Implementing HBIM for Cultural Heritage Preservation – From Documentation to Sustainable Management

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Abstract

Cultural heritage preservation faces unprecedented challenges due to the accelerating impacts of climate change and armed conflicts. International frameworks such as The Venice Charter (1964) and the UNESCO Charter on the Preservation of Digital Heritage (2003) emphasize the urgent need for effective documentation strategies for both physical and digital assets. Building Information Modeling (BIM), and more specifically Heritage Building Information Modeling (HBIM), offers a promising methodology to address these challenges by ensuring structured, object-based and life cycle-oriented digital management of historic structures. Despite its potential, the adoption of BIM standards in monument preservation remains limited, particularly within Germany's federal cultural heritage management landscape. Barriers include insufficient resources, skills, and infrastructure among preservation authorities. To address this gap, the HBIM Worms Synagogue case study was developed as a pioneering project, serving both as a model for future workflows and as a basis for stakeholder training. The project outputs include a fully operational HBIM model, a Common Data Environment (CDE), a bSDD-based classification system, and standardized templates to ensure long-term data usability and accessibility. In parallel, the establishment of the Special Interest Group "BIM in Building Survey" and efforts to integrate HBIM into buildingSMART Germany initiatives reflect the growing institutional commitment to digital transformation. Outcomes will be disseminated through a practice-oriented HBIM Mastering Workshop, including hands-on exercises and interdisciplinary training, presented at the CIPA International Conference 2025. This paper outlines the methodologies, challenges, and strategic perspectives necessary for advancing HBIM as a standard tool in sustainable heritage preservation.

1. Introduction

1.1 Endangered Cultural Heritage

The preservation of cultural heritage is confronting unprecedented challenges driven by escalating global threats, particularly climate change and armed conflict. In the context of The Venice Charter for the Conservation and Restoration of Monuments and Sites (1964), it is evident that traditional methodologies must evolve to address these contemporary risks (Avrami, 2019).

Climate change, with its associated phenomena of extreme weather events, sea-level rise, and temperature fluctuations, has emerged as a critical factor intensifying the degradation of built heritage across Europe and globally (IPCC, 2021). Simultaneously, armed conflicts have increasingly targeted cultural assets as strategic and symbolic acts of destruction (UNESCO, 2017), necessitating urgent interventions to prevent irreversible losses.

Built heritage is particularly susceptible to accelerated material decay, foundation instability, and hydrological impacts such as increased groundwater levels and flooding (Sabbioni, Brimblecombe, & Cassar, 2010).

Given the scale and complexity of these threats, there is a compelling need for the adoption of resilient, interdisciplinary conservation methodologies. These approaches must be predictive, preventive, and adaptive, combining traditional craftsmanship with advanced scientific and technological tools. Heritage policies and institutional frameworks play an indispensable role in enabling these conservation efforts (ICOMOS, 2019).

The principal objective of this article is to propose an innovative methodological framework for the documentation, planning, and preservation of cultural heritage. This framework is predicated on the integration of Building Information Modeling (BIM) standards, adapted to the specificities of heritage conservation.

1.2 Challenging Documentation

Adequate and comprehensive knowledge management constitutes the fundamental cornerstone of cultural heritage preservation. Since antiquity, stakeholders—including builders, artisans, and scholars—have progressively developed analytical survey methods and documentation practices grounded in empirical observations, accompanied by standardized graphical representations in accordance with established drawing conventions (Letellier, 2007).

However, the paradigm shift induced by digitization has posed a profound challenge to traditional documentation methodologies. Human-readable records must increasingly be transformed into machinable datasets.

Emerging technologies such as photogrammetry, terrestrial laser scanning (TLS), and unmanned aerial vehicles (UAVs) have revolutionized the standards of accuracy and completeness in the virtual representation of heritage assets (Grussenmeyer et al., 2008). These tools set the stage for advanced applications including the development of Digital Twins—dynamic, data-rich models that aim to achieve a 1:1 digital replication of the physical environment (Boje et al., 2020).

The management of built (historical) environments today necessitates in-depth documentation and meticulous data preparation to support planning and conservation services. Although the German standard DIN 18205 (Bedarfsplanung am Beginn eines Projekts, 1996) has long emphasized the importance of early-stage requirement planning, its practical application remains limited in heritage contexts.

The recent introduction of Project Stage Phase 0 and Phase 10 within German project management frameworks underscores the necessity for structured documentation both prior to and following the planning and construction phases, emphasizing an integrated, lifecycle-based approach to heritage preservation (Fig. 1).

