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SEMANTIC METADATA AND LEXICAL STANDARDS FOR ARCHITECTURAL HERITAGE DOCUMENTATION

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Digital technologies are becoming increasingly essential for documenting, conserving, and disseminating knowledge of cultural heritage. A notable transition from traditional archival methods to advanced digital representations is evident, particularly in the context of cultural heritage data. Metadata, functioning as descriptive information, is crucial in systematically organising data generated while developing digital representations of cultural heritage structures. It consistently requires a comprehensive metadata schema to effectively display architectural structures with their contextual richness and the different technologies used. Widely adopted metadata standards provide essential descriptive metadata; however, they often lack specific fields needed to capture detailed administrative-technical data of 3D models – such as acquisition methods, geometric details, and accuracy metrics – elements crucial for assessing the authenticity and scholarly value of these digital representations. Such digital structures need precise information about the technologies and processes used in their creation to ensure accuracy and interoperability. This study examines the need for a more comprehensive metadata schema designed explicitly for 3D models of architectural heritage, emphasizing the importance of a lexical standardization approach to represent its multifaceted nature. 3D documentation techniques, such as photogrammetry and laser scanning, produce a large volume of complex and multilayered data whose management requires structured descriptive systems. The proposed metadata schema aims to standardize the extensive volume of supporting data generated by these methodologies, thereby facilitating the creation of semantically rich metadata that enhances the accessibility and retrieval of heritage information.

Keywords: *Semantic metadata, Lexical standardisation, Digital Heritage, 3D models, Heritage Informatics.*

Introduction

The preservation of cultural heritage is fundamental, as it ensures the protection of the distinctive identities, knowledge systems, and traditions of communities globally. The protection of cultural heritage is increasingly recognized as a key pillar of sustainability, as cultural resources play a vital role in shaping social identity, preserving collective memory, and enhancing community resilience[1]. Serving as a key preliminary action, documenting both tangible and intangible cultural heritage is essential for improving its preservation and effectively transferring knowledge to the public. However, many historic buildings lack proper preservation, documentation, and technical information due to limited funding, lack of expertise, low awareness of heritage conservation, and data accessibility. Further, traditional methods often rely on manual documentation, which is time-consuming and susceptible to errors[2]. Adequate documentation is crucial for conservation, especially as many structures face threats of encroachment and destruction. Cultural heritage institutions and public administrations have undertaken substantial initiatives to digitize cultural heritage sites, artifacts, and historical documents for their digital preservation. As cultural heritage has continually progressed, the approaches to conserving, preserving, and exhibiting such heritage have increasingly incorporated digital technologies in recent years. In contemporary times, digital networking has significant potential to facilitate broad and equitable access to the texts, objects, sounds, and sights that constitute our global cultural heritage[3]. Digital technologies redefining how we docu-

1 Zhou, Xue, Wei, *The Emotional Foundations of Value Co-Creation in Sustainable Cultural Heritage Tourism: Insights into the Motivation–Experience–Behavior Framework.*
2 Abdelalim, *Heritage Preservation Using Laser Scanning: ArchitecturalDigital Twins Using Al-Mu'izz Street as a Case Study.*
3 Green, *A View from the Top: A Special Message for Administrators ofCultural Heritage Collections.*

