ACCSCIENCE PUBLISHING

Arts & Communication

ARTICLE

Immersive digital reconstruction and long-term preservation of cultural heritage: The case of Thomas Mann's Munich residence

Uwe M. Borghoff[1]*, Marian Sorin Nistor[2], Ulrike Haerendel[3], and Stefan Pickl[2]

[1]Department of Computer Science, Institute for Software Technology, University of the Bundeswehr Munich, Neubiberg, Bavaria, Germany

[2]Department of Computer Science, Institute for Theoretical Computer Science, Mathematics and Operations Research, University of the Bundeswehr Munich, Neubiberg, Bavaria, Germany

[3]Presidential Department, University of the Bundeswehr Munich, Neubiberg, Bavaria, Germany

Abstract

Immersive digital reconstructions are increasingly used in cultural heritage research, yet their long-term preservation is rarely addressed as an integral part of the reconstruction process. This article addresses this gap by presenting a preservation-aware workflow that combines archival research, manual three-dimensional modeling, interactive visualization, and metadata-driven preservation. Using the digital reconstruction of Thomas Mann's Munich residence ("Poschi") and, in particular, its His Master's Voice 192 gramophone as a case study, the article demonstrates how historical objects reconstructed from incomplete archival evidence can be systematically documented and preserved for long-term reuse. The proposed approach integrates the Open Archival Information System reference model with the Building Information Modeling (BIM) Core metadata model to capture both the digital assets and the production decisions underlying the reconstruction. Implementing all 23 BIM Core metadata elements demonstrates the practical applicability of this preservation strategy and provides structured representation information to support future interpretation, reuse, and migration. The study shows that integrating reconstruction and preservation from the outset improves the transparency, reproducibility, and long-term usability of immersive digital heritage environments. The proposed workflow is transferable to a broad range of digital cultural heritage projects requiring both immersive reconstruction and long-term preservation.

Keywords: Digital humanities; Digital cultural heritage; Immersive reconstruction; Three-dimensional modeling; Open Archival Information System; Building Information Modeling Core; Metadata; Long-term preservation

***Corresponding author:**
Uwe M. Borghoff
(uwe.borghoff@unibw.de)

Citation: Borghoff UM, Nistor MS, Haerendel U, Pickl S. Immersive digital reconstruction and long-term preservation of cultural heritage: The case of Thomas Mann's Munich residence. *Arts & Communication*. doi: 10.36922/AC026180026

Received: April 30, 2026

Revised: July 23, 2026

Accepted: August 3, 2026

Published online: August 13, 2026

Copyright: © 2026 Author(s). This is an Open-Access article distributed under the terms of the Creative Commons Attribution Noncommercial License, permitting all non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Publisher's Note: AccScience Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Immersive digital reconstruction has become an important tool in cultural heritage research. However, most projects focus on creating digital environments, addressing long-term preservation only after reconstruction is complete. This study presents an

integrated preservation-aware workflow that combines historical research, manual three-dimensional (3D) modeling, interactive visualization, and Open Archival Information System (OAIS)/Building Information Modeling (BIM) Core-based long-term preservation from the outset. This approach is demonstrated through the digital reconstruction of Thomas Mann's Munich residence, "Poschi," with the His Master's Voice (HMV) 192 gramophone serving as a representative case study.

1.1. Thomas Mann's residences as literary heritage

Few would object to describing Thomas Mann as part of the cultural heritage. The winner of the 1929 Nobel Prize in Literature holds a firm place not only in German secondary education but also in public memory more broadly. His name is associated with societies, associations, streets, schools, libraries, museums, archives, and digital media accounts devoted to his life and work. Biographical writing on Thomas Mann began during his lifetime and continues today, while his works have generated a vast body of scholarship, along with countless books, articles, and conferences.

In 1969, Michel Foucault argued that authorship should not be understood only through narrow biographical or historical reference. Instead, he described the author as a "function" within changing social discourses.[1] This perspective is also useful for the present study. A reconstruction of Thomas Mann's villa in Munich's Poschinger Straße ("Poschi") or of his house in Pacific Palisades has limited value if treated only as an architectural model. Its scholarly value emerges when the virtual environment connects these spaces with texts, objects, and historical sources. In this way, digital reconstruction makes it possible to study Thomas Mann not only through biography but also through the relationship between place, material setting, and literary work.

Thomas Mann's residence was selected not because writers' residences are inherently more important than other heritage sites, but because they provide a particularly rich environment for demonstrating how spatial, material, and textual evidence can be integrated into a single digital reconstruction. The underlying reconstruction and preservation workflow is intended to be transferable to other cultural heritage domains.

For this study, we collaborated with the Thomas Mann International Network, comprising the Buddenbrookhaus in Lübeck, the Monacensia in Munich, the Thomas Mann Archive in Zurich, the Thomas Mann House in Pacific Palisades, and the Thomas Mann Cultural Centre in Nida, Lithuania. Interested members of the public and researchers can use these "residences" as a guide to trace the key stages of Thomas Mann's life and creative periods. Together, these stages paint a picture of his life and work (Table 1).

1.2. The "Poschi" as a literary space

Among his places of residence, the "Poschi" holds a prominent position: It was built for the Mann family and served as an important setting for both daily life and literary work, including the writing of *The Magic Mountain*.

In the following analysis, we focused exclusively on the "Poschi," without limiting its scope. This was especially fitting for the house because it no longer existed and could only be "reconstructed" digitally. Our reconstruction included the architecture and interiors of the house, as well as a selection of furnishings and everyday objects. We primarily used historical sources to depict the house as it was in the 1930s. Where sources were lacking, we documented our interpretive decisions rather than presenting them as fact.

Thomas Mann's literary works can be explored in virtual space through their connections to other art forms, especially music. His diaries and the existing scholarship on his work provide rich evidence of the music he knew and valued.[2] These sources make it possible to trace, and in some cases even make audible, the ways in which musical experience and reflection enter his writing. Such links between life and work can make the texts more accessible and add a material and spatial dimension to their interpretation. For visitors to a virtual reconstruction of his residences, this creates a wide range of interactive paths for exploration.

At the same time, a digital environment changes the relationship between author, work, and audience. During his lifetime, Thomas Mann controlled access to his domestic space, his letters, his readings, and his first readers. In digital form, however, a virtual Thomas Mann House, digitized documents, and historical sound recordings can become broadly accessible across time and place, within the limits of available devices and software. This wider access also depends on long-term preservation, a point discussed in the following sections.

