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Article

Integrating Stakeholders' Priorities into Level of Development Supplemental Guidelines for HBIM Implementation

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Abstract: Heritage Building Information Modeling (HBIM) is increasingly utilized to develop accurate and semantic-rich databases for the representation, preservation, and renovation of cultural heritage. A critical factor in successful HBIM delivery is the intended uses of the model, which need to be established by stakeholders at the onset of the program. Despite the greater application of Building Information Modeling (BIM) technologies to HBIM workflows, the discipline continues to lack clarity regarding information requirements from a tenant perspective. The first stage of this research was a review of 26 published HBIM case studies to extract information including HBIM workflows, level of development (LOD) models in the field, and the stakeholders' participation in the HBIM program. The findings from the case studies conclude that most HBIM methodologies did not seek to understand the needs of assumptive stakeholders and lacked a clearly defined objective. Ten interviews with proprietors of ten different historic courthouses in the southeastern United States were also included in the study, which were used to identify the priorities of HBIM programs from a built heritage stakeholder's standpoint. These priorities were used in conjunction with reviewed field standards to develop LOD supplement guidelines applicable for HBIM, which were then validated through a case study. The findings of this research conclude that the creation of LOD guidelines for HBIM application is both achievable and advisable, as they allow stakeholders to identify their priorities for HBIM projects. Such guidelines would assist in standardizing the HBIM discipline and disseminating its usefulness to historic building managers. This research also provides standards that allow cultural heritage stakeholders to make informed decisions about potential HBIM programs and maximize the use of resources to implement such programs. Moreover, the methodology implemented in this research offers a valuable example for future studies on HBIM guidelines and regulations.

Keywords: cultural heritage; HBIM; level of development; LOD; reality capture

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1. Introduction

BIM provides a process for the digital representation of building characteristics for a facility through its lifecycle of planning, design, construction, operations and maintenance, alterations, and demolition [1,2]. The process consists of 3D modeling concepts incorporated into an information database that architects, engineers, construction contractors, and facilities managers can use to design, construct, and maintain facilities [3]. Current BIM technology and software are optimized to model the characteristics of modern building elements and architectural components for the full range of architectural, engineering, and construction systems [4]. Parametric object families are readily available to provide quick implementation into BIM repositories for standardized 21st century building elements. Meanwhile, reality capture (RC) technologies, used for monitoring progress during the construction of new facilities, including terrestrial laser scanning (TLS), unmanned aerial vehicles (UAV), and photogrammetry, have also been integrated into BIM. The data collected using RC techniques is processed to develop highly accurate point clouds of the current construction conditions, which can be used to develop "as-built" BIM models or to compare the built condition against the approved design [5–7].

These advances in BIM technology have seen successful application in the field of built heritage and conservation [8]. Utilizing the same innovative BIM technology used in new built projects, the aim of Heritage Building Information Modeling (HBIM) is to obtain legacy data and capture precise measurements using RC technologies to precisely model heritage structures for purposes of restoration, preservation, study, and public awareness [9]. Reconstruction utilizing historical data, RC techniques, and analog surveys can create a comprehensive and accurate digital documentation of the current conditions of built heritage to be preserved, refurbished, and examined [10–12]. However, the complex geometries and heterogeneous construction materials common in cultural heritage limit the ability to incorporate existing BIM families of parametric objects and the advantages of BIM automation procedures [13–16]. The prevailing method of HBIM modeling utilizes scan-to-BIM, a primarily manual process that requires considerable resources [4,17]. On-going research to develop automated procedures for 3D model reconstruction of unique historic building elements is still in initial stages with significant trade-offs for ease of modeling at the sacrifice of building element accuracy. Experimentations with algorithms to automatically extract geometric characteristics through point cloud are yielding promising results in the attempt to capture complicated historic geometries compounded by surface degradations [18–20].

Studies have been conducted to develop appropriate BIM frameworks in the context of built heritage. Heritage England proposed a workflow that concentrates on the managing aspects of developing a HBIM program such as modeling planning and organization, data acquisition, and general model strategies [21]. A simplified HBIM workflow developed by Martinelli et al. [22] provides a general and flexible process to support conservation activities, with a focus on the interpretation of structural systems in built heritage to support BIM processes for historic buildings. Jordan-Palomar et al. [23] provide a protocol named "BIMlegacy" as a general approach to organizational strategies for interventions of historic structure degradation. These existing methods provide limited case studies to demonstrate the validity of the proposed workflows.

Each proposed workflow requires significant preliminary planning prior to data acquisition and modeling. A proper level of engagement with owners and tenants of built heritage is necessary to develop a professional relationship and gain access to the facility for RC surveys and legacy information. The existence of and access to historical data and legacy information is heavily dependent on the historic structure under study and incorporation into the HBIM model may be of limited use because of gaps in the historic data. In the framework of HBIM, Level of Development (LOD) is the degree to which the components' specification, geometry, and attached information have been developed [24]. Understanding the current state of the built heritage and the intended model application (i.e., operations and maintenance, proactive preservation, restoration, and/or public applications) assists stakeholders in determining the required LOD necessary to satisfy the purpose of the HBIM model. More research is needed to validate proposed workflows, understand appropriate LOD based on the type of facility and the purpose of the model, and to incorporate common end user priorities in the HBIM program through case studies.

The absence of a standardized approach to HBIM development and implementation for built heritage hinders the consistent application of BIM technology and lifecycle benefits in the research and preservation of historic structures. Thus, the aim of this research study is to offer supplemental LOD guidelines in HBIM, compatible with the priorities of heritage building managers and aligned with existing corresponding BIM LOD specifications. By reviewing past HBIM literature, interviewing current built heritage stakeholders, and applying the proposed guidelines constructed based off that information on a case study, this research will demonstrate the need for and provide guidelines that allow stakeholders to make informed decisions about which LOD and priorities are desirable for the HBIM program for their built heritage.

2. Literature Review

2.1. Heritage Building Information Modeling (HBIM)

The domain of HBIM is a library of generated parametric objects from historic information blended with RC surveys to precisely reconstruct the existing architectural fabric of a heritage structure [21]. HBIM applications are used for conservation and restoration activities [15,16,25], structural analysis and monitoring [26–28], facility management [16,26,29], degradation mapping [12,13], and public visualization [25,30]. HBIM entails the incorporation of spatial and non-geometric data, and requires an understanding of building materials and construction methods in historical buildings [1,31].

A typical HBIM workflow includes a preliminary phase to identify the purpose and resource constraints of the project, a data collection phase to acquire spatial and semantic data, a model development phase, and a verification phase (Figure 1). The resulting HBIM repository stores geometrically precise representations of built heritage via parametric objects with embedded metadata. Parametric objects are instance-based objects that incorporate information (metadata) relevant to the component [32]. The published literature reveals several challenges that limit the full potential of HBIM, including the lack of parametric object libraries for historic building elements [16,33–35], issues of surveying complex and heterogeneous geometries of historic architecture [14,15,20,35], and an absence of historic construction data [20,25,31,35–37].

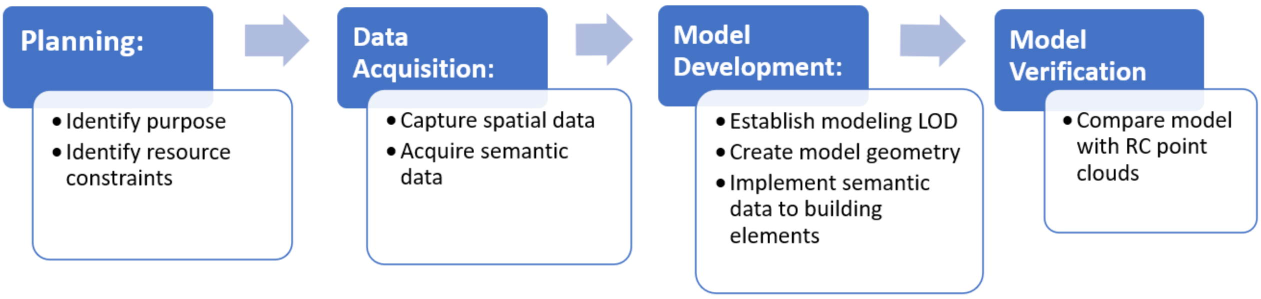


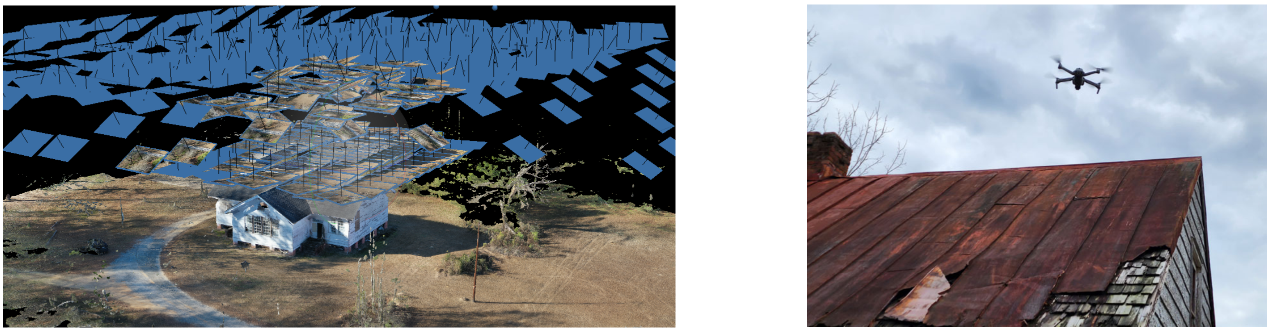
Figure 1. HBIM program workflow.

Initial data collection efforts of a HBIM program involve an in-depth review of legacy data regarding the historic structure's design, construction, and evolution over time. The availability of legacy data will directly impact the survey focus and determine the LOD that can be achieved. Historic blueprints offer valuable information regarding construction systems and building materials hidden behind finishes or later renovations. Historic accounts of building construction may reveal additional details that can be incorporated in the model. Characterization of building materials helps define the material properties associated with a unique set of parametric objects representing cultural heritage. Upon completion of the modeling process, legacy data becomes semantic data and is embedded into the precise geometric forms of building elements based on accurate RC surveys.

2.2. Reality Capture (RC) Technology

Typical RC technology implemented in HBIM contains photogrammetry, terrestrial laser scanning (TLS), and 360 degree photography [9,37]. The use of these technologies, individually or in combination, comprises the minimum effort required for the practice of HBIM [38]. These technologies provide highly accurate geometric representations of the existing condition of cultural heritage and serve as the foundation of HBIM modeling and parametric object creation.

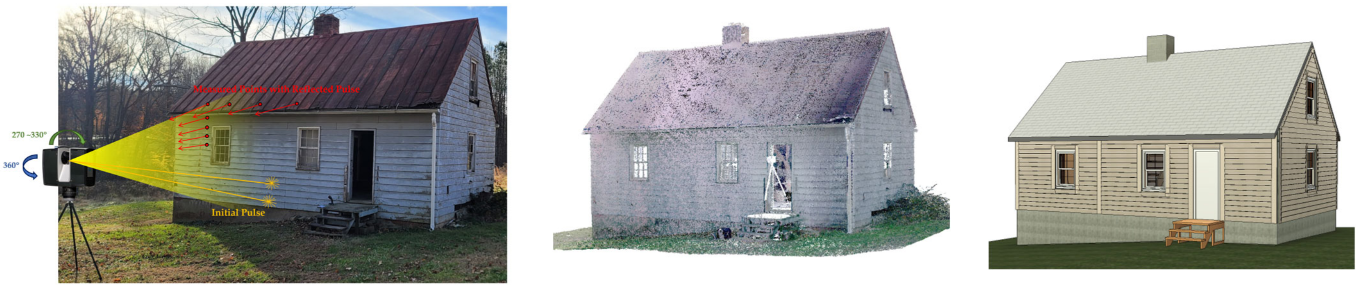
Photogrammetry is a technology that acquires information about physical objects from processes of capturing and interpreting photographs of recorded radiant electromagnetic energy and other phenomena [39]. In another word, photogrammetry uses a set of photos captured at altering locations and directions to obtain a 3D model of objects. The incorporation of unmanned aerial vehicles (UAV) with photogrammetry, as seen in Figure 2, gives scholars the enhanced capacity to obtain information of built heritage at heights [40].



