From sources to Levels of Reference (LoRef) for the virtual reconstructions of the Priene Theatre: an interoperable and informative HBIM workflow

Elisabetta Caterina Giovannini [1]*, Jacopo Bono [1]*

[1] DAD, Dept. of Architecture and Design – Politecnico di Torino, Italy - (elisabettacaterina.giovannini, jacopo.bono)@polito.it)

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Abstract

Virtual reconstruction of archaeological architecture requires transparent and reproducible methods for managing heterogeneous historical sources within three-dimensional models. This paper presents a source-driven HBIM workflow that defines a Level of Reference (LoRef) to explicitly link reconstructed architectural elements to the documentary evidence supporting them.
The methodology is applied to the virtual reconstruction of the ancient Theatre of Priene, considering multiple historical configurations derived from archival drawings, excavation documentation, survey data, and interpretative studies. Main sources were classified using the IDOVIR Source Classification Taxonomy and mapped into the buildingSMART Data Dictionary (bSDD) to ensure semantic interoperability within an openBIM environment. LoRef information is assigned to HBIM elements via shared parameters and visual thematic labelling (source filtering), enabling explicit representation of source provenance at the component level.
Instead of encoding accuracy or reliability as predefined metrics, the proposed approach treats LoRef as a primary information layer, from which qualitative and quantitative assessments are derived in a second stage based on source typology and consistency.
The resulting HBIM model functions as an interoperable, FAIR-compliant knowledge system, supporting transparent documentation, reuse, and cross-platform dissemination of virtual reconstructions.

1. Introduction

The research focuses on the virtual reconstruction of the ancient Theatre of Priene by integrating iconographic sources and digital documentation within an interoperable HBIM environment.
Rather than relying on procedural stratigraphic approaches (Demetrescu & Ferdani, 2021), generally used within the archaeological framework (eg. Matrix of Harris and the Extended Matrix), the approach of this research adopts a source-driven methodology that evaluates and classifies documentary evidence to assign a Level of Reference (LoRef) to each reconstructed component (Giovannini, 2017; Giovannini & Torresi, 2024).
The case study considers three historical configurations of the Priene Theatre, which are virtually reconstructed based on drawings, archival documentation, and survey data.
Each model is enriched with a semantic structure that relates its geometric entities to a specific set of documentary sources.
The need to organise and enrich sources with metadata and descriptive information introduces the role of Building SMART Data Dictionary (bSDD) to this research: a tool that can be interpreted not merely as a technical repository of terms, but as a semantic mediation layer situated between domain-specific taxonomies and formally operational ontologies within BIM-based knowledge environments.
A source classification allows for describing sources and their informative content with the intention of making analytical and critical processes machine-readable.
Instead of creating a new classification, the paper addresses the reuse of an already existing one, developed by the Infrastructure for Documentation of Virtual Reconstructions (IDOVIR).
The IDOVIR source taxonomy, which defines resource types and their attributes (Grellert et al., 2025), was translated into a bSDD framework to ensure semantic interoperability (Alexiev et al., 2023) and to enable the consistent exchange of heritage data across HBIM environments (Argasiński & Tomczak, 2025).

1.1 Virtual Reconstructions: Advances and Challenges

Virtual reconstruction of buildings that no longer exist or are only partially documented remains a topic that is still only partially explored. There are many reasons for this, including the heterogeneity of disciplines, the use of different tools and methods, and, at times, the diversity of dissemination purposes. Virtual reconstructions can generally be categorised into public representations and scientific reconstructions, which take the form of authentic three-dimensional critical editions.
The primary purpose of this type of content is to illustrate the critical process behind its creation, enriched by documentary and archival sources. In this context, a three-dimensional model based on dimensional and morphological features cannot fully reflect or visualise the architectural complexity to which it relates. In the field of digital cultural heritage (DCH), numerous exemplary cases have been developed to demonstrate the processes of virtual reconstruction in relation to the level of uncertainty of the sources used. The model then becomes an access point to information, which, when organised and discretised, serves as proof of its scientific validity. In this regard, the tools specific to Heritage Building Information Modelling (HBIM) can aid in visualising the knowledge-building process involved in virtual reconstructions.
In this context, the HBIM model developed for the preservation and enhancement of architectural heritage in evolution can serve as a repository of information associated with the corresponding three-dimensional component or semantically structured architectural element. Unfortunately, these platforms remain highly rigid for managing architectural heritage and require separate tools for geometric and information modelling, such as a visual programming language (VPL).
At the same time, in disciplinary fields tangential to the discipline of architectural representation, the need to create semantically organised information systems has long emerged in the field of archival and digital humanities, where knowledge modelling is

done through the creation and definition of ontologies that aim to represent and schematise reality according to classes and properties that define a specific domain of interest.

The element that combines the archaeological and architectural domains, despite the diversity of tools and methods used, is the need to create organized knowledge structures capable of making visible the connections between digital elements (3D models) and their representations, whether documents (1D), drawings (2D) or three-dimensional models obtained by reverse modelling processes from the digital acquisition of the real.

In this sense, knowledge representation systems, as HBIM models, are valuable tools for visualising the critical process of virtual reconstruction that succeeds in keeping track of paradata, defined as data about processes, as indicated and suggested by the London Charter (2009) (Denard, 2012) and the Seville Charter (2011) (Lopez-Menchero & Grande, 2011).

Most of the resulting approaches sought to address the archival and documentary complexity through digital storytelling to enrich interpretation, giving rise to virtual reconstructions, including the use of DOIs for 3D models and Virtual Reconstructions to track the provenance of data and paradata within the reconstruction processes (Van Horik et al., 2025).

Even if this approach could be considered ‘scientific’ from the humanities and historians’ perspective, which is used in the adoption of bibliographic and source references, it is completely far from following the FAIR principles (Wikinson et al., 2016) and far from an effective reuse of 3D data and information.

What is not clear in most humanities disciplines is the intrinsic value of 3D models and the 3D professional’s role in the reconstructive approach.