There is little reason to assume that Thomas Mann would have rejected such mediation of his public image. His interest in modern media is well documented, for example, in his reflections on cinema and music, and in the television film made for his 80th birthday in June 1955.[1] At

[1] The film is still available in the media library of the German television channel ARD under the title *Thomas Mann – Leben und Werk: Ein Dokumentarbericht*. SWR Retro — Der Südwesten damals: Thomas Mann: Life and Work.

Table 1. List of residences

Residence	Description	Period and major works
Buddenbrook House (Lübeck)—real-fictional place	Family residence; model for the novel; today Heinrich and Thomas Mann Center, Mengstraße 4	From 1875; *Buddenbrooks* (1901); *Tonio Kröger* (1903/1913)
"Poschi" (Munich)—authorship and family life	Family residence at Poschinger Straße 1, built for the Mann family	1914–1933; *Reflections of a Nonpolitical Man* (1918); *The Magic Mountain* (1924); *Joseph and His Brothers* (1926–1933)
Country house (Bad Tölz)—vacation home	First vacation home in the Bavarian Oberland	1909–1917; *Death in Venice* (1912); *The Magic Mountain* (1924)
"Villino" (Feldafing)—vacation home	Retreat on Lake Starnberg	1919–1923; *The Magic Mountain* (1924)
Nida (Lithuania)—vacation home	Vacation home on the Curonian Spit; now a cultural center	1929–1932; *Joseph in Egypt* (1936)
Küsnacht (Switzerland)—exile	Exile residence, Schiedhaldenstrasse 33	1933–1938; *Joseph in Egypt* (1936); *Attention, Europe!* (1938); *Lotte in Weimar* (1939)
"Seven Palms" (Pacific Palisades, USA)—exile	Main residence in American exile; today, the Thomas Mann House	1942–1952; *Joseph the Provider* (1943); *Listen, Germany! (Radio messages 1940-45); Doctor Faustus* (1947); *The Chosen One* (1951)
Kilchberg (Switzerland)—return to Europe	Final residence; estate transferred to ETH Zurich	1954–1955; *Felix Krull* (1954)

Abbreviation: ETH: Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology).

the end of that film, he addresses the television audience directly and remarks, with irony, that he cannot offer them cake despite the advances of modern technology. This scene suggests that public mediation was not foreign to him. A digital reconstruction, therefore, does not diminish the author. Rather, it opens new ways of connecting his works, his material world, and his historical presence.

The gramophone provides a clear example of the close connection between Thomas Mann's life and work (Figure 1). Although it is not known exactly when the device entered the Mann family's lounge, it plays an important role in *The Magic Mountain* (1924), especially in the chapter "Fullness of Harmony."[3] It also appears centrally in the 1925 novella *Unordnung und frühes Leid* (*Disorder and Early Sorrow*). In the digital reconstruction of "Poschi," the gramophone becomes an interactive object of interpretation. Users can examine the model in detail, access information about its type, period, and manufacturer, and explore how such a device was operated. A voice recording also places the object within a broader history of media and technology, including its status as a modern consumer device introduced to the German market by Electrola in the 1920s. In this way, the gramophone is not only displayed as a historical furnishing but also used as a link between literary text, domestic space, and media history.

1.3. The gramophone as a case study

Thomas Mann's early engagement with the gramophone is well documented in his diaries. On February 10, 1920, during a stay at the holiday cottage of his friend Georg Richter in Feldafing, he described Richter's gramophone as the highlight of the visit. He noted the works played and recorded that the experience had provided "a new motif" for *Zauberberg* (*The Magic Mountain*) and were, both intellectually and narratively, a valuable discovery. A few months later, on May 21, 1920, he referred to his "somewhat lascivious passion" for the gramophone.[4] This enthusiasm later found literary expression in the well-known gramophone scene in *The Magic Mountain*, published in 1924.[5] The intensity with which Mann depicts Hans Castorp's fascination with the device leaves little doubt about his own interest in this form of sound reproduction.

Further evidence appears in both literary and autobiographical sources. As noted above, *Unordnung und frühes Leid* (*Disorder and Early Sorrow*), written shortly after *The Magic Mountain*, centers on a domestic social scene shaped by gramophone music.[6] Monika Mann's

Figure 1. Thomas Mann in his house in Munich, looking at his gramophone in 1932
Source: https://commons.wikimedia.org/wiki/File:Bundesarchiv_Bild_183-R15883,_Thomas_Mann.jpg

memoirs likewise recall gramophone evenings in the family home, during which her father carefully operated the machine.[7] Although the quiet domestic setting described by Monika Mann differs from the lively fictional party scene, both point to the growing presence of modern media in the bourgeois home.[8]

1.4. Preservation-aware reconstruction and article organization

Existing digital heritage projects primarily emphasize the creation of immersive reconstructions, whereas long-term preservation is often addressed only after reconstruction is complete. This study addresses this gap by integrating preservation requirements into the reconstruction workflow from the outset, using the combined OAIS reference model and the BIM Core metadata model. While metadata standards such as the Europeana Data Model primarily support the description and interoperability of cultural heritage collections, BIM Core focuses on documenting the technical representation information required for the long-term preservation of complex interactive digital assets. For this reason, BIM Core was selected as the metadata model for this study. Accordingly, the digital reconstruction presented in this article serves primarily as a representative case study for demonstrating a preservation-aware workflow rather than as an end in itself. The following sections progressively narrow the scope from the broader context of historic residences to "Poschi" and, ultimately, to the digital reconstruction of the gramophone as a representative case study before turning to the long-term preservation of the resulting digital materials.

2. Digitization of the historical setting through historical fragments

The digital reconstruction of "Poschi" aims to recreate the historical atmosphere of the house in the 1930s through a structured process that combines historical research, 3D modeling, and real-time rendering. The reconstruction is based on archival sources such as architectural plans, black-and-white photographs, and written historical descriptions. Together, these materials provide the basis for a virtual representation of the house. This section describes the workflow for turning fragmentary historical evidence into detailed 3D models for interactive use in Unreal Engine.

The development process begins with extensive

source research and the collection of visual references. Archival images from the Thomas Mann Archive at *Eidgenössische Technische Hochschule* (Swiss Federal Institute of Technology) Zurich, together with published studies and image sources[9,10], provide the main basis for reconstructing the spaces and objects of the house. At the same time, the available evidence is incomplete and sometimes inconsistent. Missing details, therefore, require careful interpretation based on architectural and design features of the period. Because many original objects are no longer available, methods such as photogrammetry can only be used to a limited extent. For this reason, much of the reconstruction depends on manual 3D modeling.

