Cultural heritage management: towards informed decision-making based on integrated HBIM-GIS.

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Abstract. The management of architectural heritage, especially in designated ensembles such as cultural landscapes, faces significant challenges due to the unique characteristics of historical constructions and their distinct construction technologies. To address these challenges, the integration of technologies such as Historic Building Information Modeling (HBIM) and Geographic Information Systems (GIS) has been adopted. This study aims to explore the integration of HBIM with GIS, aiming to create a web database to simplify the visualization and management of heritage assets, with a focus on the scale of Cultural Landscape.The integrative approach involves the use of conversion software and the transformation of Building Information Modeling (BIM) data into GIS. The resulting model is then incorporated into a Facilities Management web database. The Modern Ensemble of Pampulha, recognized by UNESCO, serves as a pilot case study. The integrated application of BIM data conversion in IFC format to a geodatabase (gdb) is highlighted. The results encompass investigations into the integration of HBIM-GIS in a web database, with a particular emphasis on accessibility and usability for non-specialized users. This integrative approach in the web database, based on HBIM-GIS, aims to contribute to the effective preservation and management of architectural heritage. The study presents a replicable framework that can be applied to other historical constructions, promoting simplified accessibility and utilization of the integrated model.

Keywords: HBIM, GIS, Geodatabase, Cultural Heritage.

1 Introduction

In the past decade, Brazil has faced challenges in effectively managing its architectural heritage, including issues such as inadequate documentation, overdue restoration and maintenance activities, and a lack of monitoring of heritage sites. An illustrative example is the devastating 2018 fire at the National Museum of Brazil, which resulted in the loss of thousands of artworks. The restoration process is estimated to take six years. Despite these challenges, some scholars have been applying technologies as a means to preserve and manage built heritage, particularly those that differ from conventional structures.
According to various sources ([2], [3], [4]), the management of architectural heritage encounters significant hurdles due to the unique characteristics of historical constructions, distinct elements, and construction technologies that differ from contemporary structures. These challenges become more pronounced when dealing with architectural ensembles

classified as cultural landscapes.
As highlighted by [19], the concept of cultural landscapes extends beyond mere architectural structures to include the spatial and cultural context surrounding them. This broader perspective encompasses not only physical elements like buildings, squares, and streets but also intangible aspects such as cultural practices, traditions, and narratives linked to a specific location. Preserving a cultural landscape involves protecting not only the built environment but also maintaining the interaction between it and the natural environment, as well as the associated intangible cultural heritage.
Managing vast areas housing multiple constructions, as emphasized by [1] and [5], requires preserving the memory embedded in these structures. To address this, technologies such as Building Information Modeling (BIM) and Geographic Information Systems (GIS) offer significant advantages. An exemplary internationally recognized Cultural Landscape is the Modern Ensemble of Pampulha, located in Belo Horizonte, Brazil. Designated as a UNESCO World Heritage site in 2016, the ensemble comprises four buildings: the Casino (now the Pampulha Art Museum), the Church of São Francisco de Assis, the Casa do Baile, and the Yacht Tennis Club. [6] highlights the effectiveness of BIM and GIS technologies in Facility and Construction Management (AEOC). BIM, covering the entire life cycle of buildings, uses detailed parametric models to simulate performance over time. In addition to modeling, BIM represents a comprehensive transformation in AEOC processes, promoting data integration and a systemic, holistic approach to construction process management.
[7] emphasizes the effectiveness of GIS in managing geospatial data, enabling advanced spatial analysis and territorial modeling. [6] observes the advancement of BIM, highlighting synergistic integrations, such as BIM integrated with GIS. This integration is widely applied in conservation and restoration projects, as noted by [8] [10], and [9].
The concept of Historic Building Information Modeling (HBIM), introduced by [10], extends beyond tangible information modeling of existing constructions, incorporating intangible historical aspects into their life cycle. According to [2][3][18][4], HBIM utilizes digital scanning technologies to collect and structure data within the BIM context, applied in the documentation, preservation, and management of historical buildings.
However, the integration between HBIM and GIS, as noted by [5][8], requires additional interoperability efforts due to differences in standards and semantics used in each system. During the HBIM-GIS integration process, extracting and transforming information between models can be challenging, given the lack of structured semantic enrichment in the BIM model and the absence of geographic information in BIM. In terms of interoperability, it is emphasized that verifying and editing data and metadata in the HBIM model is essential for efficient data exchange between specific BIM and GIS software, ensuring the correct transfer of all information from the BIM method to GIS.
The integration challenges between HBIM and GIS, highlighted by [5][8], include data loss when transferring them between software. A proposed solution is the use of structured semantic enrichment, establishing a standardization for information. The application of a conversion software, such as FME mentioned by [5][11], can assist in the efficient conversion of data.
It is essential to note that relatively recent authors, such as [10][13][14][1], aim to simplify the visualization of the integrated HBIM-GIS model for non-specialized users. In these approaches, the focus of integration goes beyond mere database applications, prioritizing