From architectural and archaeological perspectives, digital representations play a key role in modelling knowledge based on object-oriented semantics that reflect architectural construction practices. The HBIM framework is now commonly used to manage and represent geometric and informative knowledge for Built Heritage. It is possible, then, to use HBIM to link provenance data and information not to the entire built structure but to individual architectural elements, and to use HBIM models to represent lost or partially documented heritage.

Data and paradata can be linked and organised in the HBIM model, reflecting the aim of a real use of a 3D model as a research product (Kuroczyński et al., 2023; Apollonio, 2024).

The paper addresses this approach in the Theatre of Priene case study. The research aims to define a structured workflow for virtual reconstruction, entirely based on iconographic sources, and to organise these sources within a digital framework interoperable with HBIM environments through the development of a bSDD based on the IDOVIR taxonomy. The virtual reconstruction of archaeological evidence from different sources represents an essential field of experimentation for digital cultural heritage (DCH). Rather than a mere geometric restitution, the virtual model is conceived here as a critical reconstruction, capable of showing the interpretative reasoning and evidential basis of each hypothesis.

In this context, the concept of Level of Reference (LoR) becomes central: it expresses the documentary type of references associated with the reconstructed elements, making the connection between the model and its sources transparent and eventually measurable. The question we asked ourselves to assign the LoRef was: *which 3D elements of the view are based on the information in the resource I am analysing?*

2. Methodology

The methodological workflow proposed for the virtual reconstruction of the Theatre of Priene is founded on the integration of iconographic and documentary sources within an interoperable HBIM environment. The process begins with the systematic classification of all available references, archival drawings, excavation reports, photographs, and scholarly interpretations, according to the taxonomy defined by the IDOVIR infrastructure.

This taxonomy, designed to describe the typologies of documentation supporting virtual reconstructions, provides the conceptual basis for describing sources used as a specific Level of Reference (LoR) for each HBIM architectural element’s configuration. These LoRs are associated with the reconstructed elements in the HBIM model through colour-coded semantic labels, allowing the visualisation of the source provenance within the three-dimensional environment.

To address Open and FAIR principles the HBIM modelling process was divided in two interoperable steps that follows two main objectives:

- informative modelling: a project file for the management and classification of the sources compliant with IDOVIR bSDD
- geometric modelling: a project file for the HBIM model and visualisation of LoRef

Both project files can be used to analyse the data, paradata and 3D elements. In addition, each HBIM project can be exported in IFC format for online visibility and interoperability. These two project files, combined, constitute a Scholarly Critical HBIM Edition for Virtual Reconstruction of the Priene Theatre.

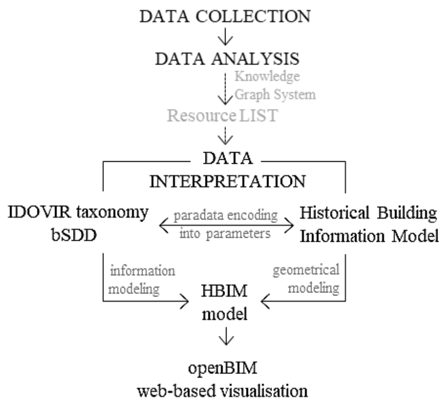

Figure 1. Methodological workflow (E.C. Giovannini).

The resulting workflow (Fig. 1), fully compliant with FAIR and openBIM principles, ensures the traceability of sources, the transparency of interpretative processes, and the reusability of data across digital heritage platforms.

By mapping the IDOVIR taxonomy into bSDD, the classificatory logic of sources is preserved while making it machine-readable and shareable, allowing interpretative knowledge to be consistently attached to BIM elements. This translation positions bSDD as an epistemic bridge between historical sources, paradata, and digital building models, supporting the controlled mediation of interpretation rather than its concealment and enabling the IDOVIR taxonomy to function as a reusable, transparent knowledge pattern within HBIM-driven virtual reconstruction processes.

3. Level of Reference (LoRef) as provenance path

Within HBIM-oriented research, several conceptual frameworks have been proposed to describe and qualify the nature of digital models and their associated information.

These diverse levels of knowledge were specifically developed for use within the HBIM framework for various purposes and are represented using different tools and methods (Tab. 1).

	Main aim	*Research question*	*Representation*
LoE	Temporal and configurational changes	Which historical or constructive phase is represented?	- Thematic and colored labelling (phase-based views)
LoR	Trustworthiness of model elements	How reliable is geometry or information?	- Thematic and colored labelling (custom views) - quantitative evaluation (numerical indicators)
LoH	Historical and documentary content	What historical knowledge is included?	- Thematic classification of historical data using VPL
LoRef	Source typology and provenance	Which references support this element?	- Thematic and colored labelling (custom views) - Classification of sources using bSDD

Table 1. Comparison between different Levels of knowledge used within the HBIM framework (E.C. Giovannini).

The Level of Evolution (LoE) focuses on the temporal and configurational development of the architectural object, describing successive historical or constructive states of the building and their representation within the model. It addresses when and how an artefact changes over time, without directly qualifying the epistemic strength of the data used (Bianchini & Nicastro, 2018a).

The Level of Reliability (LoR), instead, evaluates the degree of trustworthiness of the geometric and informative components of the model, explicitly distinguishing between measured data, documented evidence, and interpretative hypotheses. This level can be used to ensure transparency of the HBIM model, as it makes explicit the distance between the digital representation and the available sources (Bianchini & Nicastro, 2018b).

The Level of History (LoH) complements these approaches by incorporating non-computable historical knowledge, such as archival documentation, textual sources, and cultural interpretations, into the HBIM environment. While fundamental to understanding heritage, this level primarily qualifies the content of historical information rather than its direct operational role in shaping geometry or semantics (Brusaporci et al., 2021).

The proposed Level of Reference (LoRef) introduces a shift in perspective. Rather than directly measuring reliability, accuracy, or uncertainty, it classifies and formalises the types and natures of the sources used to generate each modelled element.

By explicitly linking every geometric or semantic component to its documentary references, the LoRef acts as a primary epistemic layer. Accuracy and uncertainty are not predefined attributes but emerge in a second stage from the critical evaluation of the references themselves, their typology, completeness, consistency, and interpretative distance (Giovannini, 2017).

