightforward and less familiar interface, expense(s), inability to sort and organize text-based information, and the lack of applicable tools for preservation practice.

Historic preservation, unlike typical construction projects, involves a reverse engineering process, requiring a tool with higher flexibility and adaptability in response to the very specific condition of the existing building. The type of information contained in the model is also distinctive to those of new construction, as historic information deemed important to support decision making during the intervention design process. Additionally, in most cases, deteriorations such as cracks, salts, and others need to be documented in detail, which is still a challenge to model in 3D, especially with the lack of available object family in BIM software for this purpose.

There is ongoing research regarding the benefit of refurbishing old buildings instead of new construction. Along with the growing BIM mandates, it would result in an increasing number of preservationists utilizing BIM software. Arguably, the future improvements in response to the evaluations conducted in this thesis would be highly beneficial for both preservation practitioners and BIM developers.

For Preservationists

As one part of the construction industry, it is not impossible that BIM mandates would impact the preservation field in near future. Considering the value BIM provides for historic documentation, along with the need of effort to keep up with developing technologies, it is imperative to anticipate the tool transition from "traditional" approaches to new approaches including BIM. As some of the challenges of BIM for historic documentation include the lack of skill set and less familiarity with the tool, an early start of a training would be valuable.

Additionally, the HDBIM protocol proposed in this thesis aims to support the transition, providing a very specific guide for planning and implementing the BIM approach for historic documentation. This also works the other way around, as the utilization of HDBIM protocols by preservationists would support the evaluation, where any inputs would inform future improvement of this proposed standard.