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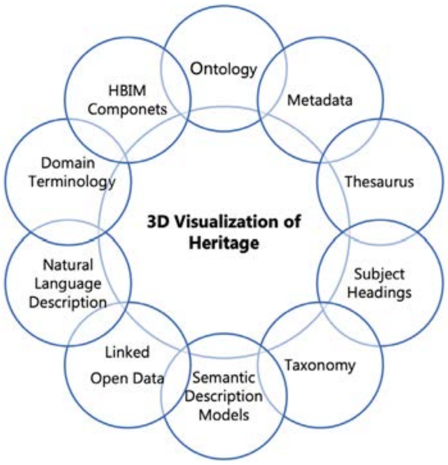
ment, safeguard, and experience heritage – revealing possibilities once beyond imagination. Developing digital cultural heritage greatly enhances a nation's identity and improves resource accessibility, reaching broader and more diverse audiences. UNESCO defined digital cultural heritage as digital materials that include texts, databases, still and moving images, audio, graphics, software, and web pages, among a wide and growing range of formats. They are frequently ephemeral and require purposeful production, maintenance, and management to be retained[4]. Advances in technology have made documenting these structures and processing their data easier than ever, helping the current generation understand heritage values and aiding in their protection, monitoring, and interpretation. This allows even ordinary users to gain a deep understanding of cultural diversity without needing to visit in person. According to UNESCO's *Charter for the Preservation of Digital Heritage*, the resources encapsulating human knowledge or expression – whether cultural, educational, scientific, administrative, technical, legal, medical, or other types of information – are progressively being generated digitally or converted into digital formats from existing analogue sources[5]. Many have created portals that offer access to 3D modeling of artifacts, built environments, and social settings as part of their restoration or reconstruction efforts. These initiatives are sometimes supported by international organisations such as UNESCO and ICOMOS, as well as national public institutions and non-governmental organisations involved in cultural heritage preservation. Furthermore, such platforms increase visibility and can foster collaboration among professionals, experts, architects, researchers, and Galleries, Libraries, Archives, and Museums (GLAM) institutions, thereby improving preservation, conservation, management, and documentation processes through effective communication and the use of advanced technologies.

Digital Tools and Techniques for Architectural Heritage Documentation

Documentation of architectural heritage involves 3D modelling of geometry and management of semantic knowledge information[6]. Documentation may include drawings, photographs, images, records of alterations, architectural designs, and structural details from different periods, helping trace historical transitions. Additionally, documenting ornamentations, sculptures, tiles, vocabularies, and other decorative elements is essential. The cultural heritage sector employs a range of tools and techniques to enhance architectural preservation and revive lost splendor. Modern methods, such as digitisation, Heritage Building Information Modeling (HBIM), 3D modeling, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), assist in documentation and virtual reconstruction, enabling efficient management and long-term quality control. These hybrid methodologies support the transition from static heritage record-keeping to an interactive, semantically structured digital representation[7]. These interconnected ecosystems can further enhance visitor experiences through visual displays and exploration. Creating such intelligent 3D models of cultural collections presents new challenges for GLAMs and cultural institutions, including storage, conservation, preservation, classification, and visualisation, particularly after digitisation. Providing accompanying information for these models is also vital. The processes of conserving, restoring, and reconstructing artifacts, buildings, and monuments at various stages can be documented with informatics tools to foster contextual understanding and engage users. Recording measurements, including 2D and 3D data, and making these accessible to the public enables experts to evaluate, comment on, and utilize them for educational purposes, research, business opportunities, and promoting cultural tourism. Digital representations of plans, elevations, topologies, columns, dimensions, and architectural and interior designs – whether existing or proposed – can be organised and shared more effectively with the global research community by adopting

4 UNESCO *Charter on the Preservation of the Digital Heritage 2003*.
5 UNESCO *Charter on the Preservation of the Digital Heritage, 2009*.
6 Xiucheng, Grussenmeyer, Koehl, Macher, Murtiyoso, *Landes, Review of Built Heritage Modelling: Integrationof HBIM and Other Information Techniques*.
7 Abdelalim, *Heritage Preservation Using Laser Scanning*, cit.
8 Lutteroth, Kuroczyński, Bajena, *Digital 3D Reconstructions of Synagogues for an Innovative Approach on Jewish Architectural Heritage in East Central Europe*.