(**a**) (**b**)

Figure 2. UAV photogrammetry: (**a**) UAV photogrammetry schematic; (**b**) a Mavic Pro 2 UAV [41] is being used to survey a historic structure.

UNAVCO [42] describes the light detection and ranging technology, or LiDAR, as a remote sensing technique that determines the precise distance to an object by timing a laser beam reflected back from that object (Figure 3a). Terrestrial laser scanning (TLS) is a process to capture dense point clouds of objects using a ground-based LiDAR device (Figure 3b) [43]. To document a structure it will typically require multiple scans to be taken to provide complete coverage [44]. The captured scans are then processed in a specialty program through the steps of colorization and registration to create a single high-density 3D point cloud of the documented structure [45]. TLS is contact-free and can be used to develop, update, and compare BIM models [46]. TLS also has immediate applicability in HBIM development [10,47–50] (Figure 3c), providing researchers and facility managers the capacity to capture the existing condition of heritage structures and identify degradation over time with multi-temporal scans [37].



(**a**) (**b**) (**c**)

Figure 3. TLS and its application in HBIM: (**a**) principle of LiDAR technology (inspired by [51]); (**b**) a resultant point cloud of TLS survey; (**c**) an HBIM model developed from TLS point cloud.

Three-hundred-and-sixty-degree photography (also referred to as virtual tours) provides modelers the ability to verify existing conditions with point cloud data (Figure 4). This platform can be further used for convenient previews of cultural heritage and allows the public to "visit" the site, regardless of location and geographic boundaries. Within the context of public education and communicative purposes, this technology is widely used to present the visualization of cultural heritage [52]. Culturally sensitive artifacts or sensitive areas can be displayed and provide viewers with a unique vantage point that is otherwise inaccessible.

(a) (b)

Figure 4. Three-hundred-and-sixty-degree photography and immersive virtual tours: (**a**) a screenshot of a virtual tour of a historic courthouse; (**b**) capturing a virtual tour of the historic courthouse with a 3D camera.

2.3. HBIM Model Development

A typical framework of developing HBIM models using RC data is called "scan-to-BIM". This process involves the following stages: acquisition and processing of reality data; identifying LOD; creating parametric families and elements; correlation and mapping of parametric elements onto reality data; and integration of information with the model elements [37]. One of the main challenges in current HBIM implementation is the inability to quicky differentiate complex non-homogenous structural and architectural details [53]. Plata et al. [54] propose an HBIM workflow that uses UAV, terrestrial photogrammetry, and TLS to capture data for the development of an HBIM model of an inaccessible urban area. In an effort to streamline the tedious manual creation of parametric BIM objects representing built heritage, Andriasyan et al. [11] propose a workflow that automatically converts TLS and photogrammetric point cloud data into textured 3D meshes and objects to be included in the HBIM repository.

The most extensive method for HBIM development is manual, requiring labor-intensive work to reconstruct non-standard historic structural and architectural components [20]. One method to control the resources required to complete a HBIM program is identifying the appropriate Level of Development in the early stage of an HBIM program.

2.4. Level of Development (LOD)

The use of BIM requires the identification of the LOD for the information in the model at various stages of the facility's life cycle. The American Institute of Architects (AIA) currently identifies six levels of development, as shown in Figure 5 [55]. For standard BIM applications, this process begins at the pre-design phase and gradually builds on the data input for model elements through the final as-built models. Except in instances of facility expansion, the LODs associated with design are not applicable to built heritage. By its nature of dealing with existing structures, a LOD of 300 is considered the minimum standard for use in HBIM [31]. In the case of refurbishment projects, the HBIM should result in a LOD of 500 since the model must represent the "as-built" condition [56,57]. However, the challenges imposed by the lack of construction data, building material parameters, and architectural interventions over time on built heritage may reduce HBM practitioners' ability to achieve this standard. Similarly, the ability to use HBIM with the higher levels of development will be limited during the turnover process by the technical capabilities and resource constraints of the building management team. Comprehensive management of HBIM requires on-going input to represent the built heritage as it continues to receive updates. The general trend in BIM for heritage structures incorporates integration of laser scanning and photogrammetry to develop a textured point cloud that can be converted into a 3D model with the creation of parametric objects [36].

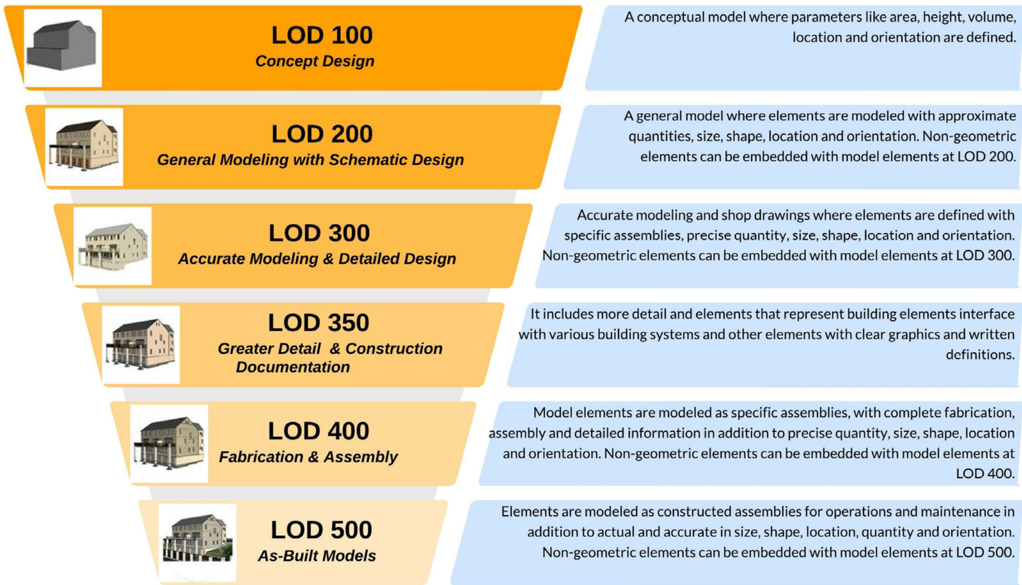


Figure 5. Levels of Development (LOD) for BIM as defined by the AIA (inspired by [58]).

Past studies propose an adaptation of the standard LOD definitions to HBIM, such as Castellano-Roman and Pinto-Perto's [59] five "Levels of Knowledge" (LOK) for HBIM. Heritage Scotland proposes three LODs applicable to HBIM, which range from standard CAD outputs (Level 0), data transferred to a 3D CAD environment (Level 1), and reality capture data used for parametric 3D modeling and collaboration (Level 2) [1].

2.5. Review of Published Case Studies: Curator Involvement and Primary Aims

Ewart and Zuecco's analysis of 52 HBIM case studies that were conducted before October 2017 concluded that there is a lack of clearly defined objective and structure for HBIM systems [60]. The results also established that most cases focused on solving technical challenges and offering proposed HBIM methodologies without seeking to understand the needs of assumptive stakeholders. Most pointedly, Ewart and Zuecco suggest that HBIM developers "do not know what HBIM is, who it is for, or why it would be used."

To obtain more up-to-date understanding of the implementation of HBIM, the researchers conducted a preliminary review of 26 HBIM case studies published between 2018 and 2022. The aim of the review is to identify primary HBIM applications and whether curators participated in the decision-making process. A literature search of Web of Science (WOS) was conducted, using the following specific keywords: case study, conservation, cultural, HBIM, heritage, historic, and restoration. Data from each case study was extracted to analyze the objectives of study, methods, results of the HBIM process, and if stakeholders were explicitly involved. Figure 6 shows the stated primary aims for each of the 26 HBIM case studies as a percentage of the whole.

The majority of case studies sought to apply preliminary HBIM frameworks to a specific field of research (e.g., structural decay of timber members, masonry analysis). A prominent trend is the development of an interactive 3D model from point clouds used in general conservation applications. Only 23% of the cases reviewed included explicit curator involvement. Specifically, Jordan-Palomar et al. proposed a BIMlegacy platform structure that enables non-technical stakeholders to participate actively in HBIM but does not address their input into the LOD selection [23]. Additionally, the current review corroborates the dominance of HBIM case study research in the Southern European countries of Italy, Spain, and Portugal, which comprise 65% of the cases as shown in Figure 7 [61]. None of these case studies were performed in the United States.

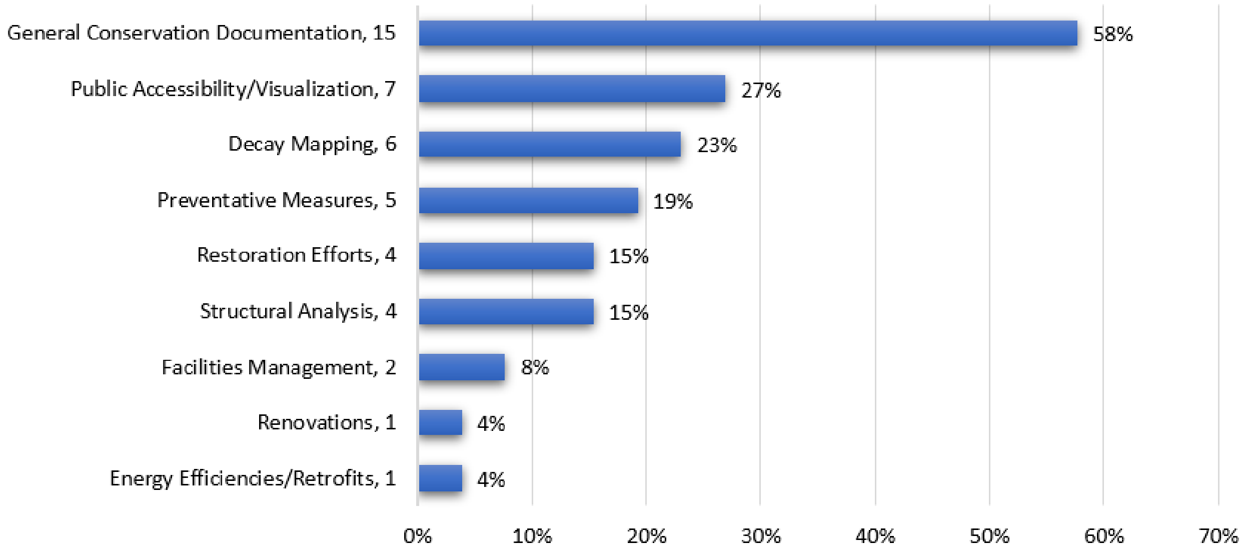


Figure 6. Frequency of primary objectives of 26 HBIM case studies published between 2018–2022. Note: Most cases have multiple objectives.

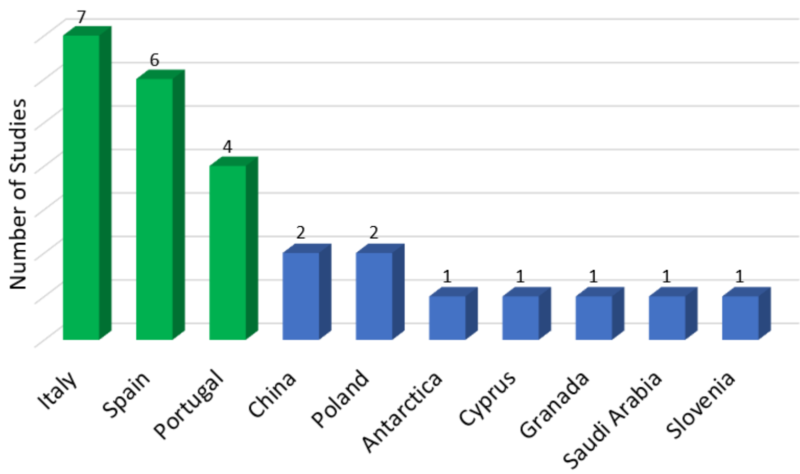


Figure 7. Location of 26 HBIM case studies published between 2018–2022.