In this sense, the LoRef does not replace existing levels but reorganises them within a source-driven framework, improving transparency, reproducibility, and interoperability in HBIM-based virtual reconstructions using the OpenBIM approach.

4. The IDOVIR source classification taxonomy

The Infrastructure for Documentation of Virtual Reconstructions (IDOVIR) is a methodological framework that formalises the epistemic foundations of source-based virtual reconstructions by systematically documenting the relationships among historical evidence, interpretative reasoning, and reconstructed outcomes (Wacker et al., 2025).

Rather than focusing solely on visual results, IDOVIR foregrounds paradata as a core research component, enabling the explicit recording and critical evaluation of the decisions that underpin the derivation of reconstruction hypotheses from heterogeneous sources. Central to this approach is a dedicated source classification taxonomy, developed to provide a consistent and reproducible structure for describing historical materials used in virtual reconstruction (Grellert et al., 2025).

The taxonomy organises sources into hierarchical categories, such as photographic representations, technical drawings, cartographic materials, written documents, and models, each further qualified by standardised attributes that articulate their intention, informational content, state of preservation, scale, and degree of interpretative mediation. By abstracting sources into a formalised descriptive system, IDOVIR taxonomy enables comparative analysis across reconstruction variants and supports the critical assessment of evidential reliability. Adopted within an HBIM framework, this taxonomy can function as a transferable analytical reference, facilitating the structured interpretation of historical drawings and archival resources and their integration into semantically enriched building models, while maintaining transparency, traceability, and scholarly reproducibility throughout the virtual reconstruction process.

4.1 A bSDD for the IDOVIR taxonomy

A bSDD data dictionary is a centralised repository of information about data, including meaning, relationships to other data, origin, usage, and format. It can be considered a database that contains metadata. Each bSDD consists of Classes and Properties, which may be related to each other or to other bSDD (e.g. IFC).

The bSDD template (Tomczak, 2025), developed by the Building Smart community, comprises a set of worksheets, each with fields and, where applicable, default values. The template collects diverse fields in accordance with ISO 23386:2020, which defines a methodology for describing, authoring, and maintaining properties in interconnected data dictionaries for building information modelling and other digital processes used in construction. The template comprises the following objects:

4.1.1 Class: A description of a set of objects that share the same characteristics.

4.1.2 Property: An inherent or acquired feature of an item (Class). The assignment of Properties to Classes is handled through the interim ClassProperty object.

4.1.3 ClassProperty: Each Class can have multiple properties, and each Property can be part of many Classes, but only one ClassProperty is always a pair of one Class and one Property.

Through ClassProperty, one can further specify a 'Property' by defining its unit or value restrictions.

4.1.4 AllowedValue: Optional value enumerations that can be listed for Properties and ClassProperties.

4.1.5 ClassRelation: Classes can be linked by relations. There are various types of relations, allowing for the definition of hierarchy, composition, similarity or reference.

4.1.6 PropertyRelation: Analogous to ClassRelations but between Properties.

Using the bSDD .xls template, you can develop a custom bSDD and publish it online for reuse across multiple projects.

The proposal for a bSDD of the IDOVIR taxonomy is an ongoing research effort to map each taxonomy category to a corresponding bSDD concept, along with its descriptive attributes and a possible list of values.

The IDOVIR taxonomy comprises 7 classes (Parent Classes) as follows:

1. PhotographicSource
2. TechnicalDrawing
3. CartographicSource
4. 3DModel
5. WrittenSource
6. ArtisticSource
7. ScientificAnalysisResult

In the IDOVIR bSDD, the IDOVIR_Source_category list is considered a list of bSDD Child Classes of objects.

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The IDOVIR_attributes can be considered bSDD Properties, and IDOVIR_values can be listed in the AllowedValue worksheet of bSDD. (Giovannini, 2026).
The development of a bSDD for IDOVIR taxonomy addresses, in this paper, the proposal for bSDD classes related to IDOVIR Technical illustrations of buildings and Movable Objects (Fig. 2).

2. Technical Illustrations of Buildings and of Movable Objects

Source category	Attribute	Values	Appl. to category
• Floor plan / ground plan • Section / profile • Elevation • Perspective	What is depicted? (M)	Interior • Exterior • Movable object • Urban space • Event • Architecture component • Sculpture • Topography	All
	Intention (M)	Preliminary design • Construction plan • Design or construction plan • General planning document • Reconstruction • Building survey/presentation of features • Presentation of findings • Documentation • Artistic documentation or representation • Functional representation	All
	State of preservation (M)	Preserved • Handed down • Accessible • Complete • Partial	All
	Information on colourfulness / materiality (M)	Colourfulness • Materiality	All
	Type of drawing (S)	Technical drawing • Freehand sketch	All
	Plan designation (B)	Yes • No	All
	Dimensioned (B)	Yes • No	All
	Vectorised (B)	Yes • No	All
	Scale bar (B)	Yes • No	All
	Scale (B,T)	Yes • No + Number	All
	Intersection line (B)	Yes • No	All
	Plan stamp (B)	Yes • No	All
	To scale (B)	Yes • No	All
	Coloured (B)	Yes • No	All
	Detailed plan (B)	Yes • No	All
	Height specifications (B)	Yes • No	Floor plan / ground plan
	North arrow (B)	Yes • No	Floor plan / ground plan

Figure 2. IDOVIR taxonomy for technical illustrations of buildings (Grellert et al., 2025).

Regarding the IDOVIR Source Categories of Technical Illustrations, this research follows a previous approach to classifying architectural representations (Giovannini, 2020). The approach assumes that published architectural representations generally include diverse views (e.g., plans, facades, and perspectives). Therefore, the taxonomy should be applied to portions of the same original source.
Ontologically speaking, these representations, as portions of the original layout, can be considered annotated portions of the original "digital image". A relationship between a primary source (image) and its derived sources (image annotations) was already formalised using the CIDOC-CRM standard and its graphical representation on the ResearchSpace platform (Oldman & Tanase, 2018).

IDOVIR taxonomy	*bSDD IDOVIR classification*
floor plan/ground plan	section
section/profile	detail
elevation	elevation
perspective	perspective

Table 2. IDOVIR taxonomy compared with the new classification for IDOVIR bSDD (E.C. Giovannini).