Comparable approaches have been applied to the digital reconstruction of individual cultural heritage artifacts, where high-resolution 3D digitization and digital modeling support both scholarly documentation and conservation-oriented reproduction.[11] However, our reconstruction differs in an important respect. While their approach is based on the digitization of an existing physical artifact, many of the original objects and even the reconstructed building no longer exist in our case. As noted above, photogrammetric methods can therefore only be applied to a limited extent. Instead, the reconstruction relies predominantly on manual 3D modeling based on archival photographs, architectural plans, and other historical sources, with interpretive decisions explicitly documented where evidence is incomplete.

This work also reflects broader developments in digital heritage research. Digital methods now offer new ways to organize historical material and to connect visual, spatial, and textual evidence.[12] In this context, digital archives are understood not only as static collections but also as environments that support ongoing interpretation, reuse, and preservation.[13] The Thomas Mann project follows this approach by combining text, space, and material culture within a single digital setting. This setting extends beyond its narrow historical context, in this case, the 1930s villa. References to the subsequent history of objects that were taken when the Manns emigrated underscore the virtual room's character as a system of reference. This system opens new possibilities for interdisciplinary research in literary studies, history, cultural studies, and digital media. The interactive nature of the reconstruction also supports wider public and educational use. At the same time, such forms of access raise questions about long-term preservation and technical sustainability.[14]

A comparable line of research uses 3D reconstruction to recover rooms shaped by individual cultural figures. The Virtual Studiolo, developed within the Isabella d'Este Archive (IDEA), digitally reassembles the *studiolo* and *grotta* of the Marchioness of Mantua, integrating immersive 3D modeling, archival evidence, and the paintings, sculptures, books, and antiquities once held there but now dispersed across European and American collections.[15] A second project, the Immersive Raphael Project, reconstructs Pope Julius II's library in Raphael's Stanza della Segnatura through a custom Unity-Scalar pipeline, repopulating the room with the manuscripts originally shelved beneath the frescoes.[16] Finally, the so-called Goethe-Apparat in Weimar (https://www.klassik-stiftung.de/ihr-besuch/ausstellung/goethe-apparat/) is also relevant. All three projects recover spaces of display and reading and link them to archival or textual material.

Our project differed in two respects. First, the reconstructed space was one of literary production rather than display, indicating that domestic objects such as the gramophone served as entry points into texts written in their immediate presence, not as exhibits. Second, the reconstruction was paired from the outset with an explicit OAIS/BIM Core preservation framework, so that the environment was built as a durable research infrastructure rather than a standalone visualization. The next subsection illustrates this production-anchored approach through the digital recreation of the HMV 192 gramophone.

2.1. Digital recreation of the His Master's Voice 192 gramophone

The study illustrates the reconstruction process through the detailed digital recreation of the HMV 192 gramophone, a historically significant object within the "Poschi" digital environment.

During the blocking phase (also known as blockmesh or grayboxing), we used 3ds Max (2026, Autodesk, USA) to create a geometric approximation of the gramophone. The focus was on defining proportions and spatial relationships. In this case, the original measurements were available online, allowing us to model the object with precise dimensions. We divided the model into key components, including the top lid, turntable, tonearm, needle, cabinet, and supporting legs. We began with basic geometric shapes, such as cubes, planes, cylinders, and spheres, and refined them step by step.

After this phase, we created a high-polygon version of the gramophone to capture fine details. Using subdivision modeling techniques in 3ds Max, we refined the geometry to produce smooth surfaces and accurate detailing. This step ensured that the digital model reflected the craftsmanship of the original object and supported a more precise reconstruction of historical artifacts and spaces. The high-polygon model also included color-coded material masks that support efficient texturing in later phases (Figure 2).

To ensure efficient performance in real-time environments, we reduced the polygon count of the high-poly model via retopology. Using 3ds Max, we removed unnecessary geometry while preserving the overall shape and key surface details. We optimized curved elements, such as the tonearm and turntable, by adjusting edge flow to avoid visual artifacts. In areas with fine detail, we applied normal map baking to transfer surface features from the high-polygon model to the low-polygon version (Figure 3).

In the next phase, we unwrapped the model's surface into a two-dimensional layout to prepare it for texturing. We used TexTools, an integrated 3ds Max script, for efficient UV unwrapping, and RizomUV (2025.0, Rizom-Lab, France) for advanced UV packing. RizomUV allowed us to arrange UV islands efficiently, reducing distortion and making better use of texture space.

We then transferred fine surface details from the high-polygon model to the low-polygon version using baking techniques such as normal and ambient occlusion maps. This approach produced realistic shading without increasing geometric complexity (Figure 4). We also assigned multiple UV channels, including a dedicated channel for baked lighting in Unreal Engine (5.3, Epic Games, USA), to ensure consistent texture display under different lighting conditions.

In the next phase, we applied textures to achieve a realistic appearance of the gramophone. We used Substance Painter (2026, Adobe Inc., USA) with physically based rendering materials to simulate how light interacts with different surfaces. This approach allowed us to represent