the accessibility and use of the HBIM-GIS model within the scope of heritage management. [10] emphasizes the relevance of integrated application through web-based solutions, allowing stakeholders to visualize the model without the need for proprietary software. This study presents the results of two investigations addressing the integration of HBIM- GIS for a web database as a simplified data dissemination form. The study was conducted on a set of buildings located in the cultural protection area of Belo Horizonte, specifically in the cultural protection area around the Pampulha Lagoon, and includes the Pampulha Art Museum (MAP) as a pilot project.

This study is justified by the importance of conserving and promoting the cultural, historical, and architectural heritage of cities, aiming to safeguard cultural identities and their proper recognition, in line with the achievement of Goal 11 of the Sustainable Development Goals (SDGs) established by the United Nations.

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The hypothesis of this study suggests that the integration of the HBIM model with a GIS system can generate structured information to support heritage management, during maintenance activities. To achieve this objective, the following specific goals have been established: (1) Assess the effectiveness of using data conversion software (FME) applied to the HBIM-GIS to integrated 3D data in a GIS. (2) Employ the integrated HBIM-GIS model for a webgeodatabase for simplified data dissemination.

1.1 Case Study.

In Belo Horizonte, Minas Gerais, Brazil, there is an iconic architectural structure known as the Pampulha Art Museum (MAP). Originally conceived as a casino, the building was designed by the renowned Brazilian architect Oscar Niemeyer and is part of the Pampulha architectural complex, which includes the Church of São Francisco de Assis, the Casa do Baile, and the Yacht Tennis Club. Figure 1 illustrates the MAP.

Figure 1. MAP. Source: Authors, 2024

The inception of the Pampulha Art Museum project dates back to 1940, with its completion in 1943, marking a notable expression of Brazilian modern architecture. Oscar Niemeyer, a visionary, infused the museum with bold characteristics, such as its curved structure, fluid lines, and the audacious use of reinforced concrete, reflecting his genius. The museum was initially intended to be a casino and, during the period when gambling was allowed in Brazil, it served as a venue for social and cultural events.
In 1946, due to the prohibition of gambling in the country, the casino was closed, leading to various transformations over the years. In 1957, the space was reborn as the Pampulha Art Museum, playing a significant role in promoting visual and cultural arts in the region. The Pampulha architectural complex, including the Art Museum, received recognition from UNESCO and was designated as a Cultural Heritage of Humanity in 2016. This status underscores the historical and aesthetic importance of the museum, consecrating it as an icon of modern architecture and Brazilian cultural identity.
The Pampulha Art Museum continues to maintain its allure, attracting visitors and architecture enthusiasts, offering a unique experience that transcends time and preserves Oscar Niemeyer's avant-garde vision.