1 | *Components of semantic annotation of a cultural heritage image.*

informatics as a tool. Virtual exhibitions showcasing historic cultural heritage structures can deepen understanding of their architecture and traditions. The results of a digital 3D reconstruction, such as 3D models, should be enriched with information that allows for the identification of model accuracy and its classification, especially in terms of its constructive aspects[8]. The 3D representations should go beyond current standards of visual depiction, facilitate data integration and connections, enable shape analysis, and provide vital semantic information to support comprehensive research by both scientists and users. In recent years, semantically enriched 3D models have emerged as comprehensive virtual representations of physical assets or systems by integrating diverse data sources, including real-time sensor inputs, historical records, and simulation models[9]. Fig. 1 indicates the significant components of a 3D architectural heritage semantic model. Data standards and structured resources, such as taxonomies and thesauri, facilitate data-level standardisation but are often specific and not easily applicable across broad, heterogeneous collections[10]. The use of ontologies and linked data promotes interoperability and lexical standardisation, while also supporting documentation and 3D reconstruction. However, effectively utilizing metadata structures is vital in a cultural heritage system to achieve meaningful audience engagement. Implementing standardisation in technical vocabularies and descriptors enhances interoperability and facilitates the documentation of cultural heritage assets. While digital images commonly store basic metadata about their creator, date, title, and brief descriptions, the absence of contextual information about the cultural contents, the most valuable information embedded, is not explicitly annotated and utilised[11].

Metadata and Digital Representation in Architectural Heritage Documentation

Advanced digital tools and technologies effectively represent and restore historical contexts, preserve embedded knowledge, and support semantically enriched metadata to enhance understanding and ensure long-term sustainability[12]. Metadata, serving as descriptive information, is essential for systematically organizing data produced during the development of digital representations of cultural heritage structures. Metadata are essential components of digital archives, defining digital and physical resources to improve discovery and interoperability. As digital objects differ in techniques, technologies, geometries, and accuracy levels, standardised frameworks are required. It conveys the meaning of data, helps locate it, enables retrieval and access, supports interpretation, specifies usage conditions, documents its history and ownership, and links it to other resources, thereby aiding in data management and control[13]. Metadata thus plays a vital role in facilitating the creation, organisation, description, identification, and access to information resources. Improving descriptive metadata is key to enhancing data management, discoverability, and standardisation.

In architectural heritage documentation, metadata is closely linked to 3D data acquisition and digital modelling processes. The methods of modeling (or 3D data acquisition) should also be documented, along with the hardware and software used[14]. Scanning the interiors and exteriors of architectural buildings is complicated due to their size and intricate details, which make comprehensive scanning challenging – especially when capturing complete surface, colour, and texture information in a single session. Such data collection is crucial for creating accurate 3D representations of interiors and decorative components. Technologies such as photogrammetry, laser scanning, and 360-degree panoramic cameras are now prevalent acquisition techniques for capturing high-quality textures and precise geometric data, enabling the generation of accurate 3D models of heritage structures. These data are processed into dense point clouds and textured meshes to form comprehensive digital reconstructions[15]. Laser scanning, in particular, is effective for digitizing sculptures; however, it requires careful selection of scanning parameters and the number of exposures[16].

9 Lutteroth, Kuroczyński, Bajena, *Digital 3D Reconstructions of Synagogues for an Innovative Approach on Jewish Architectural Heritage in East Central Europe.*
10 Belteki, Rees, Sichani, *Datafication andCultural Heritage Collections Data Infrastructures: Critical Perspectives onDocumentation, Cataloguing and Data-Sharing in Cultural Heritage Institutions*
11 Abgaz, Rocha Souza, Methuku, Koch, Dorn, *A Methodology for Semantic Enrichment of Cultural Heritage ImagesUsing Artificial Intelligence Technologies.*
12 Miłosz, Kęsik, Montusiewicz, *Three-Dimensional Digitization of Documentation and Perpetual Preservation of Cultural HeritageBuildings at Risk of Liquidation and Loss – The Methodology and Case Study of St.Adalbert's Church in Chicago.*
13 Iannella, Waugh, *Metadata: enabling the Internet.*
14 Bajena, Kuroczyński, *Metadata for 3D Digital HeritageModels: In the Search of a Common Ground.*
15 Zachos, *Anagnostopoulos, Using TLS, UAV,and MR Methodologies for 3D Modelling and Historical Recreation of Religious Heritage Monuments.*
16 Miłosz, Kęsik, Montusiewicz, *Three-Dimensional Digitization of Documentation and Perpetual Preservation of Cultural HeritageBuildings at Risk of Liquidation and Loss – The Methodology and Case Study of St.Adalbert's Church in Chicago.*