Another consideration in the definition of bSDD classes concerns the type of sources: in IDOVIR Categories, there is a distinction between "floor plan/ground plan" and "section/profile". These two categories formally represent diverse types of sections, while a category related to "detail" is missing (Tab. 2).
The classes and attributes of the IDOVIR source classification taxonomy were formalised using the template, which enables the transformation of taxonomic structures into semantically identifiable and interoperable concepts. In a first step, the main categories of the IDOVIR taxonomy were modelled as bSDD classes (Fig. 3), preserving their original hierarchical organisation. Subsequently, the descriptive attributes of the taxonomy were defined as properties (Fig. 4) and selectively associated with the relevant classes to retain the information's interpretative nature.
The dictionary was then uploaded to the bSDD platform, making the classes and properties available via persistent identifiers and enabling their reuse in HBIM environments supporting semantic coherence, interoperability, and data reusability.

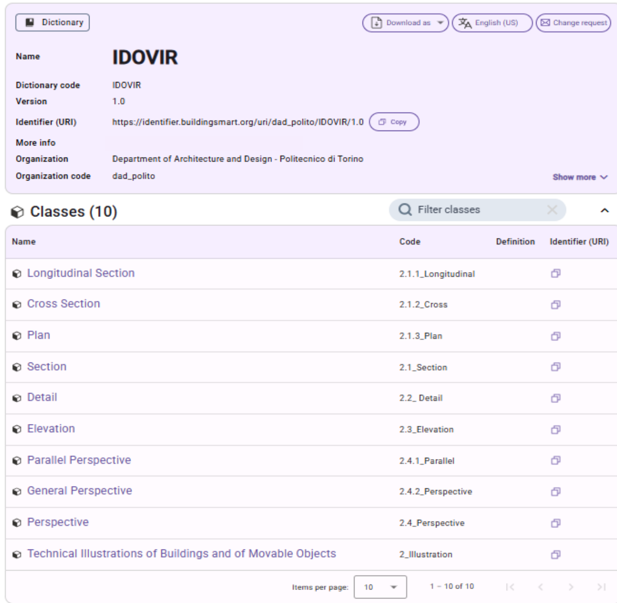


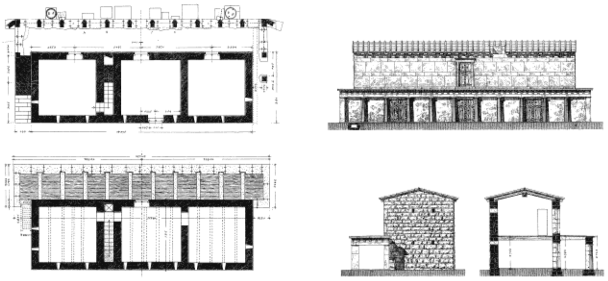
Figure 3. IDOVIR bSDD Dictionary platform with the ParentClasses and ChildClasses (E.C. Giovannini).

Code	Name	Definition	DataType
Represent	Represent	Represent	String
Intention	Intention	Intention	String
StateOfPreservation	StateOfPres	State of preservation	String
Pr_Material	Property_Material	has material	Boolean
Pr_Colour	Property_Colour	has colour	Boolean
Pr_Type	Property_Type	has type	Boolean
Pr_Dimension	Property_Dimension	has dimension	Boolean
Pr_Vectorialised	Property_Vectorialised	is vectorialised	Boolean
Pr_ScaleBar	Property_ScaleBar	has scale bar	Boolean
Pr_ScaleNumber	Property_ScaleNumber	has number	Boolean
Pr_Scale	Property_Scale	has scale	Boolean
Pr_Measurements	Property_Measurements	has measurements	Boolean
Pr_Unit	Property_Unit	has unit	Boolean

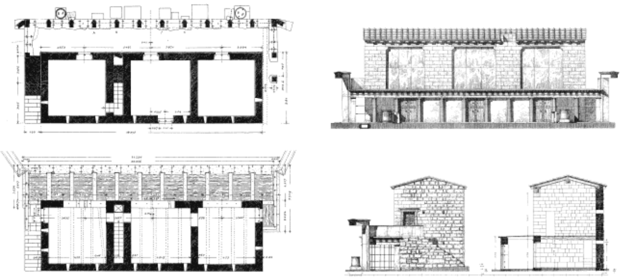
Figure 4. Properties of the IDOVIR bSDD (E.C. Giovannini).

5. Historical documentation of Priene Theatre

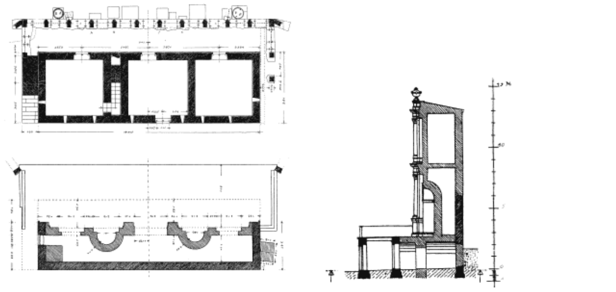
The virtual reconstruction of the Priene Theatre is based on analysing documentation produced during the excavation campaigns of the Deutschen Archäologischen Instituts (DAI) to reproduce and represent information using the HBIM methodology. The first step consisted of analyzing the drawings and documents made by archeologists who interpreted the ruins of the Theater. The literature analyzed in this study refers to German studies that allowed us to delve into the vicissitudes of the Theater's change over the centuries to its present-day configuration (Shumacher & Misiakiewicz, 2007).
The Priene Theater is one of Minor Asia's best-preserved 3rd-century scenic architectural works. Its preservation is due to the intensive research and study conducted after its discovery during the Priene excavations from 1895 to 1899.



Hellenistic era *(Gerkan, 1921, Tafel XXXI-XXXII)*



Late Hellenistic age *(Gerkan, 1921, Tafel XXXII-XXXIII)*



Roman time *(Gerkan, 1921, Abb. 9-10, pp. 83-84)*

Figure 5. The diverse configurations of Priene Theatre: plans, sections and facades (E.C. Giovannini).