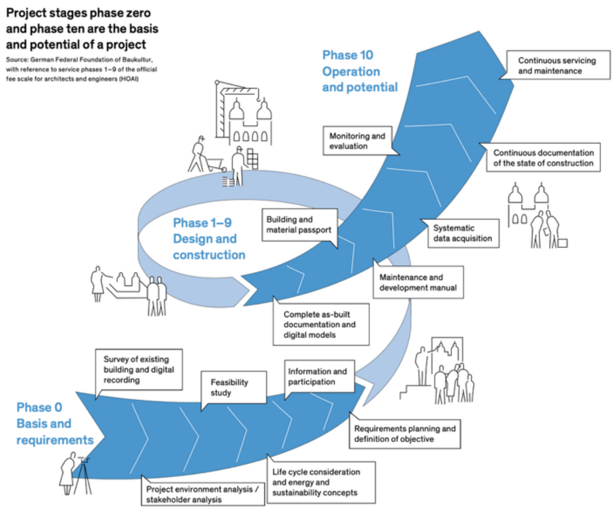

Figure 1. Federal Foundation of Baukultur, with reference to service phases 1-9 of the official fee scale for architects and engineers (Baukultur Report, 2022/2023).

In this evolving context, Building Information Modeling (BIM) standards, notably ISO 19650 and the Level of Information Need standard ISO 7817-1:2024, play a pivotal role. Moreover, model-based communication via standardized data exchange formats such as Industry Foundation Classes (IFC) and BIM Collaboration Format (BCF) ensures interoperability across different software platforms, facilitating collaborative work environments.

The introduction of the Level of Information Need concept further advances the flexibility of documentation processes, allowing the tailoring of geometric and information requirements to the specific needs of individual projects. Here the pursuit of highly detailed virtual models must be balanced against practical considerations of usability, relevance, and resource constraints. This adaptability is critical for optimizing resource allocation and ensuring that digital models serve as effective, sustainable tools throughout the lifecycle of heritage assets.

Despite these promising opportunities for enhanced project management throughout the entire lifecycle of the built environment, the practical application of innovative planning, construction, and operation methodologies has yet to yield significant impact on cultural heritage preservation (Lovell et al., 2023). The unique complexities of historic structures impede the straightforward adoption of digital workflows designed for contemporary architecture.

The application of digital 3D models in the preservation of historic buildings, particularly within the domain of practical monument conservation, remains an ongoing field of research (Ewert, 2024). Its systematic evaluation and implementation within Germany’s federally structured cultural heritage management landscape are challenges that have yet to be fully addressed.

1.3 (H)BIM is coming!

The German construction industry’s transition toward digitization was formally initiated with the proclamation of the Stufenplan Digitales Planen und Bauen 2020 in 2015. Since 2020, all federal infrastructure projects, and since 2022, all federal building construction projects are required to be delivered in accordance with Building Information Modeling (BIM) standards (BMVI, 2015). In contrast, cultural heritage preservation in Germany falls under the jurisdiction of the sixteen federal states (Bundesländer), each maintaining autonomous regulatory authority.

Within this decentralized framework, the Association of Heritage State Authorities (Verbund der Landesdenkmalpfleger, VdL) has played a pivotal role in promoting the exchange of best practices. Specifically, the VdL Working Group "Building Research" has recognized the critical importance of integrating BIM methodologies into building survey, documentation, and conservation practices.

The increasing challenges posed by climate change, including severe flooding events such as those in the Ahr Valley in 2021 and the structural risks induced by droughts in 2018 and 2019, have further underscored the necessity of advanced documentation and monitoring strategies for cultural heritage. The Worms Synagogue, designated a UNESCO World Heritage Site as part of the ShUM Cities in 2021, has become emblematic of this urgent need. Its structural stability has been compromised by subsidence of the underlying soil, necessitating coordinated, comprehensive documentation efforts to inform safety measures, continuous monitoring, and long-term preservation strategies.

An interdisciplinary symposium titled "Climate Change and Settlement-Related Structural Damage Using the Example of the Worms Synagogue" held on March 21–22, 2023, served as a critical platform for initiating dialogue between the German Federal Environmental Foundation (DBU, Deutsche Bundesstiftung Umwelt), responsible heritage authorities in the City of Worms and the State Capital Mainz, and the Institute of Architecture at the Hochschule Mainz. The symposium catalyzed the development of a research project funded by the DBU, titled "Heritage Building Information Modeling (HBIM) as a Documentation, Planning, and Monitoring Method for Mitigating Environmental Damage".

The project builds upon the authors’ longstanding engagement with the digital recording and documentation of cultural heritage, encompassing research, teaching, and practical application (Kuroczyński et al., 2021; Argasiński & Kuroczyński, 2023).

The research project focuses on three principal objectives:

1.) **Implementation of HBIM** for the documentation and preservation of the Worms Synagogue, providing a stakeholder-ready digital model for practical application.

2.) **Development of standardized templates** for Exchange Information Requirement (EIR) and BIM Execution Plan (BEP) to serve as guidelines for broader dissemination within the heritage sector.

3.) **Introduction of a Classification System** for cultural heritage assets, designed for immediate use and aligned with the buildingSMART Data Dictionary (bSDD).

In parallel, the German Special Interest Group (SIG) "BIM in Building Survey" was established in mid-2024. This networking community provides a platform for presenting ongoing projects and research activities in the field of digital heritage documentation. Building upon these developments, efforts are currently underway to form a dedicated SIG HBIM within the German Chapter of buildingSMART. This initiative seeks to better represent the specific requirements of historical building stock within the IFC standard, thereby promoting interoperability and facilitating the seamless integration of heritage-specific data into global BIM workflows.