Since these heritage structures often generate extensive datasets, it is important to store metadata in standardised formats for efficient retrieval, analysis, and historical interpretation. Metadata facilitates discoverability, interoperability, and long-term sustainability, emerging not merely as an organisational tool but as a mediating force in the epistemology of historical understanding[17]. Beyond producing photorealistic three-dimensional models, digital documentation generates a complex ecosystem of descriptive, structural, and semantic metadata that shapes how heritage is perceived and studied. The organisation and interpretation of these digital artefacts depend on metadata structures that connect technological precision with cultural significance. However, a lack of standardisation persists in providing comprehensive metadata details, particularly technical data such as acquisition methods, geometric specifics, and accuracy metrics, which are vital for ensuring authenticity and interoperability.

Technical and Descriptive Metadata in 3D Heritage Documentation

Metadata plays a vital role in the three-dimensional representation of heritage objects, providing users with essential information about what a digital model conveys. The depth of knowledge embedded in a digital structure increases with the quantity and quality of metadata linked to the object, which is crucial for enhancing discovery, access, and overall preservation of cultural heritage. Technical metadata, in particular, offers important details about the technical attributes of digital content. It enhances conservation workflows, ensures accurate documentation and analysis, addresses data quality concerns, and facilitates effective management and interpretation of built heritage. This is important because the capturing and processing stages are often carried out on local computers and are not shared externally[18]. The creation and management of cultural heritage repositories are key to digitisation efforts, with current research focusing on applying metadata standards to improve repository discoverability and user experience[19].

Detailed and specific information about the 3D modeling process – such as techniques used, hardware and software employed, model resolution, and accuracy – should be prioritised over purely aesthetic visual results. Sketchfab, Europeana, CyArk, Małopolska's Virtual Museums, and Tirtha are among the prominent repositories of 3D models. However, an examination of repositories like Sketchfab or the Smithsonian (2018) shows that many digitised objects are created using undocumented methods and lack contextual metadata[20]. Furthermore, other models, such as Europeana, do not explicitly include a rich technical metadata schema; hence, one can question the scientific credibility and authenticity of the model created. Consequently, these models often focus more on visual appeal and technological display than on meaningful documentation and interpretive value.

To guarantee the richness and reusability of 3D heritage models, a well-organised metadata framework is necessary. Core metadata categories include: descriptive metadata (e.g., building name, location, type); administrative–preservation metadata (e.g., file format, version, storage information); administrative–technical metadata (e.g., camera specifications, LiDAR resolution, photogrammetry software, flight path, timestamps); administrative–rights metadata (e.g., copyright of images or scans); and structural metadata (e.g., building components and relationships). Consistency in metadata creation is crucial for ensuring interoperability, longevity, and scholarly reliability[21]. Among these, administrative–technical metadata is particularly critical for 3D models of architectural heritage, as it documents the digital creation process and enables accurate understanding, preservation, and reuse. It ensures accuracy, durability, interoperability, and proper use while maintaining cultural and historical significance.