2 Methodology

Following [15] methodological principles, this study employs an exploratory and qualitative approach using the Case Study method. The author assumes the role of an observer, detailing the integration of HBIM (Historic Building Information Modeling) with GIS (Geographic Information System), applying it to the study object, the Pampulha Art Museum (MAP).
The integrative approach of HBIM to GIS is executed through two distinct strategies. In the first approach, we achieve direct integration of the HBIM model, constructed in Revit software version 2023, with ArcGIS software version 3.1. Meanwhile, in the second approach, inspired by the studies of [5], we utilize FME software version 2023.0 as a tool to integrate and convert data from the Industry Foundation Classes (IFC) format, following the Revit software version 4.2 standard, to the Esri GDB (Geodatabase) format.
The methodological procedures adopted for this study include:
HBIM Modeling: For HBIM modeling, we gathered data from Oscar Niemeyer's original plans, using them as a parametric foundation for HBIM modeling. Additionally, we semantically enriched the model with historical textual data associated with the intrinsic components of modern architectural works. The modeling process was carried out using Revit software version 2023.
BIM to GIS Data Conversion: We exported the HBIM model to the IFC format and subsequently imported it into the DataInspector FME and WorkBench FME software, allowing for data and metadata editing, correction, and validation. After verification, we converted the data to GDB format and then imported it into a 3D layer in ArcGIS..
Web Database Configuration: Following the HBIM-GIS integration, the generated data was exported to a proprietary web database using ACCA software. A USBIM.Gis extension was employed to visualize the three-dimensional data.

2.1 From real to HBIM.

We incorporated Oscar Niemeyer's original drawings directly into Revit. Figure 1 illustrates the modeling scheme based on existing 2D data. When shaping the Pampulha Art Museum (MAP), we deliberately chose the Level of Detail (LOD) 200, aligning with the OmniClass standard in Revit to standardize information attribution and component identification.

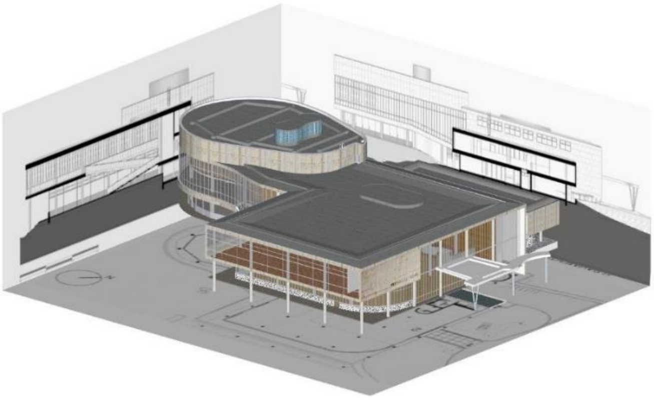

Figure 1. HBIM model based on originals plans. Source: Authors, 2024

The strategic choice of LOD 200 focused the modeling exclusively on the external part of the building, emphasizing crucial architectural features such as walls, windows, and roofs, providing a clear visualization of the external structure.

One distinctive feature of Niemeyer's work is the use of pilotis. In the Revit process, we identified three types of pilotis in the building, each with distinct radii ranging from 17 cm to 25 cm. The internal pilotis originally had a stainless steel coating, while the external ones were finished with exposed concrete. These characteristics were incorporated into Revit during the modeling phase.

To represent these features in the BIM model, we used the Architectural Column tool, creating piloti elements with specific dimensions and finishes. This approach allowed for precise modeling of the structural elements of MAP, incorporating Niemeyer's project peculiarities. We faced challenges dealing with Niemeyer's distinctive organic forms, especially in the multi-use space block of MAP, which features circular shapes and is elevated 93 cm above the rest of the building. To overcome these complexities, we chose the Ramp function in Revit, ensuring fidelity to Niemeyer's architectural proposal by connecting the slab of the multi-use space to the slab of the rest of the building, located at a lower level. Figure 3 displays the BIM model created in Revit with LOD200.

Regarding the terrain modeling, we utilized topographic data and 2D drawings provided by the municipality of Belo Horizonte. The 2D drawings, along with the topographic data, were imported into SketchUp, where we employed plugins such as Sandbox to simplify the modeling of complex shapes. After completing the terrain modeling, we applied the Digital Terrain Model (DTM) based on existing data, following the IFC guide, and exported it to Revit in IFC4 format. This allowed us to integrate the DTM into the MAP, enhancing the representation of the surrounding environment. Figure 2 illustrates the DTM model and the HBIM model in the Revit software.