2. Mastering HBIM on Worms Synagogue

Due to the focus of the project a practice-oriented HBIM Mastering Workshop has been developed. Tailored to meet real-world requirements, the workshop utilizes customized training datasets derived from the HBIM model of the Worms Synagogue.

Taking the Worms Synagogue, a UNESCO World Heritage Site threatened by environmental and structural risks, as a central case study, the workshop will demonstrate how HBIM can overcome data fragmentation and enhance interdisciplinary collaboration. Participants will gain practical experience in digital acquisition techniques such as laser scanning and photogrammetry, understand HBIM workflows for conservation planning and monitoring, and explore strategies for data exchange, integration and asset management.

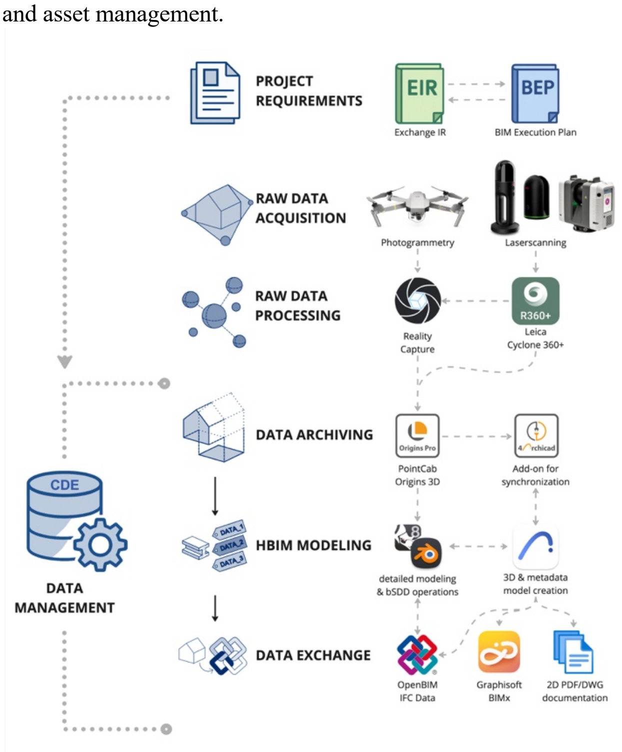

Figure 2. Mastering HBIM Process Overview (© K.Argasiński, P. Kuroczyński, 2025)

2.1 Workshop Alignment and Significance

The HBIM Mastering Workshop is structured around **key module components** (Fig. 2). These modules are accompanied by a special focus on ensuring interoperability and the long-term accessibility of digital data, following the principles outlined in the UNESCO Charter on the Preservation of Digital Heritage (UNESCO, 2003). Digital preservation encompasses all processes aimed at guaranteeing the continuity and usability of digital heritage materials for as long as they are required (Conway, 2010).

The workshop addresses the following components:

1.) **Translation of Project Requirements**: Systematic translation of conservation and documentation objectives into structured, goal-oriented project documents, providing a clear basis for digital workflows and information management.

2.) **Data Acquisition, Data Processing and Data Archiving**: Introduction to data capturing techniques and preliminary processing stages, providing the technical foundation necessary for comprehensive digital documentation.

3.) **HBIM Modeling**: Emphasis on the preparation of structured, object-based geometries, the semantic enrichment of 3D models, and the provision of adequate supporting documentation closely aligned with project-specific requirements. Particular attention is given to **classification systems and information mapping.**

4.) The workshop highlights the critical importance of **Data Exchange** as well, focusing on interoperability, reusability, and sustainable accessibility of project information which are essential components that enable BIM methodologies to be adapted effectively for cultural heritage applications (Logothetis, Delinasiou, & Stylianidis, 2015).

5.) As the project simulates real work scenarios and practices, the emphasis has been put into **Data Management.** Using Common Data Environment (CDE) to consult and coordinate work with all project participants is crucial cornerstone of the HBIM Worms Project, allowing to implement all requirements proposed in BEP.

The proper handling of project data management, modeling and data exchange according to the project requirements are fundamental prerequisites for the successful implementation of HBIM workflows in monument preservation. Equally important is the effective dissemination of the applicable knowledge related to the above-mentioned topics to ensure the analogue/physical and virtual/digital monument preservation referring to the Venice Charter (1964) and the UNESCO Charter (2003).

Ensuring the long-term accessibility, usability, and interoperability of digital heritage information is essential for maintaining the relevance and sustainability of HBIM applications. Without clear strategies for managing and sharing these processes, the potential of HBIM for supporting conservation and preservation planning, monitoring, and heritage asset management cannot be fully realized. As a result, physical monuments and their digital representations are endangered to become a ruinous state with an uncertain future.

2.2 The North-West Corner as the Example

As part of the applied implementation phase, a specific case study—The North-West Corner of the Worms Synagogue—has been selected to explore and demonstrate the application of HBIM workflows in a structurally and historically complex context (Tab. 1). This area presents a unique confluence of architectural stratigraphy, symbolic elements, and conservation challenges, making it particularly suitable for testing digital heritage documentation strategies under realistic conditions.