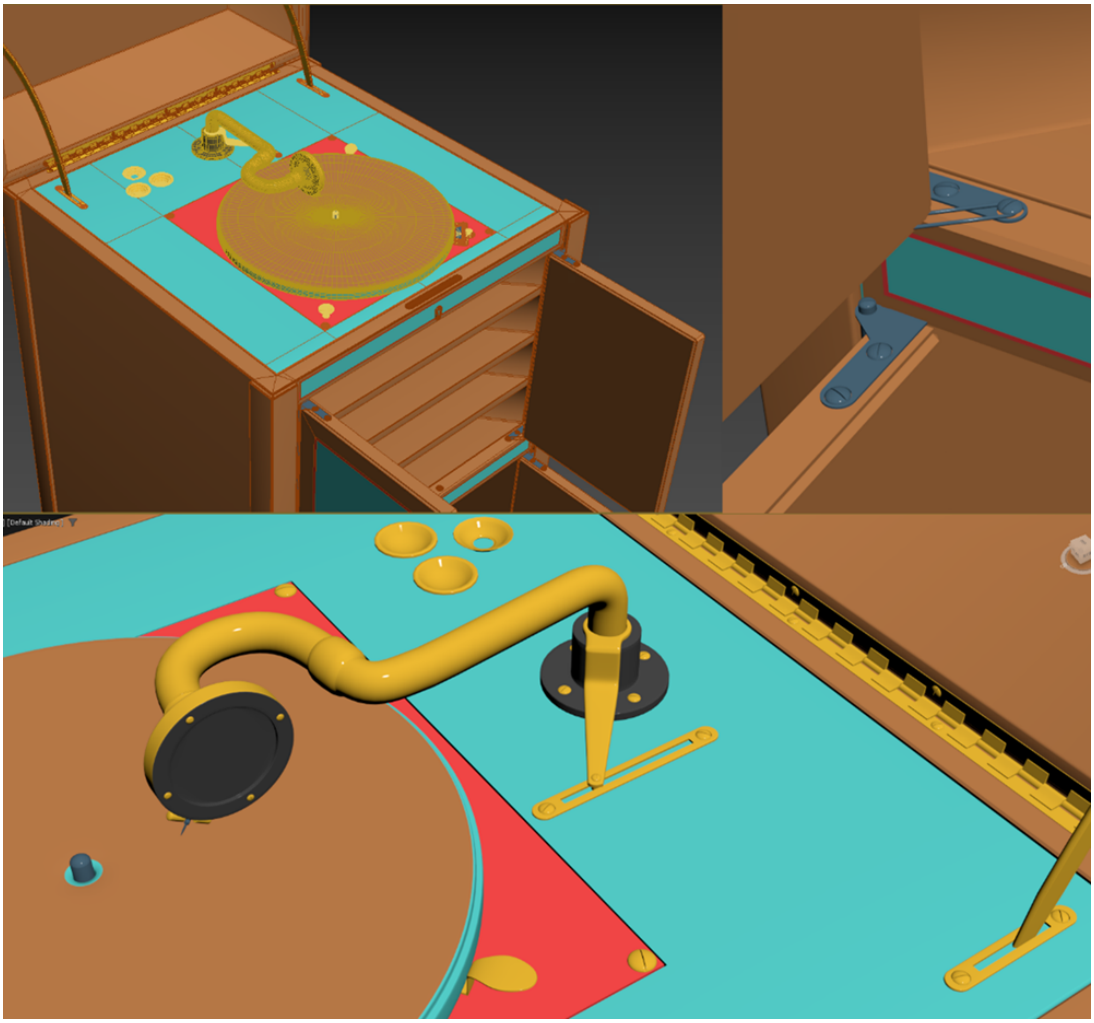

Figure 2. High-polygon model of the gramophone in 3ds Max, showcasing the tonearm's refined curvature, the turntable's detailed grooves, and the intricate mechanical joints

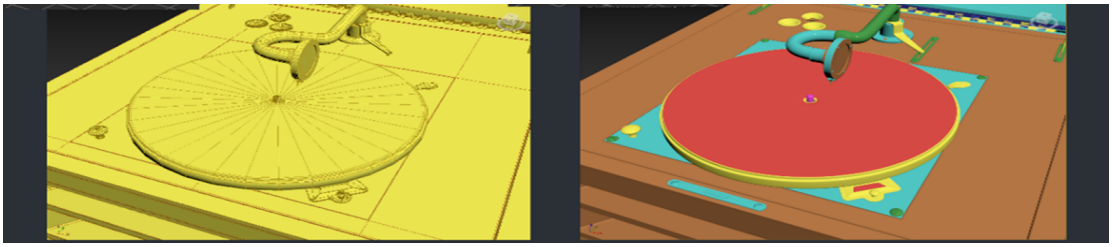

Figure 3. Comparison of the low-polygon and high-polygon versions of the gramophone model

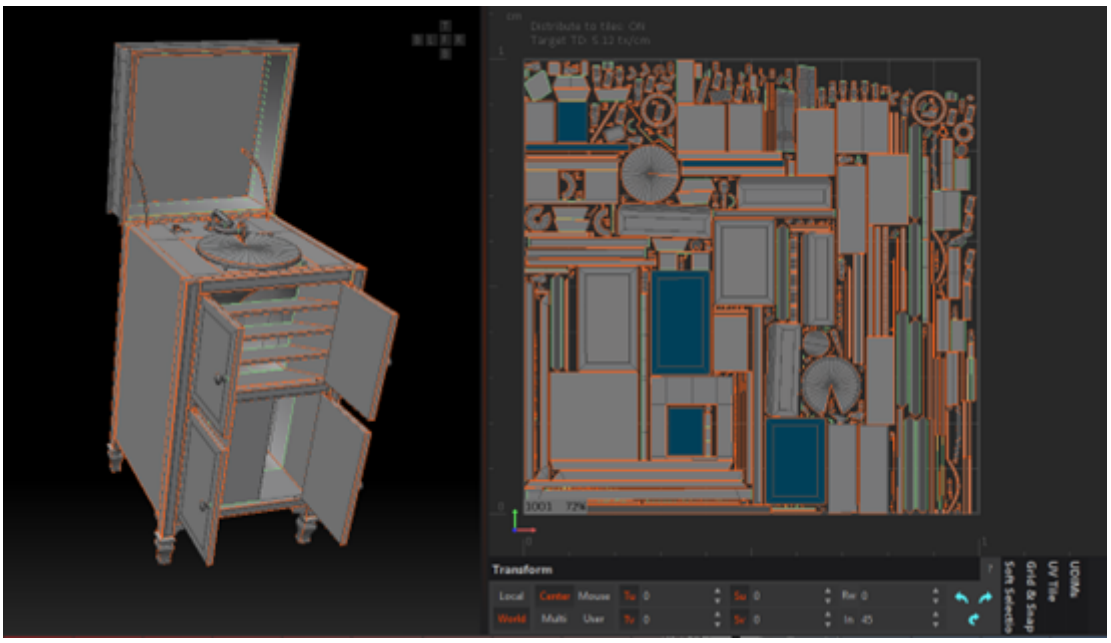

Figure 4. UV unwrapping of the gramophone model in RizomUV, showing the optimized surface layout for efficient texture mapping. The alignment minimizes distortion and maximizes texel density.

materials such as metal, wood, and fabric accurately. We began by assigning material IDs during the modeling phase, which enabled precise control over different regions of the object.

Substance Painter's layering system supports both standard and smart materials. Smart materials offer adjustable parameters, such as contrast and density, enabling flexible control of surface properties (Figure 5).

We also used tools such as masks, filters, brushes, and textures to refine details and enhance realism (Figure 6). We used baking techniques to transfer surface details from the high-polygon model to the low-polygon version. Normal, ambient occlusion, and curvature maps preserved fine features such as surface grain and signs of mechanical wear without increasing geometric complexity. We also used custom alpha maps to add small details, including engraved markings and branding elements present on the original HMV 192.

2.2. Integration into Unreal Engine and preparation for long-term preservation

We imported the final model into Unreal Engine and used a combination of point, area, and global illumination to recreate the ambient lighting of "Poschi" and enhance visual realism. We also rigged the gramophone for interaction, allowing users to operate its mechanical components, such as the turntable and needle.