The main periods of studying the Theater as the object of investigation started in 1911/12 with structural analyses on the site conducted by archaeologist Armin Von Gerkan.
In 1921, the archeologist wrote the first monograph on the theater ruins and evidence. The DAI in Istanbul (1977) successfully conducted seven excavation campaigns from 1998 onward.
The numerous investigations and studies conducted on the Theatre of Priene have helped to clarify how the archaeological site has changed over time (Fig. 5), highlighting its complex layers. As described by Gerkan (1921), these historical 'layers' can be summarised as follows:

- the Hellenistic era configuration, with a proscenium composed of two levels with central door.
- the late Hellenistic age, a three-way proscenium.
- the Roman time, which considers the proscenium richly decorated by a *scenae frons* with two levels.

Nowadays the ruins of the *cavea* shows the initial Hellenistic era configuration (Tafel XXXII), while late Hellenistic age (Tafel XXXIV) has disappeared.

6. The HBIM geometric modelling using (LoRef)

Historical documentation, survey drawings, pictures, and data of the archaeological site acquired using a UAV system (Giovannini et al., 2023; Giovannini et al., 2024) were used to HBIM model and align the diverse phases (4D).
The development of an HBIM model based on heterogeneous historical sources follows a progressive, source-driven workflow in which geometric construction and information modelling evolve in parallel through successive interpretative steps. Rather than starting from a predefined geometric completeness or proportional approach, the process is grounded in the critical analysis and classification of available references, including measured drawings, archival plans and elevations, sections, and interpretative reconstructions by Gerkan (1921).
The HBIM model was created through an initial modelling phase. System families were primarily used to define the building's architectural framework, ensuring geometric continuity, parametric coherence, and stable relationships between elements. As the model evolves, loadable families were introduced for architectural components that show typological recurrence alongside historical specificity, such as semi-columns, openings, beams, stairs, and decorative or constructive details (Fig. 6).

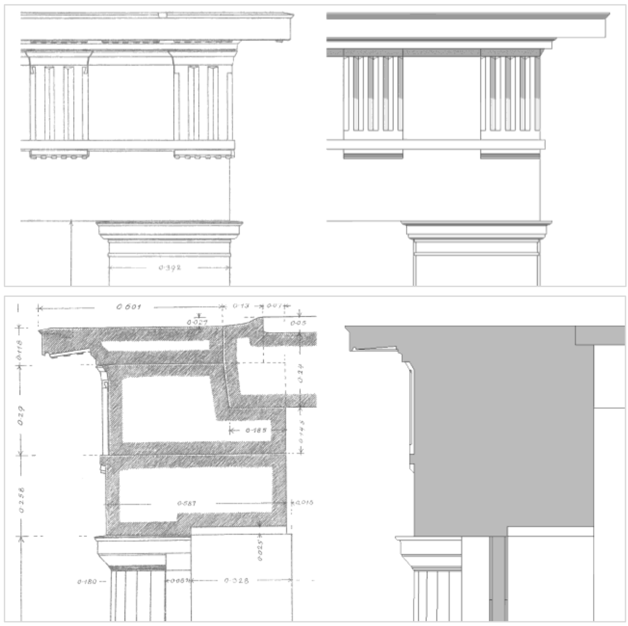


Figure 6. Details of the Prosceniums: comparison between the source on the left (Tafel XIX) and the HBIM model (J. Bono).

To manage the temporal articulation of the Theatre of Priene within the HBIM environment, a phase-based filtering system was implemented to explicitly represent the monument's three main evolutionary configurations: Hellenistic, late Hellenistic, or Roman (Fig. 7).
The HBIM modelling was driven not by a desire for exhaustive detail but by the nature of the sources and the level of knowledge they provide, encoded by the Level of Reference (LoRef).
Phase filters were then configured to selectively visualise each state (4D) and each LoRef, allowing multiple configurations to coexist within a single HBIM model while preserving their chronological order. This approach supports comparative analysis across phases and avoids the need for separate models for each historical configuration, thereby representing its historical evolution (Fig. 8).
Then, additional thematic view filters were used to indicate the Level of Reference (LoRef) for each source used in the modelling process (e.g. Tafel XXXI to XXXIII), allowing tracing of the paradata construction's provenance. Visual differentiation is achieved through colour-based representation, enabling immediate distinction between elements derived from sources and supporting comparative analysis and interpretative hypotheses. By combining phase filters and LoRef-based thematic colouring, the HBIM model serves as a readable, transparent system that simultaneously conveys temporal evolution and source provenance (Fig. 9).