Component	Sources and Implementation
Historic Water and Drainage Systems	Archival documentation (Stadt Worms, 1893) and current condition data from architectural office (2023) were used to reconstruct subsurface infrastructure. These systems were modeled in 3D and integrated into the HBIM environment to analyze their relationship to the building's foundations and surrounding conditions.
Soil Structure and Geotechnical Conditions	Geotechnical investigation data, including borehole logs and excavation documentation (Ingenieurbüro für Geotechnik Worms, 2021), were georeferenced and embedded in the model to support foundation assessment and structural risk evaluation.
Wall Structure and Historical Layering	Stratigraphic analysis was informed by a combination of historical photography (Stadtarchiv Worms, 1950s), architectural documentation (Otto Böcher, 1960), and typological studies (Baualterskartierung by Universität Heidelberg, Prof. Untermann, 2008) (Fig.3). These sources informed phase segmentation and material classification in the HBIM model.
Decorative and Symbolic Architectural Elements	Detailed elements such as inscribed stonework and the western portal were modeled using high-resolution scanning and linked with semantic metadata. Classifications were aligned with the buildingSMART Data Dictionary (bSDD) to support reuse and standardization across conservation projects.
Damage Diagnostics and Reinforcement Mapping	Diagnostic data from recent surveys—including laser scanning and photogrammetry—were interpreted in collaboration with architectural office and structural engineers. The resulting models include condition markers for cracking, reinforcement areas, and structural anomalies, documented in both graphical and metadata formats.

Table 1. Thematic Components and Data Sources (© P. Kuroczyński, K.Argasiński, 2025).

3. Workshop Modules – HBIM Worms Case Study

The following sections will outline the main workshop modules (Fig. 2) and their corresponding learning objectives, designed to equip participants with the necessary competencies to meet these challenges.

3.1 Project Requirements

In accordance with ISO 19650 principles and the methodological framework of HBIM, this section presents the structured EIR as formulated by the Lead Appointing Party—the City of Worms—and the corresponding implementation strategy, the BEP, provided by the Lead Appointed Party, represented by the BIM Manager. The aim is to operationalize conservation priorities and long-term heritage management strategies through structured, interoperable, and reusable digital workflows, using the Worms Synagogue as a pilot case.

The following table (Tab. 2) presents the preliminary mapping of project-specific EIR, as defined by the Lead Appointing Party, and the corresponding responses developed within the BEP by the BIM Manager. This synthesis reflects the outcomes of initial coordination between the Lead Appointing and Lead Appointed Parties and serves as a foundational framework for structured digital heritage documentation and management in the Worms Synagogue project.

Preliminary EIR requirements Lead Appointing Party	Preliminary BEP Response Lead Appointed Party
1. Establishment of a collaborative work and data environment. Need for a structured digital platform ensuring centralized, secure, and traceable information exchange.	Deployment of an ISO 19650-compliant CDE as a Single Source of Truth. Access rights and data responsibility matrices defined. Supports collaboration across stakeholders.
2. Documentation of Physical Condition and Environmental Context including historical building surveys. Requirement for reliable documentation of the building's structural state, subsurface conditions, and climatic influences.	In addition to historical and archival sources, integration of terrestrial laser scanning, photogrammetry, geotechnical analysis, and climate data into the HBIM model. Semantic structuring of metadata ensures traceability.
3. Level of Information Need. Clear articulation of information requirements in terms of geometry, attributes, and documentation.	Adoption of the Level of Information Need framework with specific definitions for geometry, it's information and documentation. Illustrated using the example of the decorative portal.
4. Interoperability and Long-Term Data Reuse. Information must be structured using open standards to ensure future adaptability and system integration.	Use of openBIM standards (IFC, bSDD, BCF) and structured metadata for export to external databases (e.g., national heritage registers). Data portability ensured.
5. Stakeholder-Specific Deliverables. Provision of tailored outputs adapted to different user groups (conservators, planners, administrators).	Generation of filtered 3D views, data sheets, annotated models, and reports. Deliverables structured according to predefined user requirements and use cases.
6. Terminology Harmonization and Heritage Classification. Need for alignment between local heritage vocabulary and international classification systems.	Use of the bSDD to map local terms to global standards. Extended heritage-specific taxonomy developed where needed.
7. Issue Management, Quality Assurance and Quality Control (QA/QC) must be in place for tracking issues, managing non-conformities and assuring continuous quality control through the project lifecycle (i.e. by clash detection checks and visual checks as well as metadata check).	Implementation of a structured issue management system within the CDE (e.g., BCF-based workflow). QA/QC protocols include validation of geometric and semantic accuracy, version tracking, and review procedures for milestone submissions.

Table 2. Preliminary Lead Requirements Definition (EIR/BEP) ((© K.Argasiński, P. Kuroczyński, 2025)

To ensure the effective implementation and long-term applicability of the HBIM-based methodology, the project includes a dedicated capacity-building component addressed to the Lead Appointed Party and associated stakeholders responsible for heritage conservation and digital information management. This component comprises a series of structured technical sessions focusing on the operationalization of the CDE in compliance with ISO 19650, the definition and application of the Level of Information Need and the use of standardized classification systems through the bSDD.