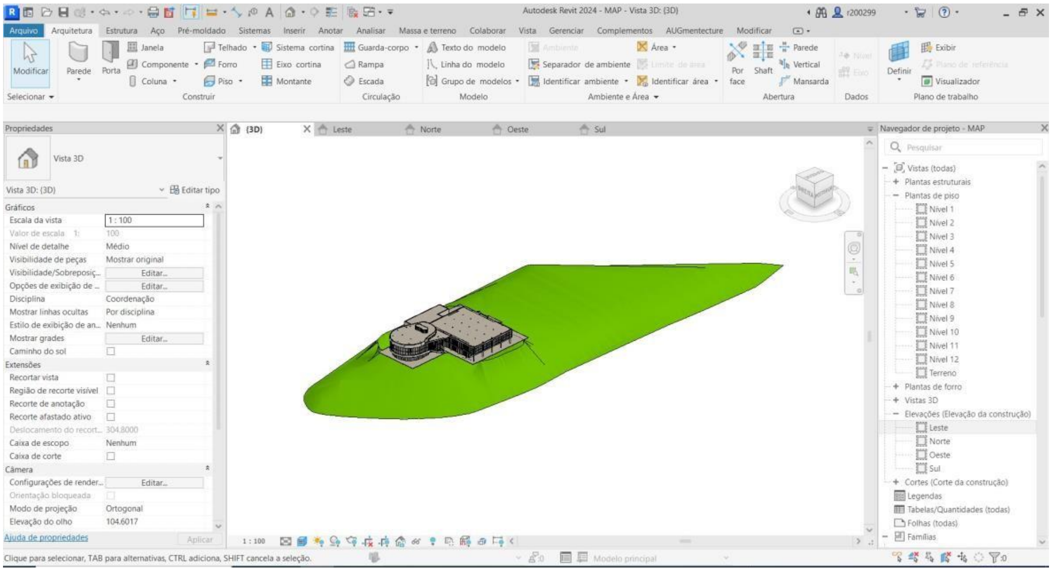

Figure 2. DTM and HBIM models in Revit. Source: Authors, 2024.

2.2 **HBIM to GIS Data.**

With the HBIM model created in Revit, we exported the BIM data to IFC4 architecture with shared coordinates. Using the generated IFC file, the model was inserted into the Data Inspector FME software, an extension of the FME software that allows for the visualization of data and metadata in 2D and 3D. When inserting the IFC model into the Data Inspector, it organized the IFC patterns based on the HBIM model. It is important to note that, depending on the adopted Level of Detail (LOD), there may be more or fewer information patterns.

Figure 3 illustrates the HBIM model with the DTM visualized in the Data Inspector. We used the Data Inspector to validate the IFC data and visualize missing information, which was later removed. We obtained a total of 15 IFC information patterns, such as IFCBuilding, IFCBuildingStorey, IFCColumn, IFCCurtainWall, IFCMember, IFCPlate, IFCProject, IFCRamp, IFCRampFlight, IFCSite, IFCSlab, IFCTYPEObject, IFCWall, PropertySetDefinition, and QuantitySetDefinition. The IFC QuantitySetDefinition patterns did not contain geometry, surface, or line information and were removed, resulting in 14 remaining information patterns.