A variety of metadata standards have been created to meet these needs, including CIDOC-CRM, Dublin Core, EAD, METS, MODS, PREMIS, EDM, and VRA Core. CIDOC-CRM, for example, provides an ontology that is necessary for interoperability, formatted as linked data, offering a formal and precise rep-

17 Zhao, *Digital Pathways to the Past: Reconstructing theHistoriographic Landscape of Medieval Church Documents through Digital Archives*.
18 Polo, Duran-Domínguez, Felicísimo, *Proposal of Metadata Schema*, cit.
19 Skublewska-Paszkowska, Miłosz, Powroźnik, Łukasik, *3D Technologies for Intangible Cultural Heritage Preservation -Literature Review for Selected Databases*.
20 Polo, Duran-Domínguez, Felicísimo, *Proposal of Metadata Schema*, cit.
21 Gilliland, *Setting the Stage*.

resentation of knowledge in the cultural heritage field. MODS supports detailed bibliographic descriptions, including physical characteristics, version details, subject terms, and annotations; however, its lack of strict business rules may lead to inconsistencies in its use[22]. Adapting frameworks like VRA Core to descriptive metadata models emphasizes the interdisciplinary expertise needed in cataloging scientific heritage by integrating technical, historical, and conservation perspectives[23]. Some 3D file formats cannot fully describe their informational content or support various rendering methods[24]. To address this, the Samvera Community (2025) offers basic recommendations for technical metadata that accompany digital media files, including 3D models. The Smithsonian Institute's 3D metadata model also outlines technical metadata fields such as focus type, fixed focus identifier, light source type, and background removal method, although its scope is still limited. A detailed analysis of the mapping among the EU-CHIC, ICCD, MIDAS, and CARARE metadata schemas revealed that most of them lack elements that would allow for documenting the technological aspects involved in producing a 3D virtual replica[25].

Technical metadata of 3D models typically includes detailed information such as dimensions, scale, material properties, and geometric structure. This ensures that critical technical aspects of 3D models are adequately documented and preserved for future reference[26]. However, systematically organised technical information is often absent. In many digitisation processes, the original historical context of objects is lost due to the fragmentation or minimal metadata, which often includes only basic details such as title, author, and inventory number[27]. Widely recognised metadata standards are extensively used in the cultural heritage sector, with a primary emphasis on methodological rather than technical metadata. However, it is necessary to include information on the techniques and materials used in the creation of religious or archaeological heritage to ensure the fidelity of 3D models. If a model aims to be a faithful reflection of the original object, technical metadata are required to determine its metric and chromatic accuracy[28]. Although these models are interoperable, flexible, and expandable, their capacity to accommodate detailed technical metadata remains limited. While attention is typically directed toward metadata describing the objects themselves, very little work has been done to define an ontology that supports interoperability at the technical level[29]. Therefore, detailed and high-quality metadata are crucial for accurately representing the complexity of 3D structures and their various modeling options. Standards, including Dublin Core and the CIDOC Conceptual Reference Model (CRM), provide fundamental descriptions but often lack the necessary granularity for complex data, thereby impacting reuse and verification. Enhancing these standards is vital for ensuring that future generations inherit a well-preserved cultural legacy. These technological advancements broaden documentation and sharing capabilities, transitioning heritage management from traditional approaches to digital methods.

Metadata Considerations for 3D Digital Heritage

A substantial amount of administrative and technical metadata is generated when using photogrammetry or Light Detection and Ranging (LiDAR), the underlying technology of Terrestrial Laser Scanning, to create detailed 3D point clouds that document architectural heritage. The quality of the metadata associated with digital heritage, as well as the inclusion of rich semantics, impacts authenticity, search, retrieval, and usability. This metadata is vital for maintaining data integrity, ensuring long-term preservation, enabling reuse, and tracking provenance. These aspects highlight the need for metadata structures capable of documenting the full range of information produced during the acquisition, processing, and modelling phases of 3D heritage documentation.

Heritage structure presents complex architectural layers, ongoing use, multiple historical phases, and diverse symbolic meanings, making it suitable for examining the relationship between architectural representation, digital documenta-

22 Zhao, *Digital Pathways to the Past*, cit.

23 Adam, Renaville, Oger (eds.), *Opening Up OurHeritage: Opportunities,* in *Digitising and Promoting Cultural and Research Collections.*

24 Blundell, Clark, DeVet, Hardesty, Metadata Requirements for 3D Data

25 Ronzino, Niccolucci, D'Andrea, *Built Heritage metadataschemas and the integration of architectural datasets using CIDOC-CRM.*