One of the first tasks given to The Lead Appointed Party is the development and documentation of practical workflows, including the semantic annotation and modeling of selected architectural elements—such as the synagogue’s decorative portal at north-west corner. These activities serve to standardize processes, improve coordination and ensure the interoperability of data across conservation and planning domains. This framework provides a reproducible model for the structured management of digital heritage information, facilitating consistent implementation across heritage projects with complex stakeholder environments.

The workshop also addresses the implementation of data management strategies, focusing on how the resulting HBIM reference model can be operationalized in the daily work of municipal authorities.

Core aspects of implementation include:

1.) **Common Data Environment (CDE)**

A structured CDE is introduced as the central coordination platform for storing, sharing, and managing all project data. Configured according to ISO 19650 requirements, it ensures secure access, version control, and information traceability. The CDE acts as the authoritative environment for all project actors, forming the **Single Source Of Truth (SSOT)**.

2.) **Role-based data access and traceability**

Data access is configured to support both specialist and non-specialist roles, including facility management personnel within the municipality. Standardized outputs derived from the HBIM model—such as drawings, annotated 3D models, and documentation—are aligned with the project’s EIR.

3.) **Data lifecycle and certification frameworks**

The project’s information workflows are designed to ensure long-term reusability and compliance with international heritage protocols, including the UNESCO Charter on Digital Heritage and CIPA/ICOMOS standards. Deliverables produced, i.a within the workshop framework, contribute to the development of a formal training.

3.1.1 Definition of the Level of Information Need: It is a structured framework used to specify the **quality, quantity and granularity** of information required to support a clearly defined **purpose**. Level of Information Need does **not** refer simply to the level of graphical detail or data richness—it represents a comprehensive articulation of **what information is required, by whom, when, and why**.

Example based on project deliverables:

Category	Definition in this context
Purpose	Conservation planning and pre-intervention documentation
Actor (Information Receiver)	Conservation architect (e.g., Architects Data), Facility manager (City of Worms)
Object	Decorative portal with inscription and adjacent masonry
Information Delivery Milestone	Before intervention planning and tendering phase
Geometrical Information	- High-resolution 3D mesh model (TLS & photogrammetry) - Detailed geometry with realistic textures - Crack geometry mapped in-place -HBIM model as a base information container
Alphanumerical Information	- Object type: Heritage portal with inscription - Material: Local sandstone - Condition: Cracks, reinforcements, weathering - Phase: 12th-century original with 20th-century intervention history
Documentation	- Historical photos (Stadtarchiv Worms, 1950s) - Otto Böcher plan and section (1960) - Excavation report (Hamm Architektur, 2023) - Drilling logs (Ingenieurbüro für Geotechnik Worms, 2021)

Table 3. Level of Information Need Matrix example – Decorative Portal of North-West Corner at Worms Synagogue (© K.Argasiński, P. Kuroczyński, 2025).

3.2 RAW Data Acquisition and Processing

Although this paper does not focus in detail on the methodology of data acquisition, it is important to acknowledge the scope and nature of the source materials that form the foundation for the HBIM modeling of the Worms Synagogue. The coordination and interpretation of these sources are central to ensuring the long-term usability and traceability of heritage information.

3.2.1 Historical Resources, Archival Data and External Contributions: The starting point for the modeling and documentation process included a broad array of historical surveys and documents: such as architectural drawings, archival photographs from the Stadtarchiv Worms (notably from the 1950s) and the architectural survey by Otto Böcher (1960). Previous point cloud surveys were conducted in earlier conservation campaigns, which also formed a contextual basis for comparison.

Additionally, the project also integrated critical documentation from architectural office and the conservator including past-time excavation reports, foundation plans, and structural assessments. These datasets were digitized, georeferenced, and linked within the CDE. The segregation between legacy data and newly acquired information allows for traceable analysis, ensuring clarity in historical interpretation and planning decisions.

3.2.2 Terrestrial Laser Scanning: The primary source of contemporary high-resolution data was obtained through Terrestrial Laser Scanning (TLS), carried out by the project team using Leica RTC360 scanners. This updated dataset was essential due to the absence of a unified and complete documentation from prior campaigns. At the request of conservator a fully continuous and registered scan dataset was generated, covering both above-ground and subterranean architectural features.

3.2.3 Mobile Scanning: To complement the TLS data and improve mobility during site work, Simultaneous Localization and Mapping (SLAM) scans were conducted using the Leica BLK2GO & BLK2GOPULSE systems. SLAM scanning was particularly effective in areas such as transitional zones and spaces of minimized access like excavations. While lower in precision compared to TLS, SLAM datasets provided rapid contextual awareness and contributed to the early-stage model structuring process.

3.2.4 Photogrammetry: The **Unmanned Aerial Vehicle (UAV)** based photogrammetry was utilized to document roofscapes, upper facades, and exterior elements not accessible from the ground. The UAV imagery was processed using RealityCapture to generate textured meshes. These outputs played a critical role in the assessment of surface condition, roof geometry, and material weathering patterns, especially where traditional survey methods were infeasible.