At the same time, long-term access to such digital material requires more than real-time visualization. It depends on clear metadata, stable file formats, and well-

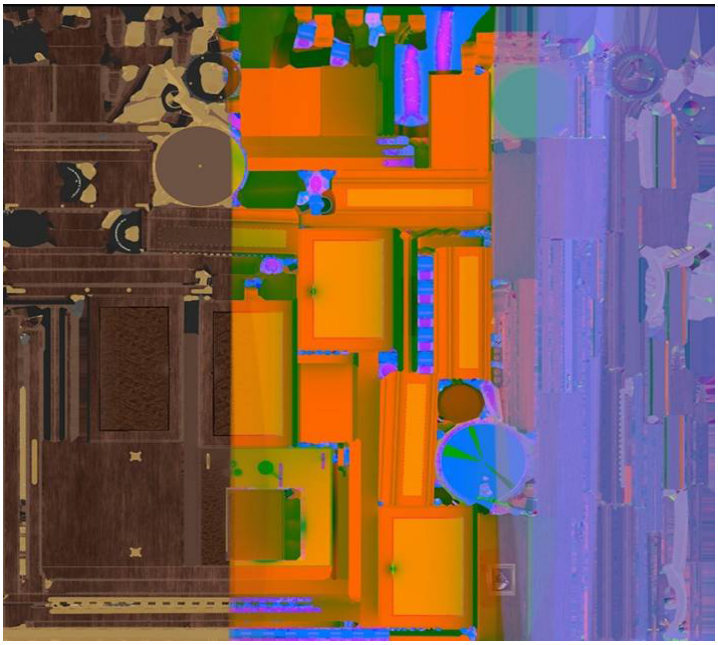

Figure 5. Layered view of the three texture maps; from left to right, they show the base color, the occlusion–roughness–metalness map, and the normal map

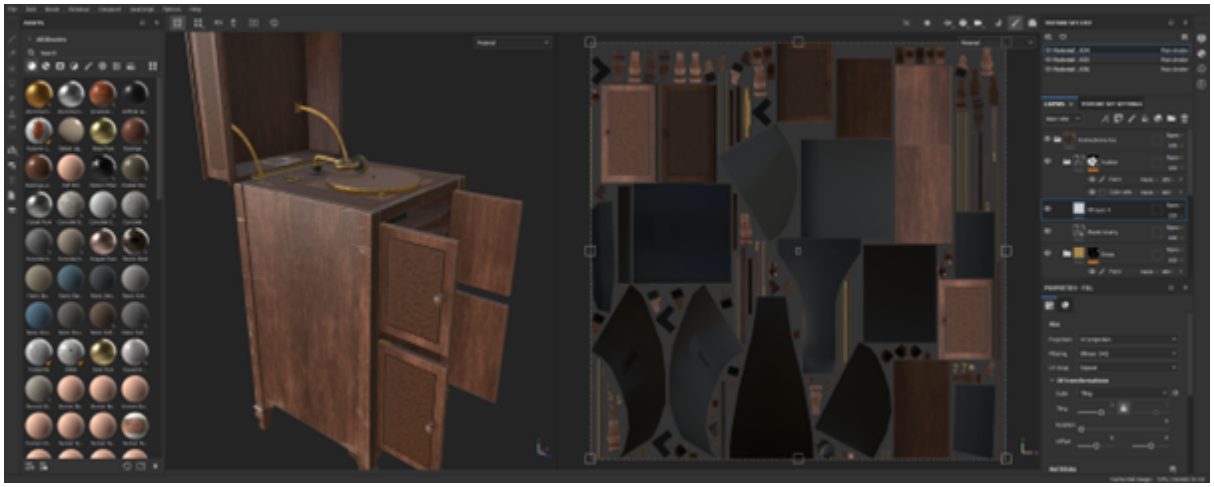

Figure 6. Substance Painter viewport displaying the clean version of the His Master's Voice 192 gramophone

defined preservation strategies. The following section, therefore, examines how OAIS and BIM can support the organization, storage, and long-term preservation of these digital materials.

3. Long-term preservation of the digitized reconstruction

Digital reconstruction produces complex data that combines geometry, textures, interaction logic, and contextual information. These elements depend on specific software environments, file formats, and workflows. Because these technical conditions change over time, preserving such data is a major challenge. File formats, operating systems, and rendering platforms evolve, making digital objects difficult to access and interpret in the future. For this reason, long-term preservation must be considered from the beginning of the digitization process.

One key requirement is the systematic creation of

metadata. In the reconstruction of "Poschi," each phase of the workflow produced information relevant to later preservation. For example, the use of specific software tools (3ds Max, Substance Painter, Unreal Engine), the creation of high- and low-polygon models, the use of baking techniques, and the assignment of UV channels all affected how the data could be reused and interpreted. Without clear documentation of these processes, the resulting digital objects would be difficult to understand or reproduce in the future.

This need is well established in digital humanities research. A previous study emphasized that digitization and metadata planning should be closely linked.[17] Careful documentation also strengthens the scholarly value of digital reconstructions and supports their long-term use.[18,19] In this context, the International Organization for Standardization reference model OAIS provides a widely accepted framework for organizing and preserving digital information. Figure 7 provides an overview of the model.[20]

The OAIS structures digital preservation around information packages that combine data and metadata. In the case of the "Poschi" reconstruction, the 3D models, textures, audio files, and interaction logic correspond to the content of such packages. The metadata generated during the workflow, such as software versions, file formats, and processing steps, form the basis for interpreting this content. Submission information packages represent the data as it is produced during modeling and texturing. Archive information packages extend this data with additional documentation, such as processing history and dependencies. Dissemination information packages provide access to selected parts of the reconstruction, for example, through the Unreal Engine environment or web-based visualization.

A central concept in OAIS is representation information, which ensures that digital data remains interpretable by providing the technical and semantic context needed to understand its structure and meaning.[21] It also supports higher-level interpretation by linking data to domain knowledge and analysis processes.[22] In the present project, this includes, for example, descriptions of file formats (such as filmbox or texture maps), documentation of modeling and baking processes, and information about how objects behave in the interactive environment. Without this information, the digital model would remain a set of data that cannot be interpreted correctly. Format registries and software documentation, therefore, play an important role in ensuring long-term access.

Context information is equally important. It links the digital objects to their historical and scholarly background. In the case of "Poschi," this includes archival sources, literary references, and information about the role of objects such as the gramophone within Thomas Mann's work. This context is essential for understanding not only the structure of the data, but also its meaning.