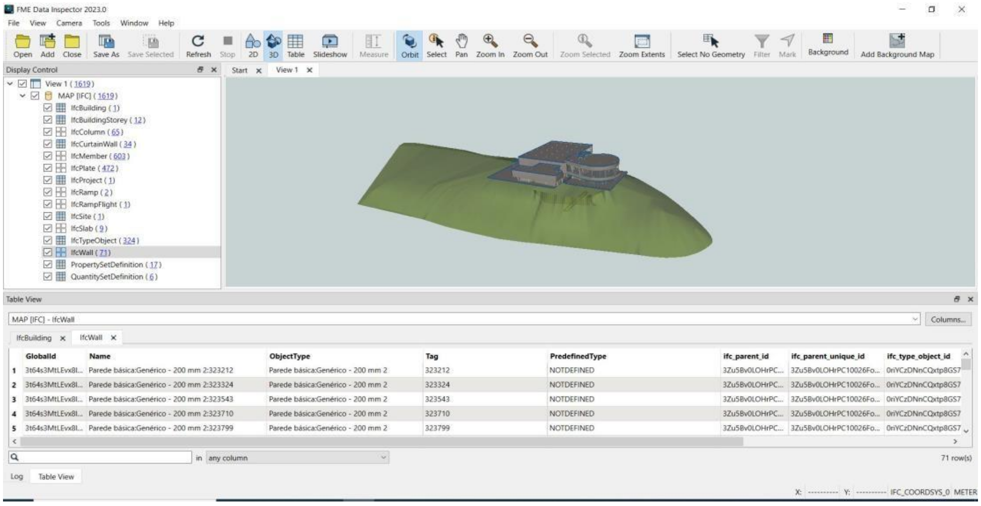

Figure 3. IFC model visualised in Data inspector FME. Source: Authors, 2024

Regarding metadata, we obtained a total of 1619 metadata items, involving geometry, surface, lines, and polygons data, along with textual data that structure an IFC pattern. Each IFC pattern has classes and subclasses; for instance, the IFCWall pattern has 71 metadata items. This same value can be verified in tables in Revit to quantitatively validate whether all data and metadata were transferred to IFC.

After visualizing all the data in the Data Inspector, we identified some missing information, such as body and axis. These missing data can be addressed in the next step. In the subsequent step, the IFC model was inserted into the Workbench FME software, where it is possible to edit, modify input and output data, and convert them to the desired format. The Data Inspector FME is solely for visualization; it does not convert or transform data, whereas the Workbench allows for edits.

When inserting the IFC format into the Workbench, we selected which IFC patterns would be transformed, opting for those that contain data. Next, the Workbench structured the IFC patterns into input (readers) and output (writers), where readers represent input information (IFC), and writers represent output information (GDB). The software automated the data conversion after this structuring. Figure 4 illustrates the IFC data patterns in the Workbench.

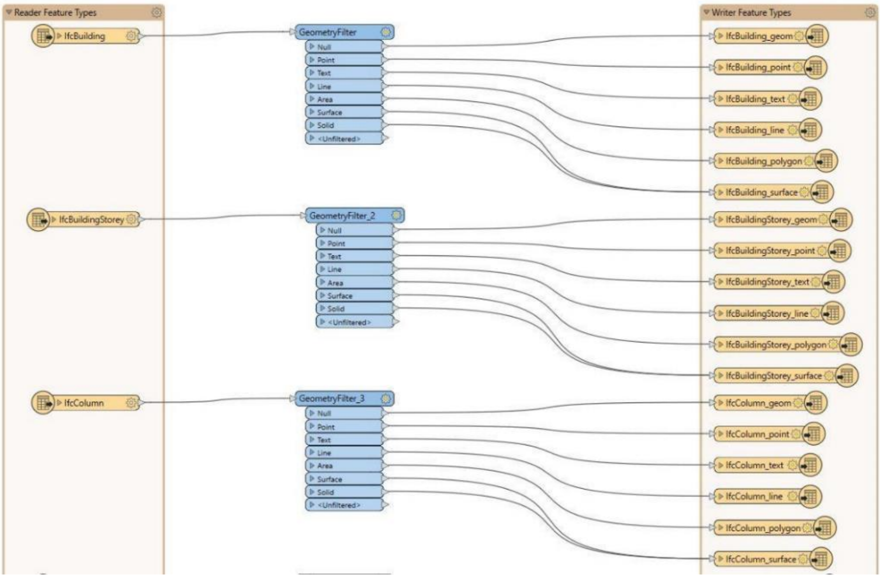

Figure 4. IFC Information Standards in Workbench FME Software. Source: Authors, 2024

2.3 Web Database Configuration

With the GDB data created, we utilized the ACCA software, which features an extension called USBIM.GIS. Software solutions with native BIM and GIS capabilities are relatively new in the market. While native GIS software, like ArcGIS, has been dedicated to meeting the demands of Industry 4.0 by allowing direct input of IFC data, companies such as ACCA strive to create software with integrated BIM-GIS solutions.