Key priorities in the acquisition phase were **accuracy**, **coverage completeness**, and the ability to **replicate measurements** in the future. The repeatability of scans was secured through the establishment of consistent reference systems and characteristic points across campaigns.
After the initial data acquisition stage, point clouds obtained from laser scanning data and photogrammetry are processed using Leica Cyclone Register 360+ and Reality Capture, respectively.

3.3 Data Archiving

The processed data is then implemented in PointCab Origins 3D, which plays a key role in **managing, archiving and preparing** point clouds for subsequent applications. PointCab Origins 3D is software that archives, manages and processes point cloud data into comprehensible documentation formats. The software facilitates many functionalities dedicated to point cloud post-processing. Its core function is the generation of 2D cross-sections, floor plans and elevations as high-resolution orthophotos. These results serve as a key link between the complete 3D point cloud and more accessible forms of representation, facilitating communication between all project stakeholders. It has been shown that professionals who do not have formal training in point cloud data management or 3D modelling, including conservators, engineers and administrative staff, are nevertheless able to interpret and use the resulting drawings satisfactorily. PointCab Origins acts as a key intermediary, transforming raw spatial data into pseudo-documentation that conforms to conventional representation formats that are widely understood across disciplines.

By implementing a dedicated 4Archicad add-on, processed point cloud data is synchronized directly with Graphisoft Archicad initiating the HBIM modeling phase. This provides a seamless transition from raw data to structured BIM environments.

3.4 HBIM Modeling

The HBIM model is strategically developed to serve as both a precise geometric representation of the Worms Synagogue and a structured semantic repository, aligned with defined use cases and stakeholder-specific information needs. The modeling process is driven by the Level of Information Need concept—defined by purpose, actor, object, and delivery milestone.

3.4.1 Model creation: Building on the framework outlined in Section 2.1, the modeling process is exemplified through a detailed representation of a selected heritage element: the decorative portal in the North-West Corner. This element incorporates high-resolution geometric detailing as well as structured semantic attributes, including typology, material composition, conservation condition, and references to historical sources. The object is cross-referenced with archival documents (e.g., Otto Böcher's drawings, excavation reports, building survey, etc.), fulfilling the documentation layer required by Level of Information Need (Tab.2). The approach ensures that the model responds to both immediate conservation planning needs and long-term documentation standards.

Environmental influences on the structure—such as moisture infiltration, subsurface movement, and thermal gradients—were captured indirectly through structural deformation readings, crack mapping, and geotechnical studies. These datasets were enriched with semantic metadata and linked to model elements to inform risk assessment and conservation planning scenarios.

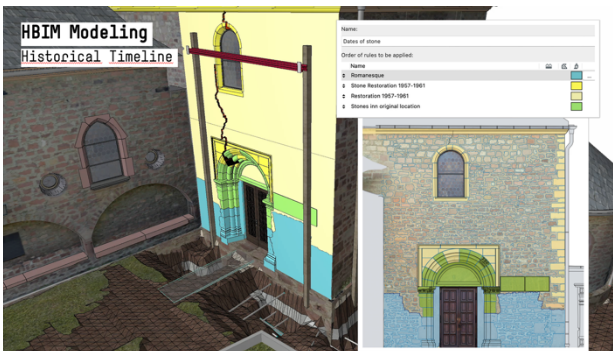

Figure 3. LOG/LOI and Document - building survey by Prof. Untermann, Universität Heidelberg (© K.Argasiński, 2024)

Modeling was carried out primarily in Graphisoft Archicad, supported by auxiliary software including Rhino, Blender, and PointCab Origins for point cloud interpretation. The model elements were built with a necessary attention to both geometry and semantic richness, avoiding excessive complexity while ensuring that critical information is embedded in each component (Fig. 3).

The preliminary HBIM model serves multiple roles: as a technical asset for decision-making and communication, a visual interface for stakeholder engagement, and a database for heritage management (Fig. 4) and monitoring. In support of data sustainability and quality assessment, the model undergoes regular proofing and compliance checks within both Archicad and IFC validation environments.

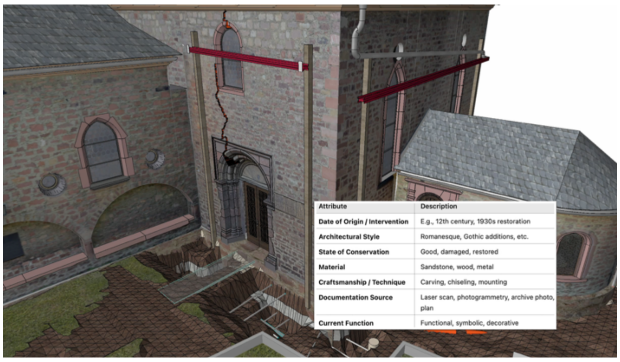

Figure 4. Common Attributes proposal for all components (© K.Argasiński, 2024)

Particular attention is paid to IFC schema compliance. Model elements are structured for compatibility with external IFC viewers and rule-based quality assessment tools, allowing independent validation of classification, property sets, and data completeness. This guarantees that deliverables can be reliably used across institutional contexts, including certification, tendering, and long-term facility management.