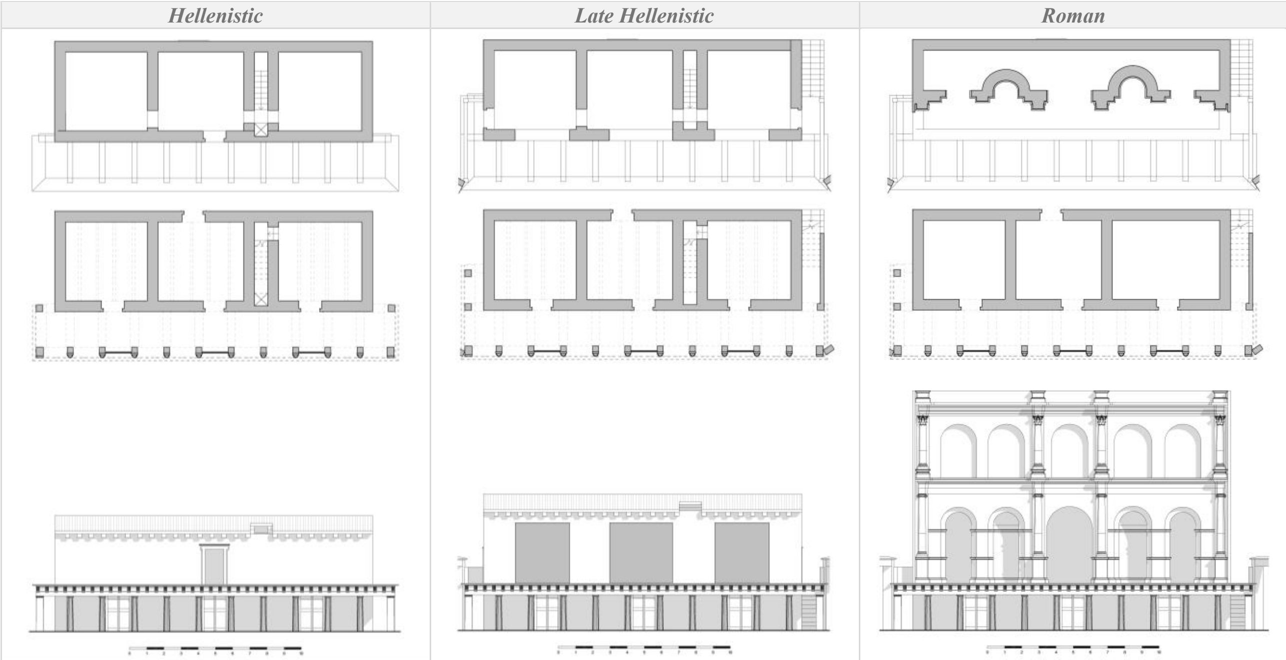


Figure 7. The HBIM model views of the different configurations of the Priene Theatre: plans and facades (J. Bono).

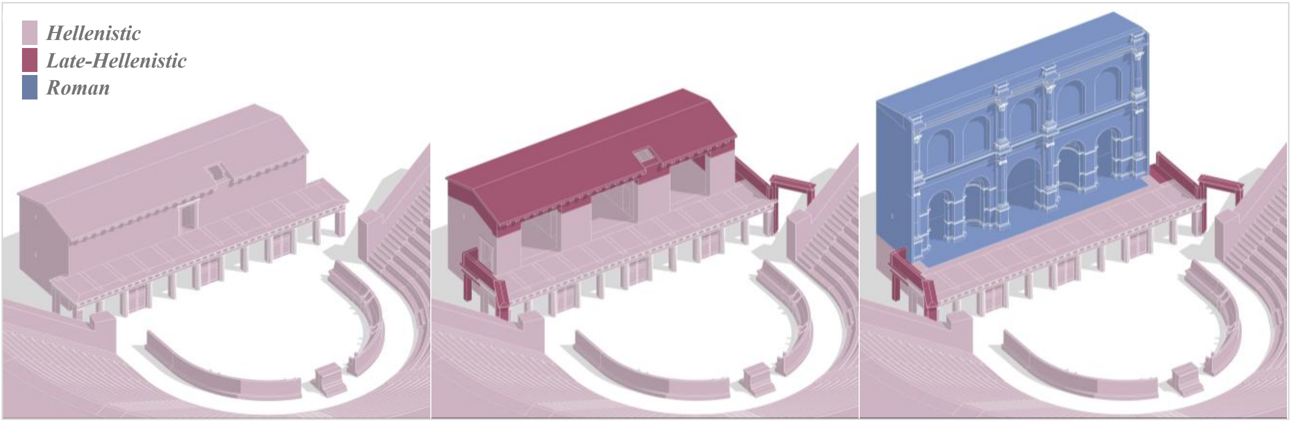


Figure 8. 3D views of Priene Theatre and its evolution, labelled by phase colours (J. Bono).

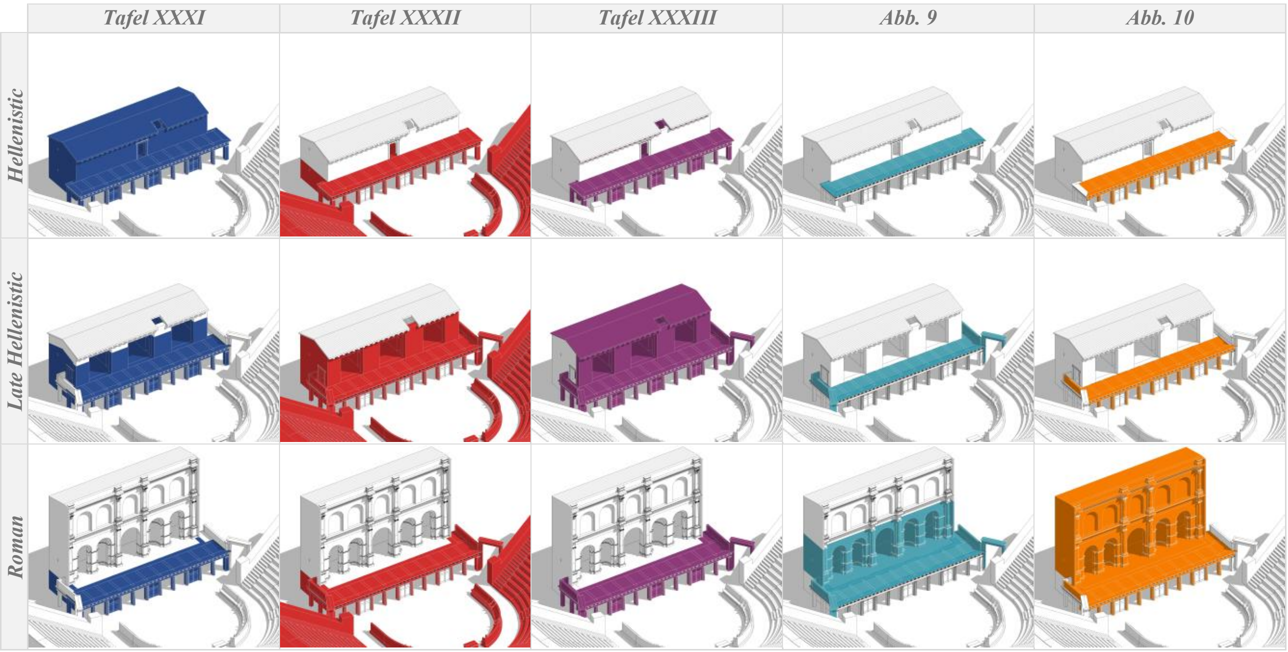


Figure 9. Matrix of comparison between LoRef and phases. Labelled HBIM views of the Priene Theatre (J. Bono).