USBIM.GIS is a web-based and free extension, making it easily accessible, and users do not require high-performance hardware to visualize data. The GDB and IFC data were input into USBIM.GIS, but only IFC data allows for visualization. The software does not enable the direct visualization of GDB data; it only provides accessibility. However, IFC data was easily visualized. When loaded and selected, the software opens a new window, allowing for the visualization of IFC data. Figure 5 illustrates the workflow for the process in USBIM.GIS.

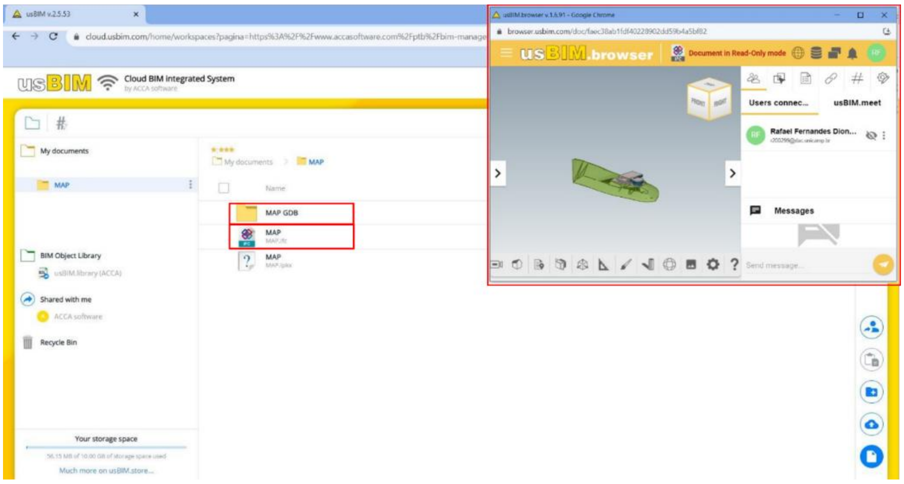

Figure 5. UsBIM.gis Workflow. Source: Authors, 2024

3 Results and Discussion

We opted to adopt established methodologies proposed by [5], using FME software as a solution. FME allowed us to visualize, edit, and validate the data and metadata contained in the HBIM model, as well as convert them into GDB for ArcGIS.
In ArcGIS Pro, we opened a local scene and created a new layer using the "3D layer" function, inserting the GDB file containing the HBIM model. Both ArcGIS and Revit use the global GPS positioning system with an accuracy of 20 meters. However, upon inserting the HBIM model into ArcGIS, we noticed a displacement of a few meters, corrected through the "move layers" function to adjust the coordinates accurately. Figure 6 illustrates the integrated HBIM-GIS model in the ArcGIS software.