3.4.2 Semantic Harmonization: Parallel to geometric interoperability, semantic harmonization can be achieved through the bSDD—a multilingual, standards-based ontology platform that enables structured vocabulary alignment between local and international classification systems. This is particularly crucial in heritage contexts, where typical BIM libraries lack meaningful categories for historical elements, material states, symbolic features, or damage typologies.

To explore this, there is a need to integrate already existing heritage dictionaries like MIDAS (Forum on Information Standards in Heritage (FISH), 2012), Getty Art & Architecture Thesaurus (Getty Research Institute, 2021), and in the German case the Bamberg Vocabulary for Historical Architecture (Arera-Rütenik, Stenzer, 2022). The last one is the only standardised data set for historical building research, building history, building conservation and building restoration which, in contrast to the established Getty AAT, now also comprehensively maps specialist terms in German and, in addition to art-historically oriented, formal and typological terms, provides a wide range of knowledge regarding building construction, the history of building technology, building equipment, condition assessment and restoration. The local heritage descriptors from regional inventories are mapped to bSDD terms.

Preliminary semantic structuring is guided by designed classification which can be aligned with bSDD. To demonstrate the application of bSDD-based harmonization in practice, the HBIM model of the Romanesque portal of the Worms Synagogue was used to create a hypothetical semantic classification structure aligned with openBIM standards (Fig. 5, 6). Each architectural element—such as the archivolt, jambs, tympanum, lintel, inscriptions, and door leaf—was described using custom classes and properties that reflect its historical function, stylistic attributes, and material characteristics. For example, the archivolt was classified as a "DecorativeArch" with Romanesque style and symbolic function, while the inscriptions were categorized as "HistoricInscription" objects containing Hebrew script of religious and commemorative value. These components were modeled with IFC entities (e.g., IfcBuildingElementProxy, IfcAnnotation, IfcDoor) and semantically enriched using a hypothetical bSDD-compliant vocabulary, demonstrating how heritage-specific elements can be encoded for use in digital workflows.

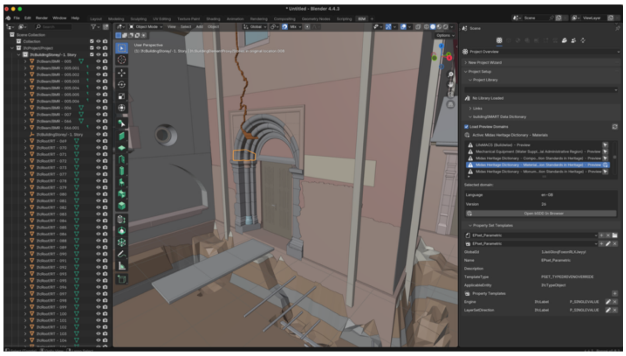

Figure 5. Preliminary examples of loaded bSDD Domains - visualization in Blender with Bonsai add-on (© K.Argasiński, 2025)

According to the MIDAS heritage dictionary, which is built into bSDD, adding or updating such data is possible even in the asset management stages. It can support a variety of stakeholders as needed, including art historians, conservators and other heritage professionals. The dictionary was chosen as a testing ground, due to its applicable structure.

3.5 Data Exchange

The structured exchange and harmonization of HBIM data are addressed through the coordinated use of open standards—specifically the IFC for geometry and semantics, and the bSDD for classification mapping. Interoperability and semantic consistency are essential not only for ensuring technical quality, but for enabling non-specialist stakeholders—such as municipal heritage managers—to actively engage with and verify model content.

To facilitate cross-platform communication and open delivery workflows, the HBIM model is structured for data exchange via IFC, ensuring that all model content—geometries, classifications, and property sets—can be exported in a structured, standards-compliant format. In this project, Graphisoft Archicad's IFC translators were utilized to define precise mappings between internal object types and IFC entity types, as well as between Archicad property groups and IFC Property Sets (PSets). Custom classification systems used for common heritage elements (Fig. 3 & Fig. 4), such as portals, inscriptions, or stratified wall components—were aligned with IFC Type and Element mappings to maintain both technical consistency and cultural specificity.

As part of the HBIM workflow for the Worms Synagogue, a structured issue management system is implemented within the CDE, following openBIM principles. The workflow is based on openBIM standards (IFC models) and leverages BCF-based workflows to ensure transparent, traceable communication among stakeholders. Tools such as BIMcollab Zoom and Solibri are used to detect, document, and track issues related to both geometric and semantic aspects of the model. Rule-based Quality Assurance and Quality Control (QA/QC) protocols include systematic validation of model accuracy, consistency checks, version control, and structured review procedures at defined project milestones. This process supports accountability, coordination, and continuous model improvement throughout the project lifecycle.