HBIM programs require different resolutions of detail and information based on the needed application. The LOD should be driven by the real need of the data to avoid expending valuable resources for unnecessary data. The reviewed case studies present the diversified uses and applications of BIM technology. Although the potential benefits of HBIM have been sufficiently demonstrated, a link needs to be established between the proposed use of HBIM models with the necessary LOD required of the model. Further research is required to simplify HBIM protocol for the use and understanding of non-technical stakeholders, including building owners and curators [23]. The participation of curators and managers of built heritage plays a critical role in the early development of a HBIM workflow.

Academic pursuits in the application of BIM for built heritage continue to expand the potential benefits of HBIM. However, the adoption of HBIM in a practical sense is still limited, in part due to a poor understanding of the potential benefits by heritage stakeholders. HBIM has been a primarily academic endeavor demonstrating the potential uses of BIM. The relationship between stakeholder requirements and the implementation of HBIM has not yet been clarified. As HBIM becomes more common in the evaluation of built heritage, it is necessary to develop programs commiserate with the priorities and capabilities of end users. Early collaboration with heritage asset managers will help define parameters and prevent unnecessary expenditure of resources. One method to further this aim is the creation of LOD supplemental guidelines predicated on end user inputs, which drives the extent of reality capture and modeling efforts.

3. Materials and Methods

The research methodology is divided into five stages as adopted from the design science research methodology proposed by Peffers, Tuunanen, and Chatterjee [62], summarized in Figure 8. The "problem", or gap in knowledge, will be identified via a literature review and analysis of published HBIM case studies. Identification of this gap will assist in defining the objectives of the research. Data collection will include semi-structured interviews, study of original design and construction documents, review of archival records, observation of physical artifacts, and incorporation of reality capture program of the case study. Development of the proposed solution incorporates an analysis of interview responses to identify the top priorities of built heritage stakeholders in the context of common HBIM applications. The analysis will be used to develop a LOD supplement suitable for HBIM. Finally, the proposed LOD supplement will be validated in a case study and demonstrated in the creation of specific building elements. An internal evaluation of the results will provide insights into areas of improvement for future research.

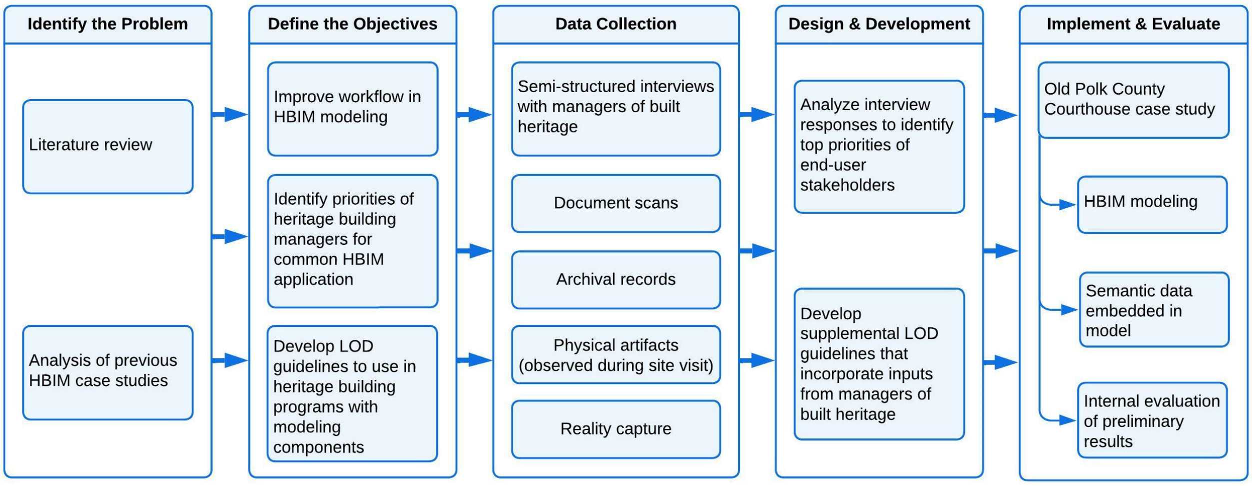


Figure 8. Research methodology and design.

3.1. Semi-Structured Interviews

This research utilizes semi-structured interviews with individuals responsible for the operations, maintenance, and preservation of built heritage of similar architectural style and of the same historic period. The fundamental aim is to understand input from tenants and conservators of built heritage in the decision-making process for the LOD and application of HBIM. Semi-structured interviews incorporate pre-determined questions that offer a focused structure for the discussion, while providing flexibility for participants' individual verbal expressions [63].

3.1.1. Interviewee Selection and Interview Format

Selection of interviewees focused on built heritage of similar use, architectural style, and historic significance within a localized geographic region. It was observed that an American architect, E.C. Hosford, designed and oversaw the construction of twelve courthouses in the states of Florida, Georgia, and Texas between 1908 and 1928. A review of Hosford's courthouse designs reveals an overlap of architectural elements. Moreover, eight of those courthouses were built by Mutual Construction Company of Louisville, Kentucky. The presence of multiple courthouses designed by the same architect and constructed by the same builder presents a unique opportunity to explore the repeatability of a HBIM library of parametric objects. Therefore, interviews were concentrated on individuals responsible for the maintenance and preservation of courthouses designed by Hosford. A total of seven individuals representing courthouses designed by Hosford were available for interviews. Three other historic courthouses in Florida were also selected for interviews based on similar architecture to supplement availability of interviewees. Therefore, a total of ten interviews were conducted. Table 1 identifies all ten courthouses selected for this research. Due to the geographic range of the selected historic structures, all interviews were conducted virtually.

3.1.2. Interview Questions

Based on the findings from the literature reviuew and the review of published HBIM case studies, the researchers have developed a set of eight interview questions to gain an understanding of the priorities of historic building managers in the operations and preservation of their facilities, their expected functionality of an HBIM program, and funding sources for the implementation of such program. A total of eight primary questions were posed, with follow-up and open-ended questions that provided a degree of flexibility to the discussion [64]. Areas of specific interest include determining tenants' prioritization of maintaining their facilities, identifying the availability of resources to support and maintain an HBIM repository, and whether end users feel involved in the managing process. A list of these questions and interviwees' answers are included in the next chapter.

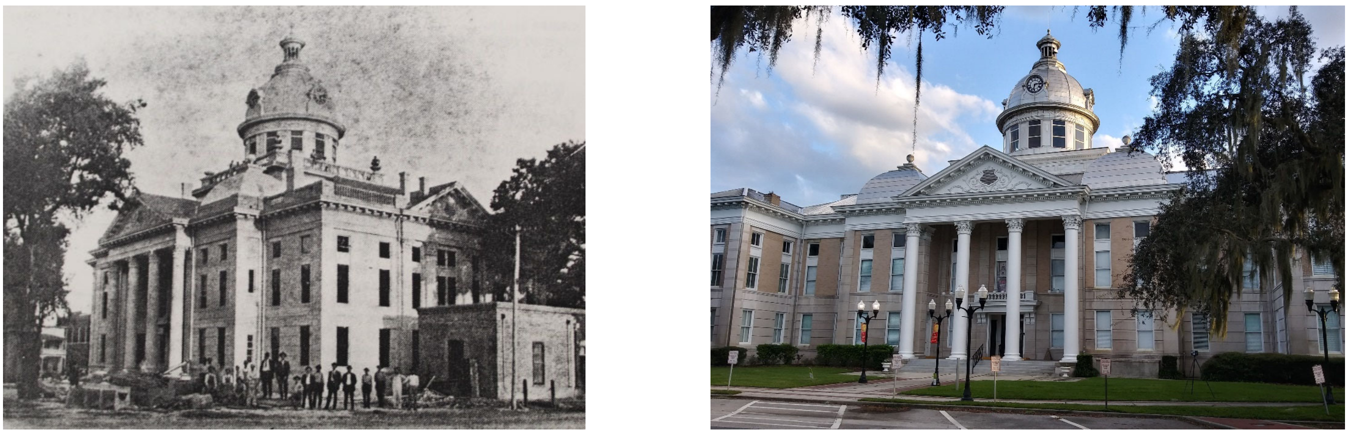
3.1.3. Analysis of Interview Responses

Interview responses were analyzed for general trends of the top priorities of heritage building managers. This analysis was then used to correlate tenant priorities with established definitions of LOD designations to a HBIM platform based on the model use, which was validated in a case study.

3.2. Case Study

3.2.1. The Project: Old Polk County Courthouse

As illustrated in Figure 9 the Old Polk County Courthouse (OPCC) was selected for implementation of the proposed LOD guidelines. This Neo-classical Revival style courthouse was designed by E.C. Hosford and constructed by Mutual Construction Company between 1908 to 1909. This building was the judicial center of Polk County, Florida until 1987 [65,66]. The building's east and west wings were added in 1926, expanding its total square footage to 50,000 square feet (4645 square meters) [67,68]. The OPCC was listed in the National Register of Historic Places in the year 1989, and then it underwent two major renovations between 1993–1996 before becoming the Polk County History Center.



(**a**) (**b**)

Figure 9. The Old Polk County Courthouse (OPCC): (**a**) workmen stood next to the newly completed courthouse in 1909 [69]; (**b**) present-day view of the building.

Table 1. The ten historic courthouses selected for review. Seven of the courthouses were designed by E.C. Hosford between 1908–1926. Six of the courthouses were built by Mutual Construction Company of Louisville, KY.

	**Property:** Old Calhoun County Courthouse * **Location:** Blountstown, FL **Year Built:** 1904 **Architectural Style**: Romanesque Revival **Architect:** Smith **Current use:** Sheriff Off.		**Property:** Suwannee County Courthouse * **Location:** Live Oak, FL **Year Built:** 1904 **Architectural Style**: Romanesque Revival **Architect:** Smith **Current use:** Courthouse
	**Property:** Old Baker County Courthouse **Location:** Macclenny, FL **Year Built:** 1908 **Architectural Style:** Colonial Revival **Builder:** Mutual Const. **Current use:** Library		**Property:** Jefferson County Courthouse **Location:** Monticello, FL **Year Built**: 1909 **Architectural Style:** Neo-classical Revival **Builder:** Mutual Const. **Current use:** Courthouse
	**Property:** Old Polk County Courthouse **Location:** Bartow, FL **Year Built:** 1909 **Architectural Style**: Neo-classical Revival **Builder:** Mutual Const. **Current use:** Museum		**Property:** Lafayette County Courthouse **Location:** Mayo, FL **Year Built:** 1909 **Architectural Style**: Neo-classical Revival **Builder:** Mutual Const. **Current use:** Courthouse
	**Property:** Mason County Courthouse **Location:** Mason, TX **Year Built:** 1909 **Architectural Style**: Classical Revival **Builder:** Mutual Const. **Current use:** Courthouse		**Property:** Glasscock County Courthouse **Location:** Garden City, TX **Year Built:** 1909 **Architectural Style**: Neo-classical Revival **Builder:** Mutual Const. **Current use:** Courthouse
	**Property:** Old Citrus County Courthouse * **Location:** Inverness, FL **Year Built:** 1912 **Architectural Style**: Neo-classical Revival **Architect:** MacEachron **Current use:** Museum		**Property:** Old Hendry County Courthouse **Location:** LaBelle, FL **Year Built:** 1926 **Architectural Style**: Mediterranean Revival **Builder:** Marshall-Jackson Company **Current use:** Vacant

* Courthouses not designed by E.C. Hosford.

3.2.2. Case Study Methodology

The focus of this case study is to incorporate the proposed LOD guidelines based on an analysis of tenant priorities to develop appropriately detailed parametric objects representing certain building elements of the OPCC. The purpose of the HBIM program will be determined by incorporating the stated aims and resource requirements of the building management team. As illustrated in Figure 10, the framework of this case study includes planinng, data acquisition, data processing, development of modeling parameters, model development, and implementation of HBIM.