To organize this information systematically, the project applied the BIM Core metadata model[23], which was influenced by the Dublin Core standard.[24] Originally developed for building documentation, BIM Core provides

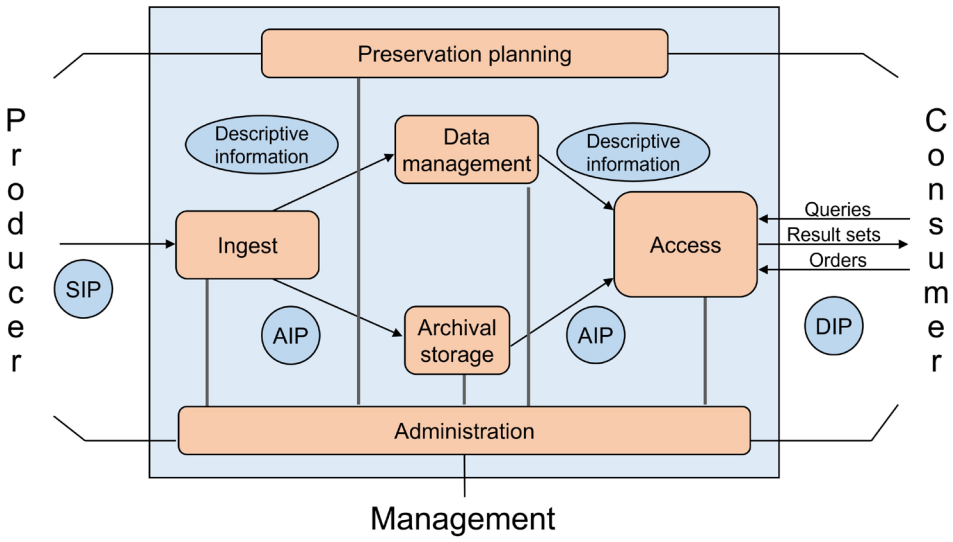

Figure 7. The International Organization for Standardization reference model of the Open Archival Information System. Abbreviations: AIP: Archival information package; DIP: Dissemination information package; SIP: Submission information package.

a set of 23 metadata elements that can be adapted to digital heritage projects.[25] These elements record key aspects of the reconstruction process. For example, they document file formats and software dependencies (relevant for modeling and rendering), describe compatibility issues (arising from different software versions), and record the tools used for UV mapping, texturing, and verification. They also capture contextual information, such as the historical sources used for reconstruction and the significance of individual objects within the overall environment.

In this context, BIM Core serves a broader purpose than conventional metadata. It records not only descriptive information about digital assets but also the technical representation information required to interpret, reproduce, and preserve them over time in accordance with the OAIS reference model. In this way, BIM Core serves as a bridge between technical production and long-term preservation. It ensures that the decisions made during modeling, texturing, and integration into Unreal Engine remain understandable and reusable in the future. The complete metadata set for the "Poschi" reconstruction, presented in the Appendix, shows how these elements can be applied in practice.

4. Conclusion

The reconstruction presented in this article serves primarily as a case study for demonstrating a preservation-aware workflow; the principal contribution is the integration of immersive reconstruction with OAIS- and BIM Core-based long-term preservation. Using the example of Thomas Mann's residences, particularly the "Poschi" house, this approach demonstrates that combining archival sources, 3D modeling, and interactive visualization allows the literary, spatial, and material aspects of heritage to be studied together within a single digital environment. Such environments extend traditional approaches in the digital humanities by enabling new forms of analysis and user interaction.

The study also shows that long-term preservation must be integrated into the digitization process from the outset. The combined use of the OAIS reference model and the BIM Core metadata model provides a practical framework for documenting, managing, and preserving complex digital assets. Implementing all 23 BIM Core metadata elements confirms that this approach is applicable in practice and transferable beyond architectural use cases to digital humanities projects.

These findings are important for the field because they connect two areas that are often treated separately: digital reconstruction and digital preservation. Our study demonstrated that interactive digital heritage environments could remain usable and meaningful over time only if they were supported by structured metadata and clear preservation strategies.

Although challenges remain, particularly regarding long-term infrastructure and the scaling of metadata workflows, the approach presented here offers a transferable model for future projects. It provides a basis for developing digital cultural heritage as a durable research infrastructure rather than as a short-lived visualization.

The present work has several limitations. First, the proposed preservation workflow has not yet been validated through a formal evaluation or comparative study. Second, although the reconstructed environment is operational and accessible through the immersive datArena installation at the University of the Bundeswehr Munich, the complete preservation package is not yet available through a public repository. Consequently, independent reproduction and reuse of the full workflow are currently limited. Future work will address both broader validation and the public dissemination of preservation assets where copyright and institutional constraints permit.

Acknowledgements

The authors thank Andrei-Cristian Florea for his valuable contribution to the preservation workflow and for providing the screenshots from the Thomas Mann Project.

Funding

None.

Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Uwe M. Borghoff
Investigation: All authors
Methodology: All authors
Software: Marian Sorin Nistor
Writing–original draft: Uwe M. Borghoff, Marian Sorin Nistor, Ulrike Haerendel
Writing–review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The immersive reconstruction presented in this study

can be experienced at the datArena (https://www.unibw.de/datarena) on the campus of the University of the Bundeswehr Munich, where visitors can take a virtual tour of the reconstructed "Poschi." The complete preservation package and digital assets are currently unavailable from a public repository.

Further disclosure

The authors also acknowledge the use of DeepL Translator, DeepL Write, and ChatGPT in the preparation of this paper. These tools were used to improve the language and to translate parts of the text from German into English. The authors confirm that the paper accurately reflects their own research and intellectual contribution.