7. The HBIM informative modelling using bSDD IDOVIR

One of the main challenges in defining the methodology for this research was ensuring a consistent, interoperable workflow between geometric modelling and information management. Interoperability is therefore closely tied to the formats in which the HBIM model and its associated information can be exported and reused over time.

Regarding geometry, exporting the model in IFC format enables effective reuse of the 3D data across different software environments. However, the intention to use the HBIM model as a medium for documenting the virtual reconstruction process revealed a critical limitation of current BIM authoring tools: the inability to directly associate a structured semantic information system with iconographic resources embedded in the project file. To overcome this limitation, a second HBIM model was developed as a structured catalogue of iconographic references used in the geometric modelling process.

Within this catalogue, images were added as Generic Model families, enabling them to be enriched with semantic information derived from the IDOVIR taxonomy and formalised through the bSDD.

This approach enables image-based resources to be progressively enriched and maintained over time, transforming them into a structured, queryable archive of references that can be consistently linked to the geometric model. Using the buildingSMART bSDD plug-in, currently compatible with Autodesk Revit 2023 and 2024, standardised parameters were assigned to each Generic Model instance to describe the attributes of the associated resource (Fig. 10).

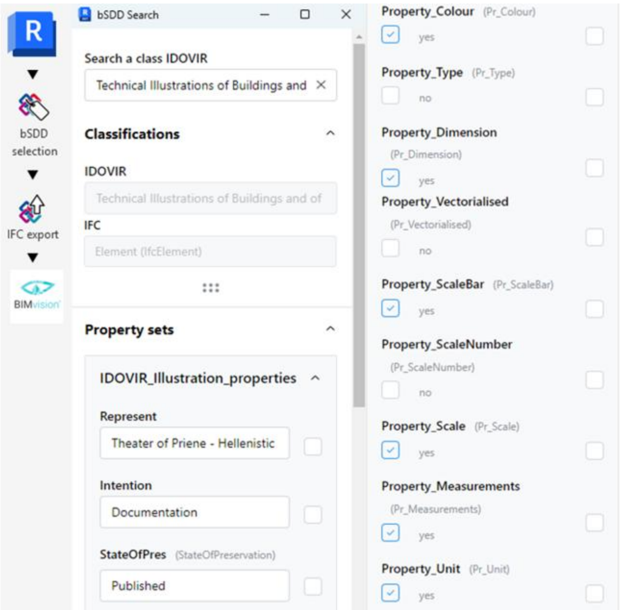


Figure 10. The UI of the bSDD manager (E.C. Giovannini).

Once semantically enriched, the HBIM file can be exported to IFC format and visualised as a three-dimensional model, ensuring that both geometry and information are organised in a structured, interoperable manner.

This workflow enables the integration of geometric data and documentary references within a single openBIM framework, supporting transparency, reuse, and long-term accessibility.

Images and documentary sources can be systematically classified, queried, and validated, while ensuring traceability between visual evidence, semantic taxonomy, and the resulting reconstruction hypotheses within the HBIM environment.

8. Conclusions

This research demonstrates that a source-driven HBIM workflow based on the Level of Reference (LoRef) is an effective method for documenting and managing virtual reconstructions of archaeological architecture.

Integrating the IDOVIR Source Classification Taxonomy into the bSDD enables the semantic formalisation of source typologies and ensures interoperability across openBIM-compliant platforms.

Rather than treating accuracy or reliability as fixed attributes, the LoRef framework establishes a primary information layer from which qualitative and quantitative evaluations can be derived in a subsequent analytical phase, based on the nature and consistency of the sources.

The case study of the Theatre of Priene confirms that semantically enriched HBIM models can serve not only as geometric representations but also as structured knowledge systems that support scientific validation, comparative analysis, and dissemination. The proposed workflow is transferable to other contexts of virtual reconstruction and contributes to the development of reproducible, interoperable, and transparent digital practices in archaeological and architectural heritage research.

Limitations of the current approach include the manual effort required for source classification and semantic mapping, as well as reliance on BIM authoring tools not natively designed for heritage-oriented knowledge modelling.

Future work will focus on mapping all classes of the IDOVIR taxonomy in the bSDD, automating parts of the LoRef assignment using rule-based or graph-driven methods (Giovannini, 2025), extending the workflow to additional case studies, and enhancing integration with web-based and extended-reality platforms to enable broader dissemination and reuse.

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Although the contribution was conceived jointly, E.C. Giovannini wrote paragraphs 2, 3, and 4. J. Bono wrote paragraphs 5, 6, and 7. Paragraphs 1 and 8 were written jointly by the authors.

References

Alexiev, V., Radkov, M., & Keberle, N., 2023. Semantic bSDD: improving the GraphQL, JSON and RDF representations of buildingSmart data dictionary. *Linked Data in Architecture and Construction Workshop*, 85-97.

Apollonio, F.I. 2024. The Three-Dimensional Model as a 'Scientific Fact': The Scientific Methodology in Hypothetical Reconstruction. *Heritage*, 7(10), 5413-5427. dx.doi.org/10.3390/heritage7100255

Argasiński, K., Tomczak, A. 2025. Enhancing semantic interoperability of heritage BIM-based asset preservation. *Heritage*, 8(10), 1-15. doi.org/10.3390/heritage8100410

Bianchini, C., Nicastro, S. 2018a. From BIM to H-BIM. *3rd Digital Heritage International Congress - Digital HERITAGE held jointly with 24th International Conference on Virtual Systems & Multimedia* (VSMM 2018). IEEE, 1-4. 10.1109/DigitalHeritage.2018.8810087

Bianchini, C., & Nicastro, S., 2018b. The definition of the level of Reliability. A contribution to the transparency of historical-BIM processes. *3D Modeling&BIM. Nuove Frontiere*. DEI Tipografia del Genio Civile, Roma, 208-225.