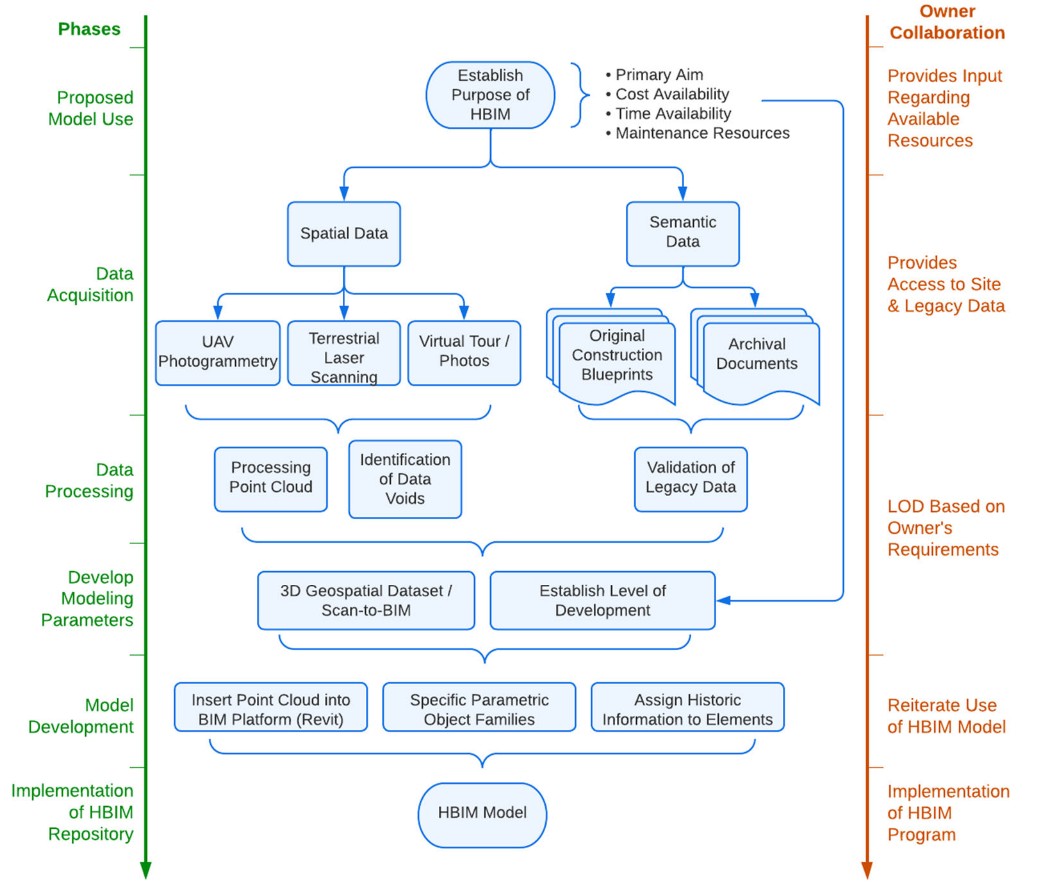


Figure 10. Methodology used in the HBIM program case study of the OPCC.

4. Results and Discussion

4.1. Qualitative Data Results from Semi-Structured Interviews

4.1.1. Interviewee Backgrounds

Ten individuals with roles and responsibilities regarding the operations, facilities management, or restoration of historic county courthouses were interviewed for this research. Nine of the ten interviewees are county employees serving in the role of public works director, facilities management director, county manager, clerks of court, deputy clerk of court, museum director, or judge. Interviewee #1 holds a joint appointment of public works director and facilities management director. Interviewee #7 is a project manager at a private company specialized in professional construction and renovation services for historic preservation projects.

4.1.2. Interview Question Results

Each of the ten interviews was held via Zoom or phone teleconference and then digitally transcribed. Interview transcripts were proofread and revised for added accuracy. Qualitative color coding (QCC) was performed for each interview transcript to derive themes and patterns from the analysis. QCC is an important tool for turning the raw qualitative research data into a more communicative and reliable format for the audience [70]. This process involved generating a series of codes created through non-numerical key words or phrases, including the following broad codes: staffing, training/software, knowledge limitations, funding, data maintenance, role/responsibility, population, perceived benefits of HBIM, and facility priorities. A thematic analysis further examines the responses to determine their similarities and differences. The results of each question are presented, analyzed, and discussed below.

Question 1: What are the primary issues with the operations, maintenance, and/or preservation of your facility?

This question was posed to determine the current primary issues with each of the historic facilities, which could then lead to investigating the potential use of HBIM in correcting the most important problems. As seen in Figure 11, the three primary problems raised by stakeholders are Mechanical Electrical Plumbing (MEP) systems, water intrusion, and issues caused by limited funding.

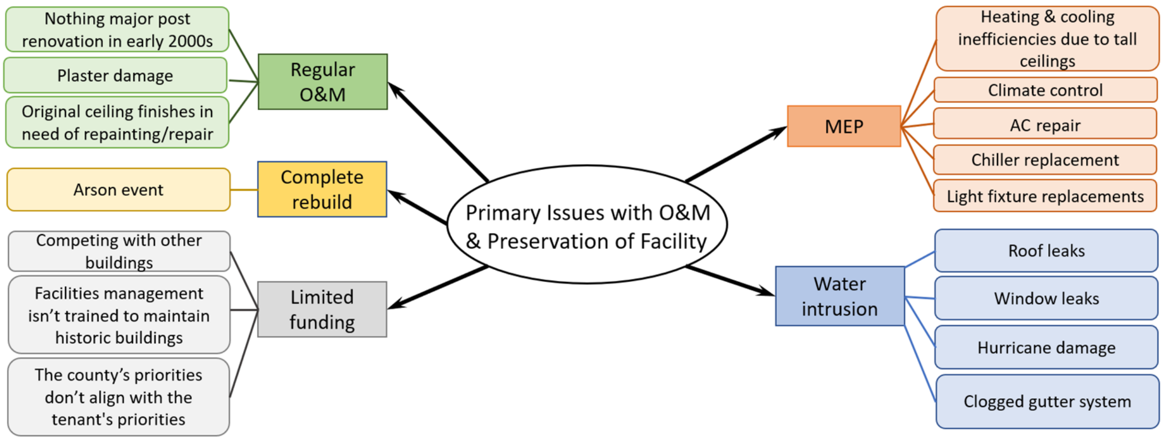


Figure 11. Results to interview question #1: primary issues with O&M and preservation of the historic courthouses.

Question 2: What is your organization's prioritization process to determine needs assessments and allocation of resources?

This question was used to determine how curators typically distribute their resources. As shown in Figure 12, most respondents stated that the prioritization process is based on immediate needs and within the funding limits of the local government. All ten interviewees mentioned a heavy reliance on state funding sources (grants, appropriations, and other state funding sources) to perform major repairs/restoration efforts. In general, respondents stated there is significant time and resources required to apply for these state funding programs. Interviewees #1 and #3 mentioned a purposeful prioritization based on building system importance, starting with ensuring structural integrity, followed by "drying-in" the facility and finally interior and exterior cosmetics.

Question 3: Have you been involved in previous renovation/preservation efforts? If "yes", have you felt included in the decision-making process?

This question was used to identify the extent of interviewees' involvement in previous renovation efforts and whether they have felt included in decision-making. As shown in Figure 13, 80% of interviewees have experience in previous renovation/preservation efforts related to the historic courthouse under their responsibility. Seven of the eight individuals who responded in the affirmative are county employees. One is an experienced project manager acting as the county's representative for the rebuild of their facility after an arson event reduced the building to its exterior load-bearing masonry walls. Two respondents who do not have prior experience stated this is due to the short tenure in their current position. All interviewees involved in previous renovation/preservation efforts stated they felt included in the decision-making process. However, in a follow-up question about their particular role in the process, it was determined that the majority of their involvement related to contracting, review of proposals, and selecting contractors. As HBIM becomes more common, it is critical to include building managers centrally into the HBIM process through the use of LOD guidelines and other practices.

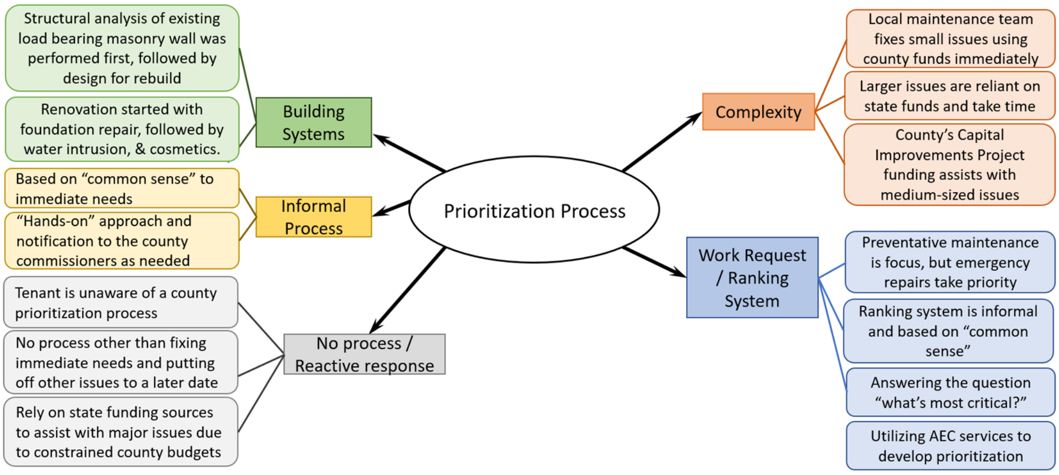


Figure 12. Results to interview question #2: organization's prioritization process.

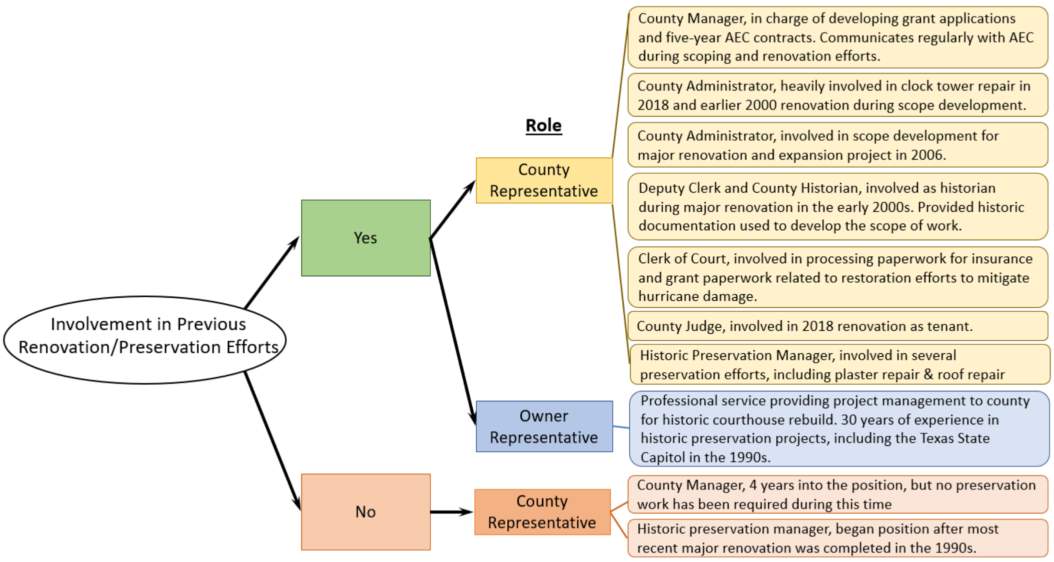


Figure 13. Results to interview question #3: involvement in previous renovation/preservation efforts.

Question 4: What is your organization's process for managing the following?

- Conservation Documentation
- Public Accessibility/Visualization
- Preventative Measures
- Facilities Management
- Decay/Degradation Mapping
- Structural Analysis
- Energy Efficiency Retrofits
- Renovation/Re-use
- Restoration

The purpose of this question was to identify commonalities and differences in the data management techniques of built heritage proprietors. Responses were used during analysis and development of the proposed HBIM supplement to LOD guidelines as a way to address inefficiencies or absence of data management for the categories listed in this question. The results, as shown in Figure 14, reveal common data management methods adopted by the built heritage managers.