References

1. Foucault M. What is an author? In: Harari J, ed. *Textual Strategies: Perspectives in Post-Structuralist Criticism*. Ithaca, NY: Cornell University Press; 1979;20(1):13-34.

   doi: 10.1093/screen/20.1.13

2. Vaget HR. *Seelenzauber: Thomas Mann und die Musik*. 2nd ed. FISCHER Taschenbuch; 2011.

3. Beßlich B. Vom Nutzen und Nachteil des Grammophons für das Leben Hans Castorps. Narratologische, intermediale und reproduktionsästhetische Betrachtungen zum "Zauberberg". In: Schmidt WG, Falk T, eds. *Literatur intermedial. Paradigmenbildung zwischen 1918 und 1968*. Berlin and New York: Walter de Gruyter; 2009:153-166.

   doi: 10.1515/9783110217018.153

4. Mann T. *Tagebücher 1918-1921*. de Mendelssohn P, ed. Frankfurt am Main: S. Fischer; 1979. Accessed July 23, 2026. https://www.fischerverlage.de/buch/thomas-mann-tagebuecher-1918-1921-9783100481924

5. Heißerer D. Thomas Manns "Villino" in Feldafing am Starnberger See. Thomas-Mann-Forum München. Accessed July 23, 2026. https://tmfm.de/thomas-manns-villino-in-feldafing/

6. Mann T. *Unordnung und frühes Leid*. Berlin: S. Fischer; 1926. Accessed July 23, 2026. https://www.fischerverlage.de/buch/thomas-mann-unordnung-und-fruehes-leid-9783104034317

7. Mann M. *Vergangenes und Gegenwärtiges: Erinnerungen*. Rowohlt; 2001. Accessed July 30, 2026. https://www.rowohlt.de/buch/monika-mann-vergangenes-und-gegenwaertiges-9783499230875

8. Sandberger W. Zur Bedeutung der medial vermittelten Musik in der Erzählung *Unordnung und frühes Leid* von Thomas Mann. *Thomas Mann Jahrb.* 2010;23:9-26. Accessed July 30, 2026. https://www.jstor.org/stable/24745314

9. Estermann A, Rück M. *Das Haus der Familie Mann: Ein Rundgang zwischen Literatur und Wirklichkeit*. Würzburg: Königshausen & Neumann; 2016. Accessed July 30, 2026. https://verlag.koenigshausen-neumann.de/product/9783826060144-das-haus-der-familie-mann/

10. Bastek A. Thomas Mann, Carl Georg Heise und die bildende Kunst in Lübeck. *Thomas Mann Jahrb.* 2013;26:53-67. Accessed July 29, 2026. https://www.jstor.org/stable/24745452

11. Barboutis I, Kamperidou V, Economidis G. Handcrafted Reproduction of a 17th Century Bema Door Supported by 3D Digitization and CNC Machining. *Appl Sci.* 2023;13(21):11690.

    doi: 10.3390/app132111690

12. Lang S, Ommer B. Transforming information into knowledge: how computational methods reshape art history. *Digit Humanit Q.* 2021;15(3).

    doi: 10.63744/4vkc72ax2hj6

13. Escobar Varela M. The archive as repertoire: transience and sustainability in digital archives. *Digit Humanit Q.* 2016;10(4).

    doi: 10.63744/rvgksdzj5kvu

14. Uherek A, Maier S, Borghoff UM. Requirements for long-term preservation of digital videos and first experiments with an XMT-based approach. In: Moreno-Díaz R, Pichler F, Quesada-Arencibia A, eds. *Computer Aided Systems Theory—EUROCAST 2015*. LNCS 9520. Cham: Springer; 2015:203-210.

    doi: 10.1007/978-3-319-27340-2_26

15. Shemek D, Guidazzoli A, Liguori MC, et al. Renaissance Remix. Isabella d'Este: Virtual Studiolo. *Digit Humanit Q.* 2018;12(4).

    doi: 10.63744/ce7wwkk53het

16. van Orden K, Pon L. Im/Materiality in Renaissance Arts. *Arts.* 2024;13(1):39.

    doi: 10.3390/arts13010039

17. Papadopoulos C, Schreibman S. Towards 3D scholarly editions: the Battle of Mount Street Bridge. *Digit Humanit Q.* 2019;13(1).

    doi: 10.63744/fekqh6esrwwx

18. Sullivan EA, Snyder LM. Digital Karnak: an experiment in publication and peer review of interactive, three-dimensional content. *J Soc Archit Hist.* 2017;76(4):464-482.

    doi: 10.1525/jsah.2017.76.4.464

19. Manz MC, Raemy JA, Fornaro PR. Recommended 3D workflow for digital heritage practices. *Archiving Conference.* 2023;20(1):23-28.

    doi: 10.2352/issn.2168-3204.2023.20.1.5

20. International Organization for Standardization. *ISO 14721:2025. Space Data System Practices—Reference Model*

for an Open Archival Information System (OAIS). 3rd ed. International Organization for Standardization; 2025.

21. Farghaly K, Soman RK, Collinge W, Mosleh MH, Manu P, Cheung CM. Construction safety ontology development and alignment with industry foundation classes (IFC). *J Inf Technol Constr.* 2022;27:94-108.

    doi: 10.36680/j.itcon.2022.005

22. Bohne T, Rönnau S, Borghoff UM. Efficient keyword extraction for meaningful document perception. In: Hardy MRB, Tompa FW, eds. *Proceedings of the 2011 ACM Symposium on Document Engineering.* New York, NY: ACM; 2011:185-194.

    doi: 10.1145/2034691.2034732

23. Borghoff UM, Pfeiffer E, Rödig P. Unveiling BIM Core: enhancing long-term usability of digital building documentation with an advanced representation information repository. *J Inf Technol Constr.* 2024;29:596-611.

    doi: 10.36680/j.itcon.2024.027

24. Weibel SL, Koch T. The Dublin core metadata initiative. *D-lib Mag.* 2000;6(12). Accessed July 30, 2026. https://webdoc.sub.gwdg.de/edoc/aw/d-lib/dlib/december00/weibel/12weibel.html

25. Borghoff UM, Pfeiffer E, Rödig P. Long-term lifecycle-related management of digital building documents. In: Wigington C, Hardy M, Bagley SR, Simske SJ, eds. *Proceedings of the 22nd ACM Symposium on Document Engineering.* New York, NY: ACM; 2022:6:1-6:10.

    doi: 10.1145/3558100.3563842

Appendix

Building Information Modeling Core metadata for the "Poschi" reconstruction

The following metadata entries adapt the 23 Building Information Modeling (BIM) Core elements to an immersive digital heritage reconstruction. They document not only file formats, software dependencies, and access tools, but also source references, interpretive decisions, significant properties, and contextual information needed to preserve the reconstruction as a reusable scholarly object.

A.1. Structural and semantic features

(i) Format identification
The project used multiple file types, including Unreal Engine assets (.uasset), three-dimensional (3D) models (.fbx), audio files (.wav), and image formats (.tif/.jpg/.png). These formats represent geometry, textures, audio content, and archival sources.

(ii) Format versioning
Software versions were documented to ensure reproducibility. The reconstruction used Unreal Engine 5.3, 3ds Max 2026, Blender (5.0, Blender Foundation, Netherlands), Adobe Photoshop 2026, Substance Designer (2026, Adobe Inc., USA), and Substance Painter 2026. In addition to software versions, format and schema versions were documented where available, including filmbox (FBX) export version, Unreal Engine asset version, texture map specifications, waveform audio file format (WAV) encoding parameters, .tif/.jpg/.png variants, and any project-specific export presets.