26 Amico, Felicetti, *3D Data Long-Term Preservation in Cultural Heritage.*

27 Zhao, *Digital Pathways to the Past*, cit.

28 Polo, Duran-Domínguez, Felicísimo, *Proposal of Metadata Schema*, cit.

29 Homburg, Cramer, Raddatz, Mara, *Metadata schemaand ontology for capturing and processing of 3D cultural heritage objects.*

tion, and heritage semantics. Building a high-quality 3D model requires a substantial amount of technical data. However, only a small portion of it is usually made public. Is there a lack of technical data on 3D models, such as acquisition methods, geometric details, and accuracy metrics, that need to be tested with the existing schema? These are highly technical metadata fields and are crucial for validating the scientific accuracy of 3D models, as well as providing a detailed description of complex processes and structures. Furthermore, this information is crucial for researchers and conservators who require an understanding of the absolute accuracy and limitations of these models for precise analysis. However, it is often considered proprietary or simply too large to share.

For example, if someone wants to create a high-resolution model instead of the publicly shared version, they need the raw data. It also allows for reducing or increasing polygon count, which affects the geometry's accuracy. In this sense, structuring and managing raw data relies on acquisition techniques such as laser scanning and photogrammetry, which make it possible to capture dense point clouds suitable for different processing needs. Both terrestrial laser scanning (TLS) and photogrammetry (SfM) constitute today the main mass data acquisition techniques (MDCSs)[30].

The development of metadata for a 3D model of a complex heritage structure involves a comprehensive process from data acquisition to digital representation. The CIDOC CRM is used as a case study to evaluate the effectiveness of the metadata schema, as it effectively captures the documentation and semantics of cultural heritage. The CIDOC Conceptual Reference Model is a complex system comprising 94 entities (classes) and 168 relationships (properties) that represent and share cultural heritage metadata, including the representation of events associated with an object throughout its existence[31]. However, analysis reveals that it is not fully optimized for the technical or quantitative details involved in 3D acquisition, which is common in digital heritage and 3D recording workflows. It is neither a geometric nor a technical data model and is not designed to specify the structure or format of 3D datasets in detail. Additionally, it lacks entities for sensor setup, calibration, or geometric acquisition configuration, highlighting the need for a solution.

Extensions like CRMdig (*Digital Provenance model*) can document certain aspects, such as equipment used or file lineage, but do not cover the numeric or spatial details. CIDOC CRM can represent Events (such as data acquisition and processing), actors (like operators and institutions), objects (including 3D model files), and aspects related to Temporal and Provenance data. However, it cannot include sensor and calibration parameters, acquisition geometry or station layout, numerical quality and accuracy metrics, algorithmic or software parameters, and 3D coordinate systems and spatial transformations. Therefore, an evaluated metadata schema (CRM3D Mapping) of selected fields based on the data available in the images has been proposed for 3D documentation of architectural heritage with regard to its acquisition methods, geometric details, and accuracy metrics.

Lexical Standardisation and Semantic Interoperability

Controlled vocabularies are specific data formats that play a vital role in semantic annotation and indexing, thereby improving access to cultural heritage resources. They are also vital tools and systems for organizing knowledge in cataloging, helping to maintain consistency and accuracy when identifying items. Many GLAM institutions and cultural heritage centers utilize various controlled vocabularies to organize and describe their collections; however, many of these vocabularies are independently created in different countries without referencing existing standards, resulting in fragmentation and inconsistency. These variations can hinder users from performing conceptual or thematic searches across multiple databases, especially when creating portals for 3D repositories of heritage structures, making robust support for authority lists and controlled vocabularies essential in the cultural heritage sector. A wide range of information can be extracted from a 3D

30 Moyano, Pili, Nieto-Julián, Della Torre, Bruno, *Semantic Interoperability for Cultural Heritage Conservation: Workflow from Ontologies to a Tool for Managing and Sharing Data.*