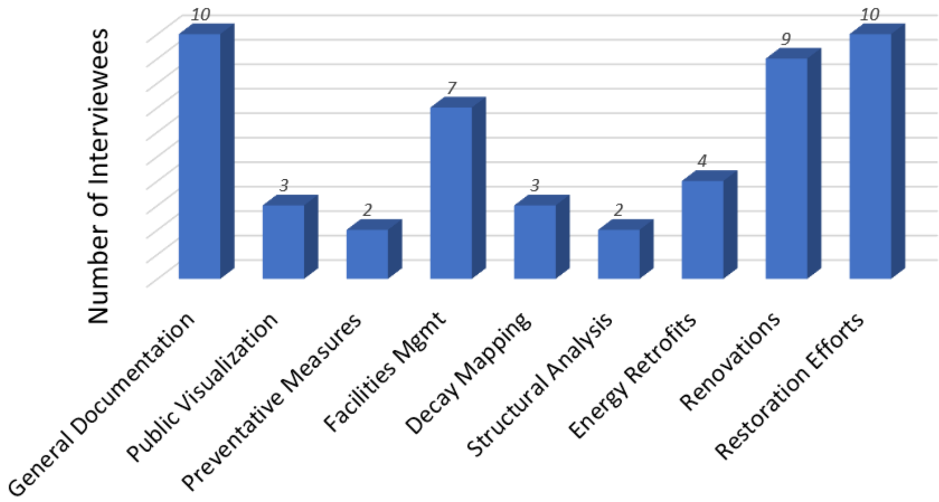


Figure 14. Results to interview question #4: data management techniques.

All ten courthouses have some form of data management for general conservation, renovation, or restoration data. The management method is limited to maintaining paper and/or electronic copies of drawings and specifications upon completion of projects. None of the interviewees indicated the documentation is used in a technical sense to sustain on-going operations and maintenance of their facilities. In terms of public accessibility or visualization, only three respondents offer such programs in the form of periodic public tours or with informational plaques and other visuals of the historic courthouse. The remainder of respondents do not currently provide a public accessibility program, although three respondents acknowledged a desire to do so in the future.

Only two respondents acknowledged a method of tracking and developing preventative measures for their respective courthouses with a formal process. Seven courthouses have a method to track facilities maintenance, through either a formal work order process or informal procedures. The other three courthouses lack such a program due to budget and staffing limitations. Three respondents stated they maintain some form of decay mapping to track existing damage over time until it is repaired. Their damage tracking and monitoring methods include using periodic inspections by their own staff and coordination with staff and facilities management team from the county. The remaining seven interviewees cited a lack of such processes due to staffing and technical limitations. Only two courthouses have established a structural analysis data management program via maintaining paper and electronic copies of completed building structural assessments. Four interviewees identified management of energy efficiency retrofits for their facilities as either maintaining copies of completed retrofit construction plans and specifications or copies of preliminary energy efficiency reports for potential future use.

Question 5: Have you heard of Heritage Building Information Modeling (HBIM)? (If the answer is "no," the interview guide provided a definition of HBIM)

This question was posed to determine awareness of HBIM, which could then lead to investigating how to better advocate for the benefits of HBIM for smaller, regional historic facilities. The responses to this question, as shown in Figure 15, reveal an overwhelming lack of knowledge or application of HBIM, or BIM in general. The interviewee of the Old Polk County Courthouse is only aware of HBIM due to the researcher's previous reality capture site investigation. The project manager assisting in the rebuilding of another courthouse acknowledged that he commonly uses BIM for his company's projects involving new construction. However, in a follow-up question about his experience using BIM in historical facilities, he stated that he has never incorporated BIM in preservation/restoration projects of historic structures. This result clearly shows a lack of awareness of HBIM/BIM among the built heritage managers.

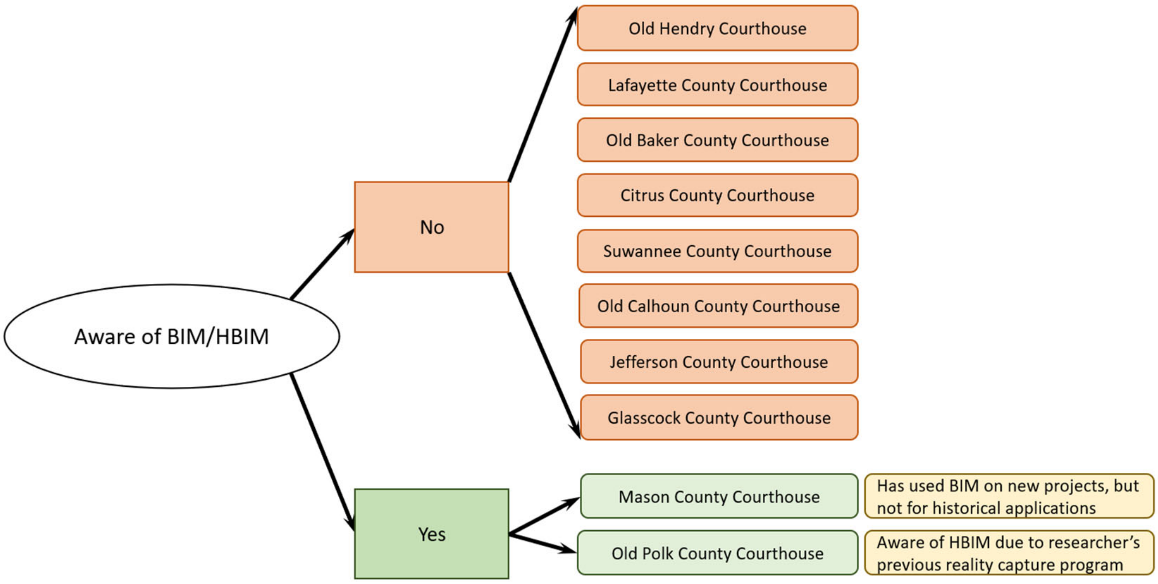


Figure 15. Results to interview question #5: awareness of BIM/HBIM.

In order to provide the respondents who had not heard of the discipline or its corresponding technology with basic knowledge of HBIM, the researcher presented a definition and explanation of the technology, a couple of use cases, and discussed the benefits and limitations of the technology.

Question 6: Identify the primary benefits of having access to a HBIM repository of your facility:

- Conservation Documentation
- Public Accessibility/Visualization
- Preventative Measures
- Facilities Management
- Decay/Degradation Mapping
- Structural Analysis
- Energy Efficiency Retrofits
- Renovation/Re-use
- Restoration

The goal of this question was to determine stakeholders' top perceived benefits of HBIM for their facility to determine if there is a discrepancy between these benefits and the current practice for HBIM research as addressed in the literature review. As shown in Figure 16, the top two perceived priorities of a HBIM repository recognized by the interviewees include general conservation documentation and preventative measures. Compared with the primary objectives of the case studies discussed in the literature review (Figure 16), stakeholders' priorities are more diverse than current academic pursuits in the application of HBIM, which favors general conservation documentation and public visibility. However, the general theme among interviewees is a lack of funding, staffing, and technical capability. These limitations may prevent the ability of small, rural jurisdictions from implementing an HBIM program for their respective courthouses.

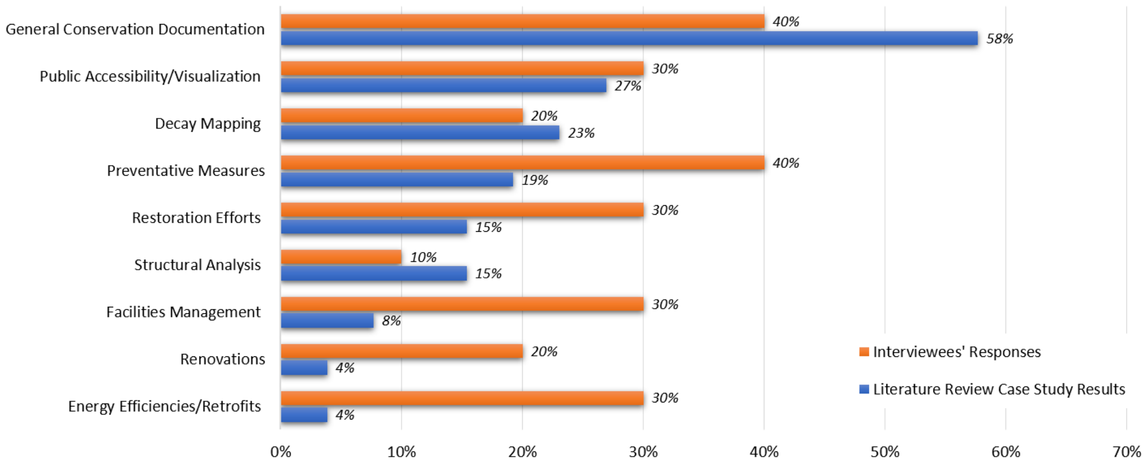


Figure 16. Interviewees' primary perceived benefits of HBIM vs. the primary objectives identified in the 26 published HBIM case studies. Note: Interviewees were allowed to select multiple benefits.

Question 7: What resources are available to you for funding initial data acquisition and modeling associated with an HBIM repository?

This question was utilized to establish common resource channels to support the implementation of an HBIM program, which is useful for researchers to assist clients with the pursuit of funds. The responses to this question, as shown in Figure 17, reveal resource constraints due to the small tax bases of rural counties and a heavy reliance on state funding to supplement county budgets. Nine of the respondents mentioned the small size of their county, limited staff, and limited funding to support the resources required for initial HBIM data acquisition. Only one of the interviewees mentioned a county initiative to plan, budget, and execute a GIS and BIM program for their historic county facilities. A useful insight was provided by interviewee #7, the project manager for the rebuilding of the Old Mason County Courthouse, which has a population of less than 2000 people. During the interview, he discussed the difficulty of small, rural counties maintaining regular operating budgets, much less maintaining a technically complex BIM repository. He contrasted these rural counties with his leading role in the restoration of the Texas Capitol, where the agency in charge of maintaining the Texas Capitol has significant personnel and budget resources to keep a robust BIM repository.

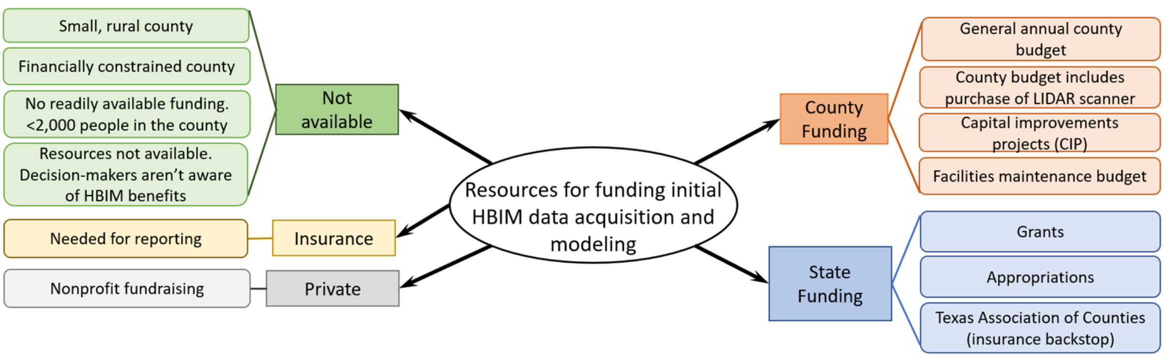


Figure 17. Results to interview question #7: resources for implementation of an HBIM program.

Question 8: What resources do you have to support continued upkeep of a HBIM repository? (i.e., trained personnel, software, funding)

The purpose of this question was to understand stakeholders' abilities to sustain the technical knowledge and software licenses required to maintain a HBIM repository. Like the responses to Question #7, the majority of respondents cited a lack of local staffing, funding, and technical expertise to properly maintain a HBIM repository (Figure 18). Two respondents identified difficulties attracting and retaining younger, more technically savvy professionals to maintain advanced software programs or IT departments. Only one county has existing plans and budget to support an initial laser scanning program to supplement their GIS department, which includes a dedicated staff trained in GIS software. This is the same county as mentioned in the previous question which has an initiative to implement GIS and BIM. One other respondent stated their county outsources their GIS and technical capabilities, where a hypothetical HBIM repository could be managed if developed in the future.