(iii) Source repositories
Primary materials were obtained from the Eidgenössische Technische Hochschule (ETH; Swiss Federal Institute of Technology) Zurich Thomas Mann Archive and the Munich City Archive, ensuring traceability of historical references. Format-related information was linked, where applicable, to external registries.

(iv) Compatibility constraints
The FBX and Unreal Engine formats showed limited backward compatibility, while archival formats such as TIFF remained stable across software generations.

(v) Format openness
Open formats (e.g., TIFF, WAV) supported long-term access, whereas proprietary formats (.uasset, .fbx) required additional documentation and migration strategies.

(vi) Rights and licensing
Image materials were used under CC-BY-SA 3.0 DE, while literary rights were maintained by the Thomas Mann Archive. Newly created assets were released under open licenses where possible. We distinguished rights for source images, literary materials, 3D models, textures, audio, software, and derivative assets.

(vii) Structural and semantic encoding
The 3D models encoded both geometry and meaning. For example, the gramophone model included mechanical components and references to its role in *The Magic Mountain*. We added syntax/formal structure and semantics/meaning of elements and relationships.

(viii) Data encoding
Textures followed physically based rendering conventions, while textual data and metadata used Unicode Transformation Format—8-bit encoding where applicable. Numeric, textual, color, texture, and audio encodings were documented, including coordinate units, scale conventions, color spaces, bit depth, sampling rates, character encoding, and metadata encoding.

(ix) Compression and data handling
In certain cases, audio was stored uncompressed to preserve quality. Texture compression (e.g., DXT5) balanced visual fidelity and performance. No encryption was applied to avoid long-term access barriers; no checksums/fixity are used.

(x) External standards
The project adhered to standards such as ISO 12234-2 (TIFF), ISO/IEC 10918 (JPEG), and World Wide Web Consortium metadata standards. Where applicable, documentation recorded relevant specifications for FBX, WAV, PNG, glTF, EXR/HDR texture formats, physically based rendering material conventions, and Unreal Engine asset documentation.

(xi) Embedded metadata
Assets produced in Unreal Engine, Substance Painter, Blender, 3ds Max, and other software applications may contain internal metadata describing materials, geometry, lighting, configuration settings, export parameters, and related

technical settings, depending on the format. Embedded metadata were extracted where possible and preserved with the asset package, including authoring software, creation dates, export settings, material definitions, texture assignments, object names, scene hierarchy, and lighting parameters.

(xii) Reference linking
The relevant models and documents were linked to source materials such as archival images and textual references, ensuring traceability. External references were tested for resolvability and, where preservation permits, materialized by storing local preservation copies or stable identifiers. Broken, inaccessible, or rights-restricted links are documented.

(xiii) Software and hardware dependencies
The reconstruction depended on Unreal Engine and graphics processing unit-based rendering hardware. These dependencies, as well as graphics processing unit/virtual reality/browser requirements, were documented to support future emulation.

(xiv) Format customization
Assets were provided in multiple versions, including reduced-resolution models for educational use and high-resolution versions for archival storage. Customization included project-specific export presets, polygon-reduction rules, texture-resolution variants, Unreal Engine import settings, collision settings, level-of-detail generation, and educational or web-optimized derivatives.

(xv) Historical grounding
The reconstruction was based on archival sources, historical photographs, and architectural plans, ensuring accuracy and scholarly reliability.

A.2. File format handling tools

This section documents the tools used to identify, verify, and inspect digital formats generated during the preservation workflow.

(i) Format recognition tools
Formats were identified using tools such as JHOVE (v1.32, Open Preservation Foundation, UK) for image validation and FBX Review (v.06/2025, Autodesk Inc., USA) for 3D model inspection. Additional recognition tools included PRONOM/DROID (v122, The National Archives, UK), Siegfried (v1.11.1, Richard Lehane, Australia), Unix file, ExifTool (v13.59, Phil Harvey, Canada), MediaInfo (v26.5, MediaArea.net SARL, France), and software-specific import diagnostics for Unreal Engine, Blender, and Substance tools.

(ii) Format verification tools
UVPackmaster3 addon in Blender was used to verify UV mapping consistency and ensure correct texture alignment across models. Format verification and quality assurance combined with archival validation, metadata inspection, and domain-specific asset checks. JHOVE was used where supported for format identification, validation, and characterization; ExifTool was used to inspect embedded technical metadata; MediaInfo was used for audio and audiovisual metadata; Blender, FBX Review, and Unreal Engine imported logs supported inspection of 3D assets and import behavior; and UVPackmaster3 or comparable UV tools supported checks of UV packing and texture-layout consistency.

(iii) Inspection and presentation tools
Unreal Engine and Substance 3D Viewer (2026, Adobe Inc., USA) were used for visualization, while virtual reality solutions provided public access to the reconstructed environment. Inspection tools were distinguished from public presentation tools: Unreal Engine and Blender supported technical inspection; Substance 3D Viewer supported material inspection; virtual reality and simplified viewers supported dissemination to non-specialist users.

A.3. Contextual information

This section captures the historical and interpretive context required to understand the reconstructed environment.

(i) Significant objects and properties
The gramophone was documented as a key object representing early twentieth-century media culture. The "Poschi" residence reflected Thomas Mann's most productive period and provided insight into his literary and social environment. Significant properties included object identity, scale, spatial position, geometry, material appearance, texture fidelity, interaction behavior, source linkage, historical interpretation, and literary/contextual associations.

(ii) Building-specific context
The "Poschi" was the only house in which all six Mann children lived together. It was directly linked to major works

such as *The Magic Mountain*.

(iii) Format adoption and usage
Formats such as FBX and WAV are widely used in digital heritage projects, which supports their long-term accessibility and reduces the risk of obsolescence. Adoption is assessed separately from preservation suitability. Widely used formats such as FBX support exchange in production workflows, while open or better-documented formats are preferred for preservation masters where feasible.

(iv) Historical sources and validation
The reconstruction was validated using published studies and archival materials from ETH Zurich and the Munich City Archive. Validation records distinguished directly documented features, historically inferred features, and hypothetical reconstructions. Each uncertain element was linked to the source or reasoning that supports it.

(v) Use case and domain context
The project aligned with broader digital heritage initiatives and conceptual frameworks such as buildingSMART. It supported the identification of significant properties and structured documentation of cultural heritage data. Use cases included scholarly analysis, museum/public communication, educational access, long-term archival preservation, migration testing, and future reuse in digital humanities or heritage BIM contexts.