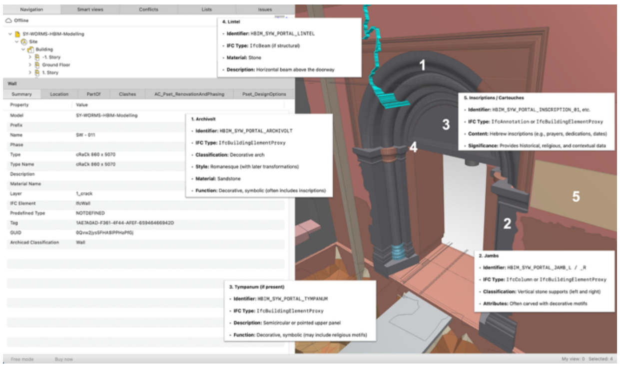

Figure 6. Preliminary examples of mapped Properties based on needs of municipaly conservation office - visualization in BIMcollab Zoom (© K.Argasiński, 2025).

3.6 Data Management

The core focus of this paper lies in the structured **organization of digital heritage data**, both as a prerequisite for interdisciplinary collaboration and as means to support sustainable conservation workflows. As heritage documentation transitions from static records to dynamic, interconnected datasets, establishing a robust digital infrastructure becomes essential. The Worms Synagogue HBIM project therefore emphasizes the integration of modeling environments, classification protocols, and data delivery platforms into a unified and accessible system.

In addition to the modeling environment facilitated by Archicad, the HBIM project prioritizes the development and operational implementation of a structured CDE. Operational accessibility constitutes a primary objective of the CDE configuration. The system has been structured to allow intuitive access to essential data types. By providing a user-friendly interface and clearly categorized datasets, the platform enables non-specialist users—particularly those in municipal roles—to retrieve relevant information without requiring specialized knowledge of BIM environments or modeling software. Furthermore, role-based information delivery is integral to data usability across the asset lifecycle. Planners and external consultants are required to produce deliverables that respond to predefined EIR and the Level of Information Need matrix, which was collaboratively developed during preliminary project’s phase.

To support quality assurance and accountability, the CDE is embedded within the Mastering HBIM training framework. This didactic component ensures that contributors are informed not only of technical modeling protocols, but also of documentation standards required for operational implementation. All project participants are trained in the structuring, validation, and submission of data packages in accordance with ISO 19650 and applicable national heritage data protocols. These procedures are intended to promote both replicability and transparency across phases of documentation, analysis, and intervention planning.

The project implements Catenda Hub CDE as the foundational component of its digital infrastructure. Structured in compliance with ISO 19650, the platform supports centralized, version-controlled storage and management of all project data—including point clouds, HBIM models, scanned drawings, and supporting documentation.

This centralized structure further enables predictive monitoring and risk assessment, allowing users to cross-reference structural data with environmental factors over time. Each data object within the system—whether a geometric element, document, or classification entry—is attributed with metadata detailing its origin, date, author, and intended purpose. These attributes ensure high traceability and facilitate seamless interdisciplinary collaboration.

User access and data privileges are defined according to role profiles, which streamlines both operational application (e.g., condition report retrieval by facility managers) and technical assessment (e.g., structural issue annotation by engineers). Additionally, the platform architecture supports open data standards, notably IFC for semantic and geometric structuring as well as BIM Collaboration Format BCF for issue management and communication. Since the platform is based on open standards, it enables a long-term interoperability with external systems, such as national heritage databases and municipal infrastructures.

4. Conclusion and Perspectives

4.1 Conclusion

The escalating threats to cultural heritage posed by climate change and armed conflicts underscore the urgent need for comprehensive documentation and preservation strategies. Both The Venice Charter (1964) and the UNESCO Charter (2003) emphasize the necessity of safeguarding not only physical monuments but also their digital counterparts, particularly the emerging Digital Twins of endangered heritage assets.

In this context, Building Information Modeling (BIM) standards present a highly promising framework, offering object-based, life cycle-oriented communication and documentation tools capable of addressing the complex requirements of heritage preservation. However, despite its potential, the practical application of BIM in monument preservation and management remains limited. Persistent barriers—including a lack of resources, skills, and digital infrastructure within management and conservation authorities, particularly in Germany—continue to hinder effective implementation.

Nevertheless, a growing interest in BIM applications can be observed, notably within the Working Group Building Research of the Association of Heritage State Authorities (VdL) and the ongoing establishment of a Special Interest Group on Heritage BIM (HBIM) within the buildingSMART German Chapter.
The HBIM case study of the Worms Synagogue serves as a cornerstone for fostering discussion within the cultural heritage community and developing a practical, applicable methodology tailored to the needs of stakeholders.

As tangible outcomes of the project, a dissemination and workshop format will be developed and evaluated, including training sessions for emerging experts at the CIPA International Conference in Seoul 2025. In parallel, a bSDD-based classification system will be further developed and shared in cooperation with the aforementioned working and special interest groups to support standardized information management in HBIM workflows.

In addition to dissemination efforts, an operational HBIM model and a CDE will be handed over to the responsible authorities. This will be accompanied by guidelines and standardized templates designed to ensure the sustainable, long-term usage of the created data and to establish robust digital workflows that secure the future of cultural heritage preservation through digitization.

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