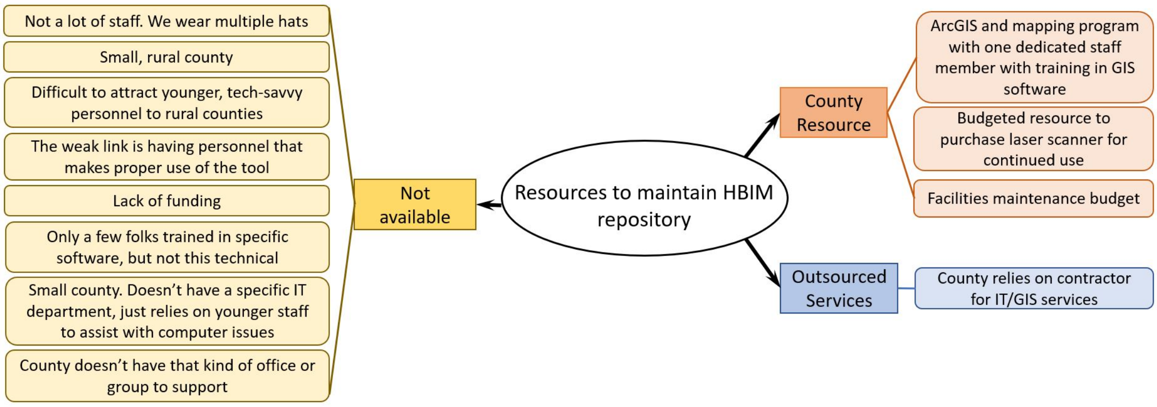


Figure 18. Results to interview question #8: resources to maintain a HBIM program.

4.1.3. Qualitative Data Analysis and Discussion

Thematic analysis was performed to analyze interviewees' responses for similarities and differences. The primary themes that emerged from this analysis include funding, staffing and technical limitations, and trade shortage.

The sources and limitations of funding to support the operations, maintenance, and preservation of the historic courthouses were a recurring topic of discussion among interviewees. All ten interviewees mentioned a heavy reliance on state grants to accomplish efforts beyond routine facilities maintenance. With populations ranging from only 2000 residents (Mason County, TX, USA) to 725,000 residents (Polk County, FL, USA), the small population size and resulting tax base limit availability of county funds. Three interviewees cited a feeling of competing priorities with other county stakeholders to receive requested facilities management. All respondents stated that some form of state or federal funding would be required to pursue a HBIM program and future preservation efforts for their courthouse. As shown in Figure 19, the term "grant" and "state funding" were mentioned a total of 49 times, equating to over 63% of funding terms used.

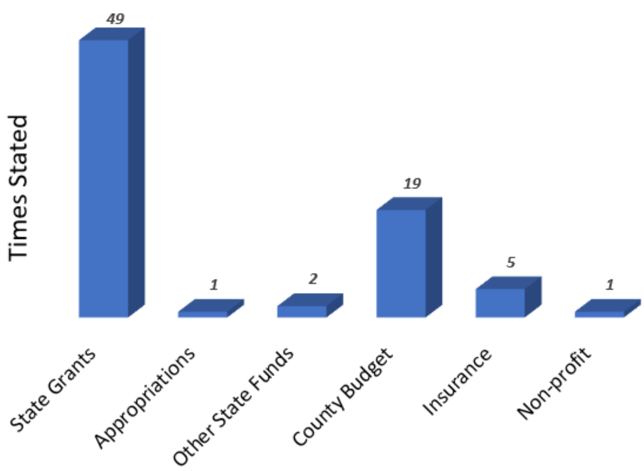


Figure 19. Funding terms used during interviews.

Similar to the funding constraints cited, staffing is another resource constraint to HBIM implementation for historic structures in small, rural counties. All ten interviewees mentioned insufficient staff are available to maintain an HBIM program. Interviewees used phrases like "wearing multiple hats" and "multiple roles/positions" to describe how their county management staff currently operates. The effects of limited funding result in an inability to hire dedicated staff to operate and maintain a comprehensive HBIM repository. A repeated theme of technical constraints was also observed across several interviews. County facilities management groups are the primary source of operations and maintenance of the historic courthouses for normal operating procedures. An unanticipated theme that emerged from the interviews is an on-going stakeholder concern over dwindling trade expertise for historic preservation. Three interviewees mentioned a lack of qualified companies and tradesmen to perform historic preservation and restoration. This theme reveals a larger issue for the general historic preservation discipline.

The main findings of the primary themes that emerged from this analysis are that government funding programs are commonly used for larger preservation efforts, and local staffing is not sufficient to maintain an HBIM program due to funding and technical capabilities. Additionally, a shortage of trades specializing in historic preservation efforts are increasing the difficulty in achieving preservation goals.

4.2. HBIM Supplement for LOD Guidelines

Based on the findings from the literature review and the semi-structured interviews, the researcher proposes an HBIM supplement for standard BIM LOD guidelines to incorporate built heritage stakeholders' priorities. Sequential to establishing stakeholder priorities, this supplement can assist users in understanding the required equipment, technology, costs, and other resources needed to establish the appropriate complexity of the HBIM program. The intent of this supplement is to appropriately size the scale of the HBIM effort and make the best use of limited resources. Utilizing this approach may provide an increased stakeholder interest in advocating for the use of HBIM programs in smaller regional and local built heritage. These proposed guidelines, as shown in Figure 20 includes five levels of development: visual representation, general model, advanced model, complex model, and global facilities management.

4.2.1. Visual Representation

Based on the interview responses, resource constraints remain an obstacle for many historic facility managers from utilizing HBIM. The proposed "Visual Representation" supplement to LOD 100 provides a budget-friendly adaptation of an HBIM repository. Public accessibility and visualization can be achieved by following the HBIM "Visual Representation" supplement to LOD 100. Initial data acquisition using TLS, photogrammetry, and/or a 3D immersive virtual tour provides the minimum data needed to accomplish this application. The resulting 3D model is not categorized and does not incorporate parametric objects. The combination of the model and virtual tour can be applied to a variety of uses, including virtual visits and development of informational and interpretational programs. Due to the limited modeling maintenance after the initial reality capture program, this LOD is considered the least resource intensive for implementation.

4.2.2. General Model

Expanding upon the Visual Representation model uses, the "General Model" supplement to LOD 200 incorporates modeling of main building elements such as walls, floors, roofs, and ceilings. Based on the interview results to Question 4, this model development can be used as a standardized approach to maintain general conservation documentation during the development, performance, and record-keeping of previous preservation efforts. Although this LOD requires more initial resources to develop the model, it could be marketed as a highly accurate, secure, and efficient baseline for archiving general conservation documentation.

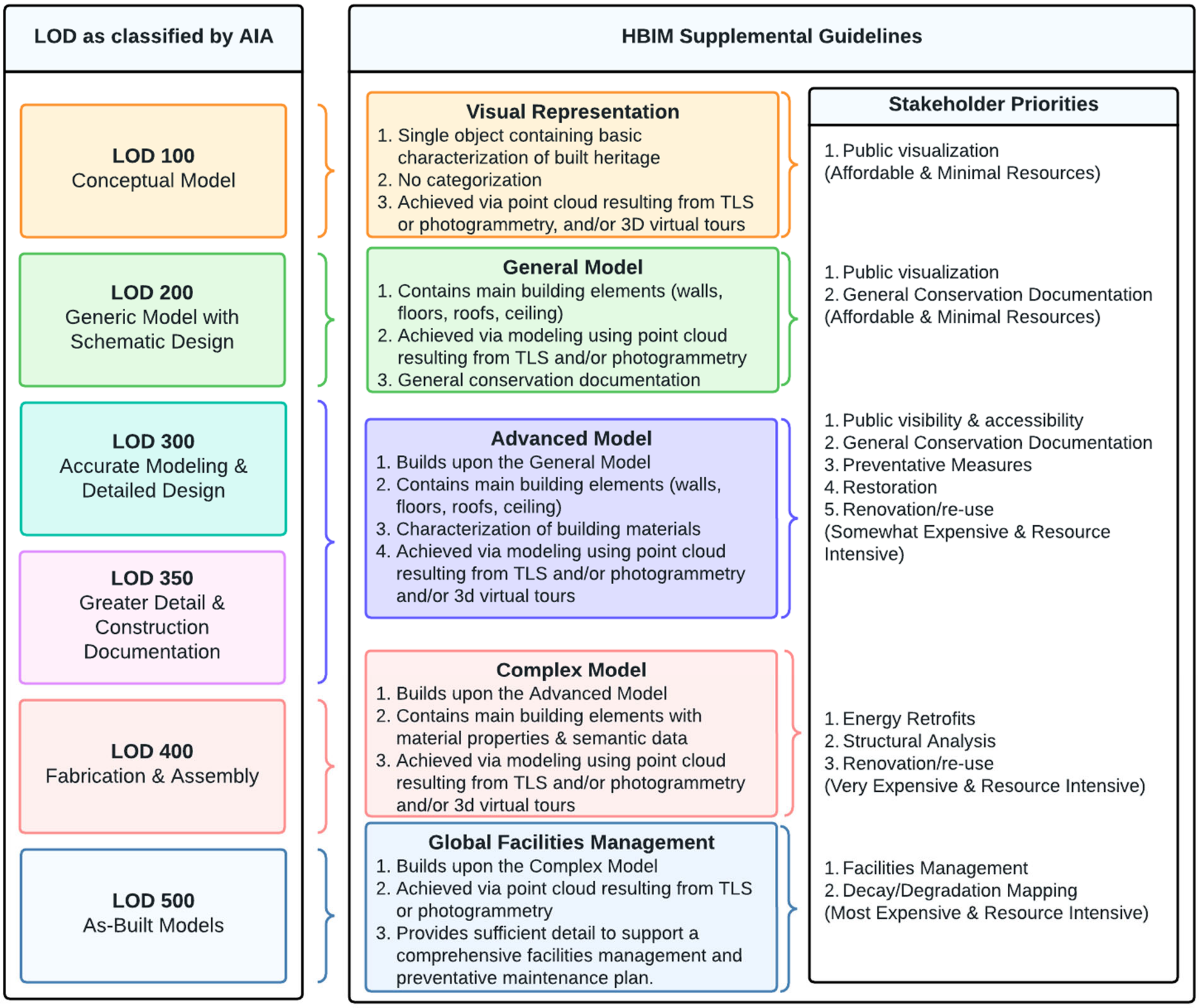


Figure 20. Proposed HBIM supplement for LOD Guidelines.

4.2.3. Advanced Model

In general BIM application for new design and construction projects, LOD 300 results in an accurate model with detailed design. LOD 350 provides greater detail and incorporates construction documentation as construction commences. Since HBIM is used for existing structures post construction, the "Advanced Model" correlates HBIM applications with both LOD 300 and LOD 350. This model development includes characterization of main building elements and finishes that provide a baseline for preventative measures, restorations, and future renovations. Due to the increased resources required to manually model unique historic building elements, this model supplement could be promoted as a necessary element in major preservation/renovation efforts for historic structures. Specifically, this model development could be incorporated as a feature in cost estimates for state or federal grant applications. Once the Advanced Model is created, it could be updated during future preservation efforts without the need for local staff to maintain the database on a recurring basis. This LOD provides a resource for preventative measures, public accessibility, general conservation documentation, restoration efforts, and renovations. This represents the interviewees' top perceived primary benefits of having access to a HBIM repository.

4.2.4. Complex Model

The "Complex Model" correlates to LOD 400 and represents the incorporation of material properties and semantic data to the model. Structural analysis and deformation are incorporated at this LOD. Due to the increasing funding and resource requirements to maintain the Complex Model, this LOD is anticipated to be best utilized for large scale renovations or rebuilding efforts with sufficient resources to maintain the HBIM repository on a recurring basis at the local level.