Brusaporci S., Tata A., Maiezza P., 2021. The "LoH - Level of History" for an Aware HBIM Process. *Connecting. Drawing for weaving relationship. Languages Distances Technologies. Proceedings of the 42th International Conference of Representation Disciplines Teachers*. FrancoAngeli, Milano, 2110-2118. doi.org/10.3280/oa-693.79

Castellano-Román, M., & Pinto-Puerto, F., 2019. Dimensions and levels of knowledge in heritage building information modelling, HBIM: The model of the Charterhouse of Jerez (Cádiz, Spain). *Digital Applications in Archaeology and Cultural Heritage*, 14. doi.org/10.1016/j.daach.2019.e00110

Demetrescu, E., & Ferdani, D., 2021. From field archaeology to virtual reconstruction: A five steps method using the extended matrix. *Applied Sciences*, 11(11), 1-23. doi.org/10.3390/app11115206

Denard, H., 2012. A new introduction to the London Charter. *Paradata and Transparency in Virtual Heritage*. Routledge, London, 57-71.

Dörpfeld, W., 1924. Das Theater von Priene und die griechische Bühne. *Mitteilungen des Deutschen Archäologischen Instituts, Athenische Abteilung*. Archäologisches Institut, Berlin, 50–101.

Gerkan, A.V., 1921. Das Theater von Priene, als Einzelanlage und in Seiner Bedeutung für das hellenistische Bühnenwesen. Schmidt, Muenchen.

Giovannini, E.C., 2017. VRIM workflow: semantic H-BIM objects using parametric geometries. *3D Modeling&BIM. Progettazione, design, proposte per la ricostruzione*. DEI Tipografia del Genio Civile, Roma, 212-229.

Giovannini, E.C., 2020. Analyzing architectural representations with a Knowledge Graph System. *Dwelling on Earth/Abitare la Terra*, 6, 26-27.

Giovannini, E.C., 2025. VRIM workflow: semantic H-BIM objects using parametric geometries. In *3D Modeling&BIM. Progettazione, design, proposte per la ricostruzione,* pp. 212-229. DEI Tipografia del Genio Civile, Roma.

Giovannini E.C., 2026. IDOVIR bSDD at bSDD platform. buildingSMART Data Dictionary. https://search.bsdd.buildingsmart.org/uri/dad_polito/IDOVIR/1.0 (22 January 2026)

Giovannini, E.C., Tomalini, A., Bono, J., Pristeri, E., 2023. 3D Outputs for an Archeological Site: The Priene Theater. *Beyond Digital Representation: Advanced Experiences in AR and AI for Cultural Heritage and Innovative Design*. Springer Nature Switzerland, Cham, 621-638. doi.org/10.1007/978-3-031-36155-5_40

Giovannini E.C. & Torresi L. (2024). *Prefiguration and configuration of Dynamic Models for digital environments: the Mole Antonelliana in 3D.* Measure/Out of Measure. Transitions. Proceedings of the 45th International Conference of Representation Disciplines Teachers. FrancoAngeli, Milano, 2971-2994. dx.doi.org/10.3280/oa-1180-c622

Giovannini, E.C., Verdiani, G., & Cardinali, V., 2024. Priene, a Monumental Disaster in the Aegean: Digital Approaches to the Doric Stoa's and the Theater's Lost Evidence. *Heritage*, 7(8), 4538-4561. doi.org/10.3390/heritage7080214

Grellert, M., Wacker, M., Bruschke, J., Clausen, C., & Beck, D., 2025. *Source Classification Taxonomy for Virtual Reconstructions (v. 0.1.1).* doi.org/10.5281/zenodo.17661581

International Organization for Standardization, 2020. Building information modelling and other digital processes used in construction. Methodology to describe, author and maintain properties in interconnected data dictionaries (ISO Standard No. 23386:2020).

Koenigs, W., 2009. Priene: Die Anastilosis des Theater. *Schutzbauten und Rekonstruktionen in der Archäologie : Von der Ausgrabung zur Präsentation*, B.O.S.S Druck und Medien, Goch, 415–426.

Kuroczyński, P., Apollonio, F.I., Bajena, I.P., and Cazzaro, I., 2023. Scientific Reference Model - defining standards, methodology and implementation of serious 3d models in archaeology, art and architectural history. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-M-2-2023*, 895-902. doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-895-2023

Lopez-Menchero, V. M., & Grande, A., 2011. The principles of the Seville Charter. In *CIPA symposium proceedings* 2011, 2-6.

Oldman, D., & Tanase, D., 2018. Reshaping the knowledge graph by connecting researchers, data and practices in ResearchSpace. *International Semantic Web Conference*. Springer International Publishing, Cham, 325-340. doi.org/10.1007/978-3-030-00668-6_20

Sanseverino A. & Giovannini, E.C., 2026. EM-BIM: VPL interoperable processes for paradata management in archaeological virtual reconstructions using Extended Matrix (EM) and bSDD as knowledge representation systems. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*

Schumacher, A., Misiakiewicz, J., 2007. *Priene: die Restaurierung des Theaters 1992-1998*. Verlag Philipp von Zabern, Mainz am Main.

Tomczak A. (2025.11.18) Excel2bSDD_template, v. 5.0. https://github.com/buildingSMART/bSDD/blob/1ebd340de2d47ef3d5c462865390ef9eae291b1e/Model/Import%20Model/spreadsheet-import/Excel2bSDD_template.xlsx%20 (22 January 2026)

Van Horik, R., Saldner, S., Gilissen, V., & Papadopoulos, C. 2025. Making 3D Scholarly Editions Reusable: A step-by-step guide for depositing FAIR 3DSEs (v.2.0). doi.org/10.5281/zenodo.16779822

Wacker, M., Grellert, M., Stille, W., Bruschke, J., & Beck, D. 2025. IDOVIR Infrastructure for Documentation of Virtual Reconstructions: Towards a Documentation Practice for Everyone. *Heritage*, 8(8), 1-16. doi.org/10.3390/heritage8080328

Wiegand, T., Schrader, H., 1904. *Priene: Ergebnisse der Ausgrabungen und Untersuchungen in den Jahren 1895–1898*. Reimer, Berlin.

Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., et al., 2016. The FAIR Guiding Principles for scientific data management and stewardship. *Scientific data*, 3(1), 1-9. doi.org/10.1038/sdata.2016.18