31 Silva, Terra, *Cultural Heritage on the SemanticWeb: The Europeana Data Model.*

scan during acquisition or post-processing, and suitable vocabularies are necessary to accurately capture these measurements, particularly for creating 3D visualisations that include geometric, software, and accuracy metadata. When index terms come from a controlled vocabulary, search portals can generate hyperlinks for enhanced semantic search and navigation[32]. Controlled vocabularies are designed to clearly distinguish specific cultural heritage items. Many are widely used in digital collections of cultural heritage: for example, the *Art and Architecture Thesaurus* (AAT) is the most common controlled vocabulary for art collections in North American digital libraries[33], the *Library of Congress Subject Headings* (LCSH) is the most frequently used controlled vocabulary among American digital repositories[34], and among all thesauri available, the AAT remains the most significant and most stable within the cultural heritage field. Additionally, an ethnographic thesaurus developed in the Netherlands – the Stichting Volkenkundige Collectie Nederland (SVCN) – is used by several Dutch ethnographic museums[35]. To better understand ancient buildings, cataloging can be combined with digital documentation, including historical sources and heritage records, to offer representations of cultural heritage assets through text, images, drawings, and 3D models[36].
Because developing controlled vocabularies is a complex and time-consuming process, establishing transparent, standardised vocabularies is crucial, along with considering semantic metadata annotation for 3D constructions. Understanding user information-seeking behavior is also key to developing effective vocabularies that ensure accessibility and semantic precision. Within the proposed metadata schema, the controlled vocabulary was aligned with recognised scholarly resources and digital cultural heritage ontologies: architectural terms were matched to Getty AAT entries, saint names and historical events were linked via Wikidata, and ritual terminology was referenced across Christian liturgical studies. This alignment ensures that the metadata not only describes but also connects the digital data within larger heritage networks and multilingual environments, thereby improving semantic interoperability and cultural context.

Conclusion

Digital representations of architectural heritage – shaped by cultural, historical, aesthetic, and material transformations – generate extensive and diverse datasets that require robust metadata management and detailed semantic annotation. The integration of digital and analog techniques, along with multiple sensors and varied datasets, enables the creation of highly accurate 3D models that support both documentation and restoration efforts. Photogrammetry and TLS technologies provide substantial point cloud data, which is crucial for developing reliable reconstructions. Meanwhile, emerging semantic-aware simplification methods show great promise for producing models with meaningful and organised levels of detail. Despite these technological advances, finding a single comprehensive metadata standard capable of capturing the full scope of cultural heritage information remains difficult, especially considering the complex contextual, symbolic, and internal content embedded in heritage imagery. Most existing standards focus on visual features but often overlook deeper semantic and interpretive aspects, highlighting the need for interdisciplinary collaboration and expert input to define key metadata elements that improve discoverability and scholarly utility. Building a sustainable, research-based metadata framework that includes all relevant elements is essential for ensuring long-term accuracy, authenticity, interoperability, and accessibility. This multidisciplinary approach will enhance conservation, preservation, and academic research efforts while enabling metadata schemas to more effectively represent the complexity of architectural heritage in digital environments.
The management of extensive datasets and detailed metadata continues to pose challenges, underscoring the need for improved standards to accommodate layered datasets derived from 3D reconstructions. Therefore, combining detailed administrative and technical metadata fields with semantic annotations and controlled vocabularies supports the future reuse of enriched 3D models.

32 ICOM-CIDOC LIDO Working Group, LIDO Primer, version 1.1 2024.
33 Shiri, Chase-Kruszewski, *Knowledge organisation systems in NorthAmerican digital library collections*.
34 Park, Tosaka, *Metadata creation practices in digital repositoriesand collections: Schemata, selection criteria, and interoperability.*
35 Hollink, Van Assem, Wang, Isaac, Schreiber, *Two variations on ontology alignment evaluation: Methodological issues.*
36 Ronzino, Amico, Niccolucci, *Assessment and Comparison of Metadata Schemas for Architectural Heritage.*

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