4.2.5. Global Facilities Management

The "Global Facilities Management" model meets the intent of developing a "digital twin" of built heritage. This LOD supplement requires the greatest extent of resource expenditure to (1) develop the digital twin model, and (2) maintain and use the model to support regular facilities management. This LOD fully models all building and mechanical systems with integrated facilities related control systems. Decay mapping is achieved through a baseline level of known damage, with recurring mapping efforts to analyze changes to building decay zones. This LOD supplement requires the most extensive use of resources to create and maintain the HBIM repository. Based on the interview results, this LOD is primarily achievable only for historic preservation programs with robust funding and technically trained and dedicated staffing.

4.3. Case Study-Old Polk County Courthouse

The HBIM supplement for LOD guidelines was validated in a limited capacity for the OPCC to demonstrate its application for the stated aims and resource requirements of the building management team.

4.3.1. Data Acquisition

A reality capture (RC) program was performed by the researchers in support of a preliminary HBIM investigation of the OPCC. Semantic data was also acquired through a review of original construction documents, archival docments, and observation of physical artifacts.

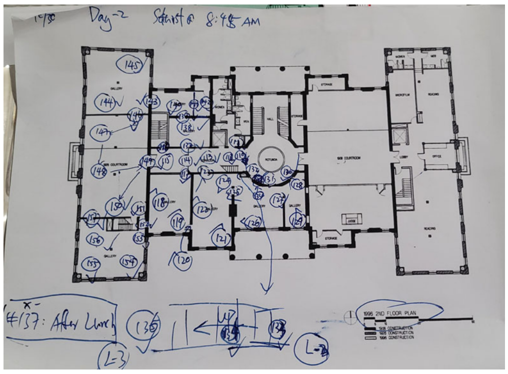
Reality Data Capture. The RC program was performed in late 2021 utilizing the following technological tools:

- TLS LiDAR. Captures high-density point clouds and panoramic photos of the building;
- UAV aerial photogrammetry. Complements the TLS scans and captures the condition and details of the roof;
- 360-degree photography. Provides an immersive virtual tour to assist with developing the HBIM model.

The TLS scanning took approximately 13 h with two LiDAR scanners: a FARO Focus3D X130 HDR and a FARO Focus S-350. A total of 241 scans of both interior surfaces and exterior facades of the OPCC were captured (Figure 21a). Scanning was performed using a medium resolution setting (12 million–28 million points captured by each scan) with a field of view of 360° horizontally and 270° vertically. Panoramic photographs were also captured for colorizing the points. Each scan lasted about seven minutes on average, including setting up scan station, laser scanning, and capturing panoramic photographs. Field notes were taken to track scan locations for post-processing (Figure 21b).

UAV photogrammetry was conducted using a DJI Mavic Pro-2 drone (Figure 22a). Utilizing a mobile app named DJI Pilot, five flight routes were pre-programmed (Figure 22b) to document the building at an elevation of 150 feet (45.7 m). 200 photos of the courthouse were taken from a 90° bird's-eye view. Another 750 photos were captured at a 60° oblique angle.

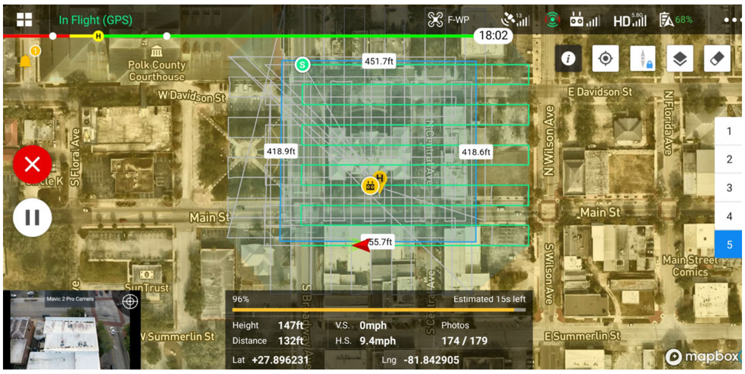
(a)



(b)

Figure 21. TLS survey of the OPCC: (**a**) laser scanning from the 3rd floor balcony of the 1908 courtroom; (**b**) field notes maintained to corroborate scan locations.

(a)



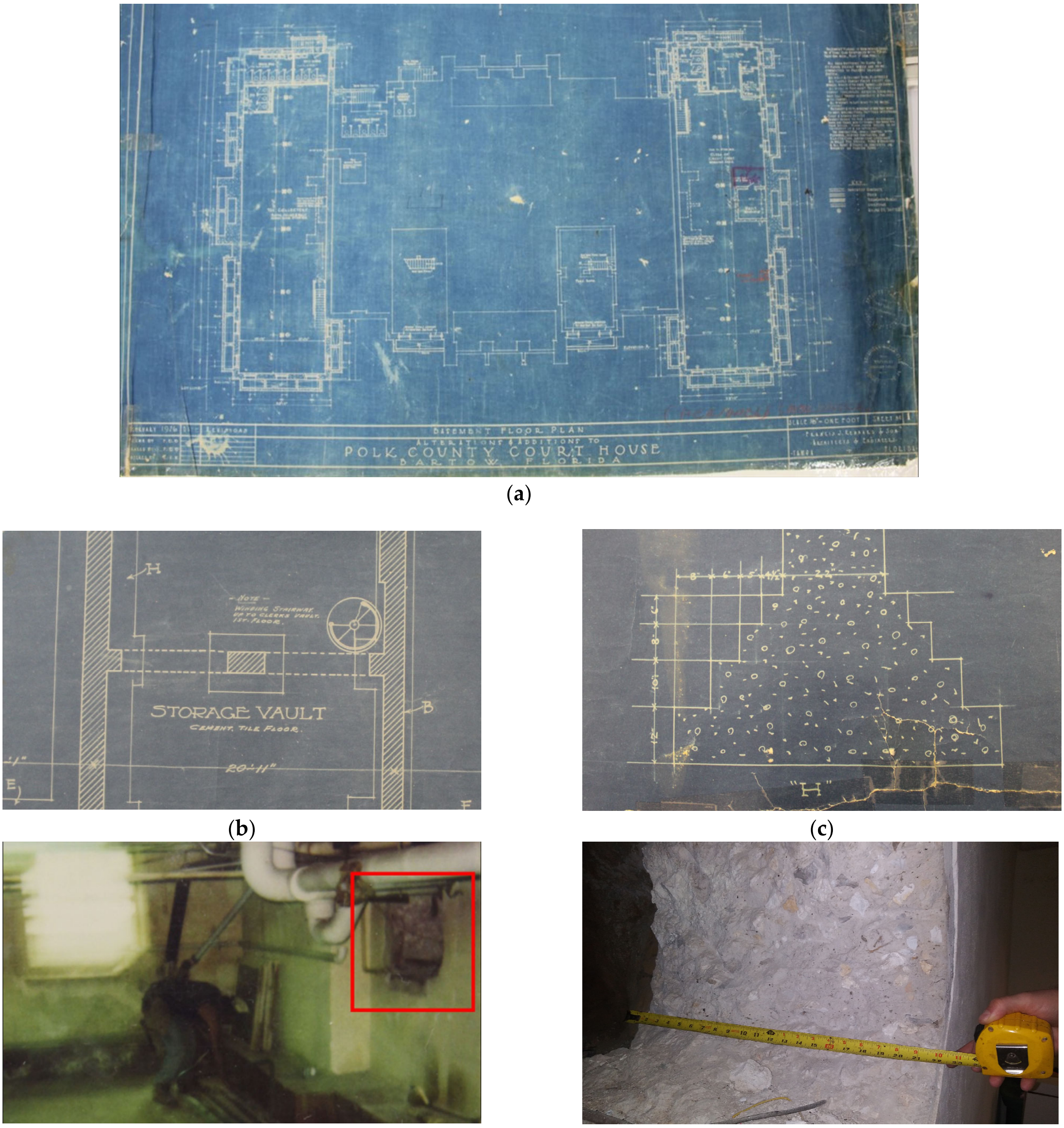
(b)

Figure 22. Capturing aerial photos of the OPCC with an UAV: (**a**) a DJI Mavic Pro2 UAV taking off to capture aerial photos; (**b**) the pre-programmed UAV flight routes.

The acquisition of a 360-degree immersive virtual tour was performed using a Matterport Pro2 3D Camera in one half of a day (Figure 23). This tour includes 470 scans and covers the entire area of the first and second levels, and the 1908 courtroom balcony as a part of the third level.

Figure 23. Capturing 360-degree photos to create a virtual tour of the OPCC with a Matterport Pro2 3D camera.

Semantic Data Capture. Both legacy and metric data of the OPCC was gathered during site visits. The legacy data included digital copies of the original 1908 construction blueprints (Figure 24a), the 1926 expansion blueprints, digital copies of photos from the early 1900s, and articles related to the original and expanded OPCC configurations. It also included a firsthand account of building materials by the superintendent of construction for the original 1908/9 construction [71], which would provide valuable insight into the existing building texture that can be integrated into parametric objects for model development. Analog surveys were also conducted to capture metric data of building materials and construction methods for the verification against legacy and RC data. Figure 24 shows the combination of legacy data (Figure 24b,c) and field measurements (Figure 24d,e) to validate the designed wall thickness against the actual wall thickness.

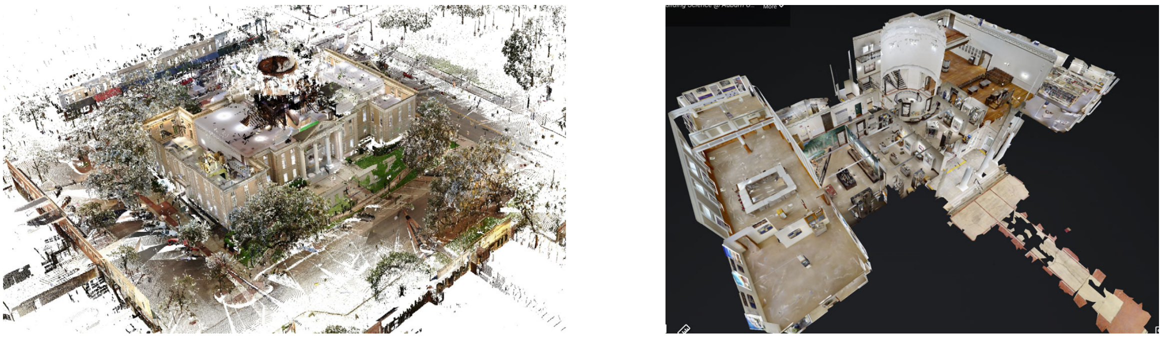


(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 24. Semantic data capture of the OPCC: (**a**) basement floor plan of the original 1908 blueprints; (**b**) 1908 blueprint of southeast basement wall; (**c**) 1908 blueprint of Type-H foundation with 22 in (0.56 m) wall; (**d**) 1995 renovation showing exposed wall section; (**e**) measurement of the constructed wall section.

4.3.2. RC Data Processing

Processing of the RC data resulted in a high-resolution point cloud (Figure 25a) and an immersive virtual tour (Figure 25b). Data voids were also identified in certain areas of the facility. The area to be modeled in this case study focuses on the original 1908 courtroom located on the second story, which has a high degree of representation in the captured RC data.



(**a**) (**b**)

Figure 25. Processed RT data of the OPCC: (**a**) TLS point cloud consisting of approximately 1.8 billion points; (**b**) "doll-house" view of the immersive 3D virtual tour.

4.3.3. Development of Modeling Parameters

Upon review and disscusson of the proposed HBIM LOD guidelines with the OPCC building management team, the researchers identified three primary aims of a hypothetical future HBIM program. These aims are as follows:

- Public visualization/accessibility;
- General conservation documentation;
- Decay mapping.

4.3.4. Model Development

A partial HBIM model focused on the 1908 courtroom of the OPCC was created to incorporate the identified primary aims of the HBIM program. During the model development phase, the point cloud was inserted into a BIM platform (Autodesk® Revit). Specific parametric objects were created to demonstrate the proposed LOD supplemental guidelines based on the intended application. These elements include interior walls, exterior walls, floors, and cast iron interior columns. Integration of historic information to the elements further demonstrate the use of HBIM for historic preservation.

Public Accessibility/Visualization. Public accessibility and visualization can be achieved by following the HBIM "Visual Representation" supplement to LOD 100. Initial data acquisition using TLS (Figure 26a), UAV photogrammetry (Figure 26b), and a 3D virtual tour (Figure 26c,d) provides the data needed to accomplish this application. The resulting 3D model is not categorized and does not incorporate parametric objects. The combination of the model and 3D virtual tour can be applied to a variety of uses, including virtual site visits and development of informational and interpretational programs.

General Conservation Documentation. General conservation documentation is achieved using the "General Model" supplement to LOD 200, which incorporates main building elements and includes attachments with relevant conservation documentation. The main building elements of the 1908 courtroom were developed in Revit to illustrate the extent of modeling for this LOD supplement. Using the accurate TLS point cloud, the highly detailed 3D virtual tour, and the original 1908 blueprints, the general features of interior walls, floor, doors, windows, and ceiling were developed (Figure 27a,c). The floor structure for the 1908 courtroom was developed using the 1908 blueprints (Figure 27b). Conservation documentation, consisting of the 1908 blueprints and renovation photos from the 1990s, was incorporated with the HBIM repository as shown in Figure 27d.

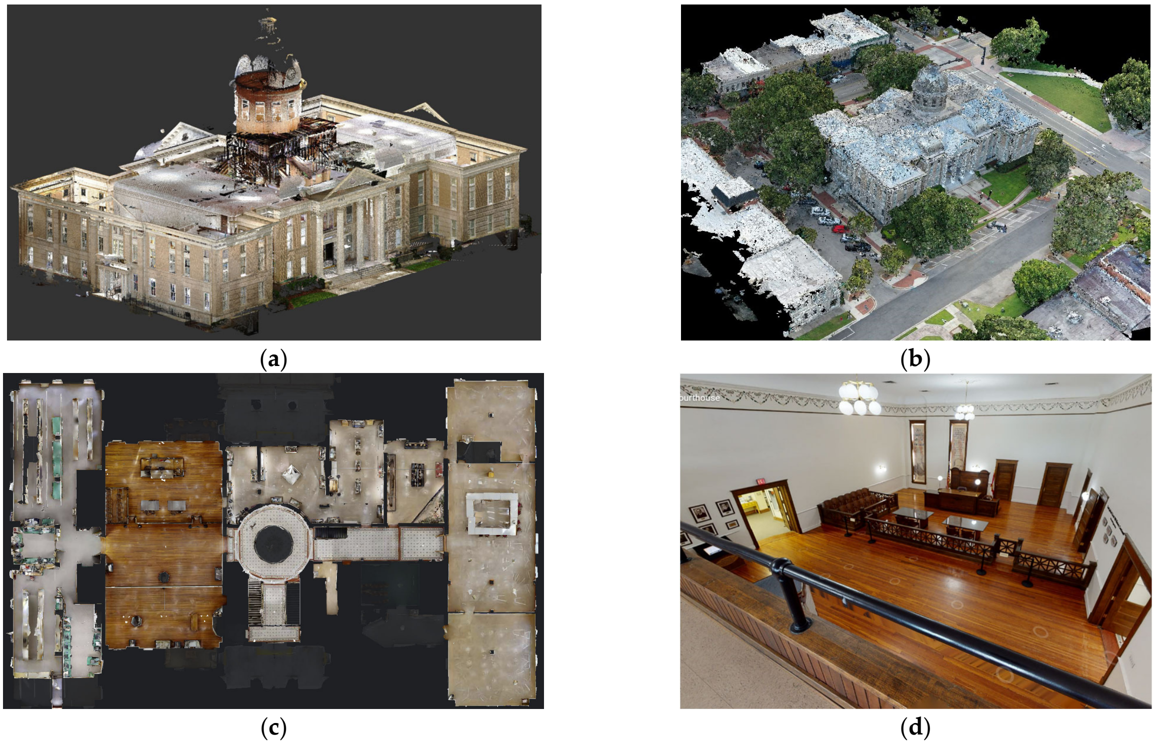


Figure 26. Demonstration of the HBIM "Visual Representation" supplement to LOD 100: (**a**) "cleaned" TLS point cloud; (**b**) UAV photogrammetric point cloud; (**c**) second floor plan of the virtual tour (the 1908 courtroom is visible with solid wood flooring); (**d**) view from third floor balcony of the 1908 courtroom in the virtual tour.

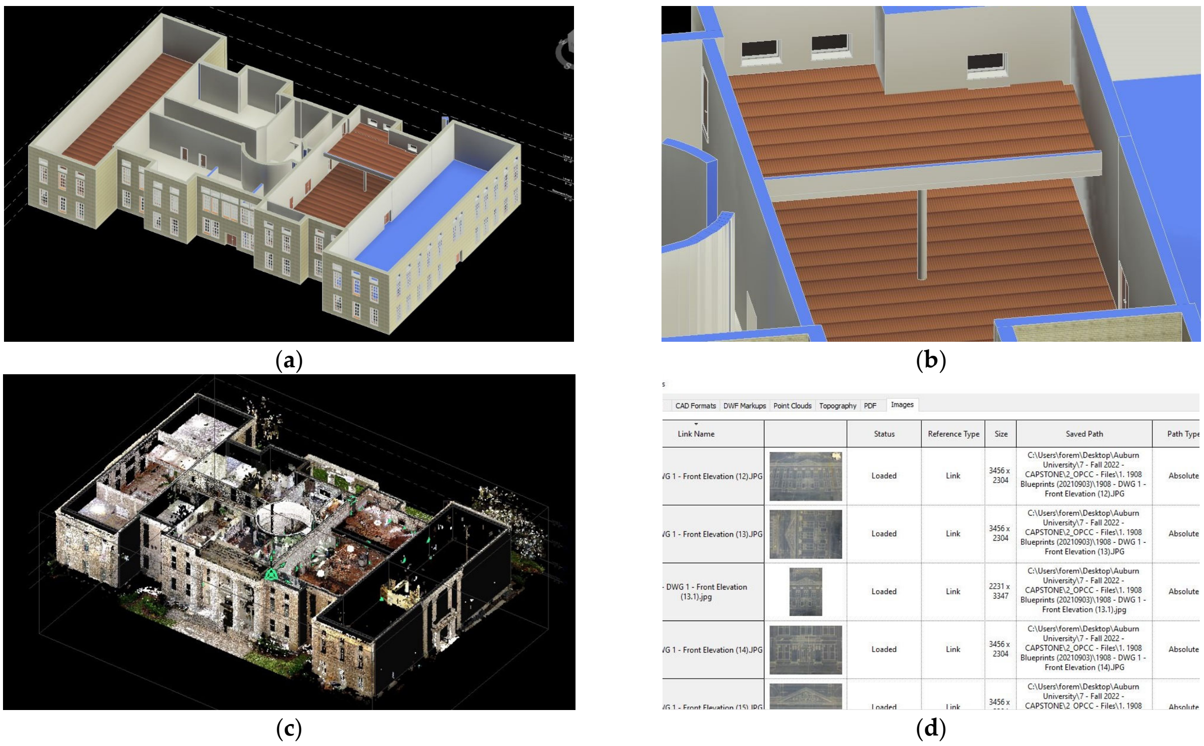


Figure 27. Demonstration of the HBIM "General Model" supplement to LOD 200: (**a**) 3D model detail of main building elements in Revit; (**b**) main building elements of the 1908 courtoom were created; (**c**) model imposed with TLS point cloud; (**d**) a view showing incorporation of the 1908 blueprints as general conservation documentation to the model in Revit.

Decay Mapping. Comprehensive long-term decay/damage mapping requires repeated observation and a method for tracking and recording the damage over time until it can be rehabilitated. In the case of the OPCC, the current most critical deterioration is related to water intrusion exacerbated by damage sustained during Hurricane Ian in October 2022 (Figure 28a,b). The historical preservation manager confirmed during her interview that water intrusion in the original 1908 courtroom has become more severe over time. Two locations of areas of concern are identified in the Revit model using tags, as shown in Figure 28c. Using this technique, continuous decay mapping provides insight into damage progression and helps curators determine changes to the damage over time. Detailed records of damage can assist decision-makers in focusing resources on the most critical areas and providing the most benefit to preserving built heritage.

(**a**) (**b**) (**c**)

Figure 28. Demonstration of decay mapping using the HBIM "Complex Model": (**a**) water damage to the courtoom balcony; (**b**) water damage to the courtoom plaster ceiling; (**c**) identification of damage using tags in Revit.

4.3.5. Implementation of HBIM Repository

The last phase of the case study is implementation of the HBIM repository. For the purpose of this research, this phase was focused on an internal review of the proposed LOD guidelines. It was determined that this HBIM supplement for LOD guidelines is an easy-to-use guide to explain the process to non-technical stakeholders and help them understand the HBIM program selected for their facility. The guidelines have the potential to reduce expenditure of unecessary resources.

5. Conclusions and Recommendations

Heritage Building Information Modeling (HBIM) is increasingly implemented in the development of accurate and semantic-rich databases used for the representation, preservation, and renovation of built heritage. A key factor in successful HBIM delivery is the intended uses of the model, which need to be established by stakeholders at the beginning of the program. The objectives of this research were to identify the top priorities of HBIM implementations for tenants and managers of built heritage, and to develop supplemental guidelines for LOD applicable to HBIM.

Through the review of published literature and the examination of 26 published HBIM case studies since 2018, it was concluded that recent HBIM studies have focused on developing an interactive 3D model used for general conservation documentation with minimal stakeholder participation or acknowledgement. The data gathered through 10 semi-structured interviews with stakeholders of historic courthouses in the southeastern United States provided a sample of procedures, priorities, and limitations for operating, preserving, and restoring built heritage.

It was recognized in this research that there is a significant lack of knowledge regarding the potential uses of HBIM for the operations and preservation of historic buildings due to the lack of resources in smaller communities. The diversity of the primary perceived benefits of HBIM for stakeholders of built heritage indicates varied interests and needs of the technology.

The proposed HBIM supplement to LOD guidelines provides a useful structure to develop HBIM programs in connection with the budget and resources of the end users, while being streamlined enough to allow easy explanation to non-technical stakeholders. These guidelines may also help the built heritage stakeholders appropriately size the scale of the HBIM effort and make the best use of their limited resources.

This research provides guidelines that allow cultural heritage stakeholders to make informed decisions about potential HBIM programs and maximize the use of resources to implement such programs. Moreover, the methodology implemented in this research offers a valuable example for future studies on HBIM guidelines and regulations.

Based on the findings of this research, the following recommendations to improve wider application of HBIM to meet the diversified needs of built heritage stakeholders are as follows:

- Identifying stakeholder priorities, available resources, and limitations at the onset of preservation programs will assist HBIM professionals tailor the program to a commiserate Level of Development;
- Future HBIM research should incorporate research aims related to the more diverse nature of stakeholder's perceived benefits of HBIM applications;
- Marketing strategies should be pursued by HBIM professionals to advocate the benefits of HBIM services to a larger customer base of built heritage custodians;
- Future methods and software should seek to simplify long-term utilization of HBIM to expand its application beyond the current use for historic facilities with robust resources;
- The proposed HBIM supplement to LOD guidelines should be further analyzed in additional case studies to refine elements at each level of development.

There are several limitations to the data contained within this study. The scope of this research did not explore the specific data management practices, nor seek to review software identified during interviews to determine how existing data management practices can be improved. Similarly, this research does not address the implementation of new HBIM technologies, nor does it seek to develop HBIM programming to address the shortcomings of BIM for built heritage. The data was limited to a subset of built heritage stakeholders representing county courthouses of an explicit architectural style and time period in the southeastern United States. Also, the 26 case studies included in this work may not represent all of the published HBIM case studies.

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Data Availability Statement: The data that support the findings of this study are available upon request from the corresponding author. Due to the sensitive nature of the data and their file size, access to the data will be granted on a case-by-case basis and may require a data use agreement to be signed.

Conflicts of Interest: The authors declare no conflict of interest.

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