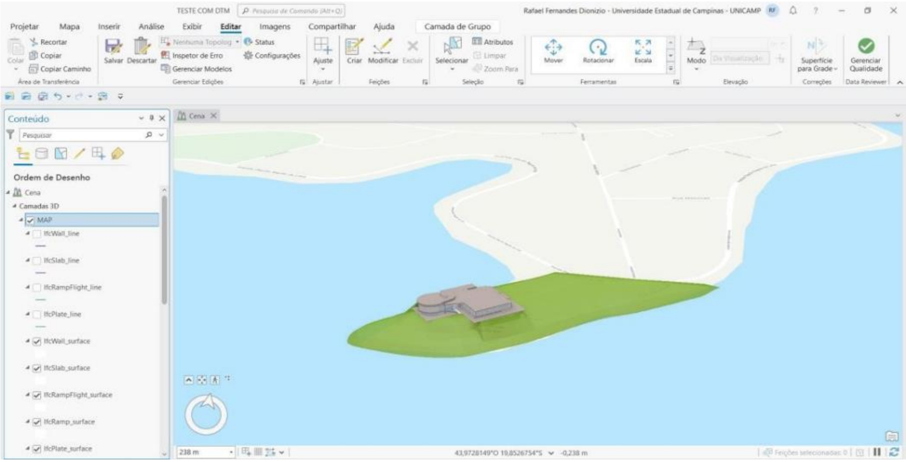

Figure 6. HBIM-GIS model in Arcgis. Source: Authors, 2024

Direct insertion of coordinates in Revit yielded more accurate results than in WorkBench FME. This approach to integrating and analyzing HBIM models in ArcGIS Pro and WorkBench FME provides a more comprehensive and detailed view of the data, enabling spatial analysis and the assignment of relevant information to model components.

Considering the cultural landscape with five buildings, efficient heritage management is achieved through the HBIM-GIS model. In ArcGIS, it is possible to input custom attributes not feasible in Revit, and to visualize multiple buildings in a georeferenced manner, facilitating monitoring. 3D analyses enable the creation of quantitative and qualitative attributes regarding the buildings, including conservation data and the need for maintenance or restoration. This approach allows for comprehensive and detailed management of cultural heritage, aiding informed decisions on the preservation and care of historical buildings.

To verify the integration of Revit BIM data into ArcGIS, we conducted a comparison using tables available in both platforms. By using the Data Inspector FME to open the IFC file, we could visualize all IFC parameters. As an example, we focused on the IFCWall standard, and the Data Inspector quantified 71 walls of this class, including information such as type, family, materials, and dimensions.

Accessing metadata in ArcGIS through the "Attributes" function, we could tabularly visualize 70 IFCWall data, consistently correlating with what was observed in the Data Inspector. Figure 7 illustrates the quantity of wall data in the environments of the Data Inspector FME, and ArcGIS.

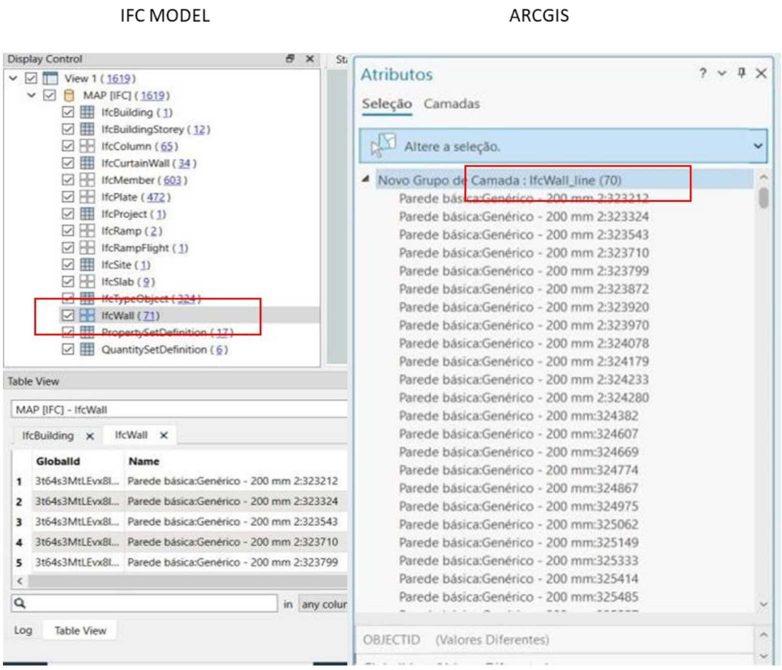

Figure 7. Comparison on Revit, FME, and Arcgis table. Source: Authors, 2024

It is important to emphasize that we dealt with 14 IFC information standards, each with metadata organized in tables. We used IFCWall as an example to demonstrate that all Revit BIM data was successfully transferred to ArcGIS.

While we were unable to visualize GDB data in the USBIM.GIS web database, we achieved success in visualizing and providing access to this data, exercising control over who has access to this database. Figure 8 outlines the workflow in USBIM.GIS and highlights the sharing capability. We were able to manage whether stakeholders could only view, download, or edit the file. This prevents inexperienced individuals from deleting or altering the model, ensuring secure sharing in USBIM.GIS.

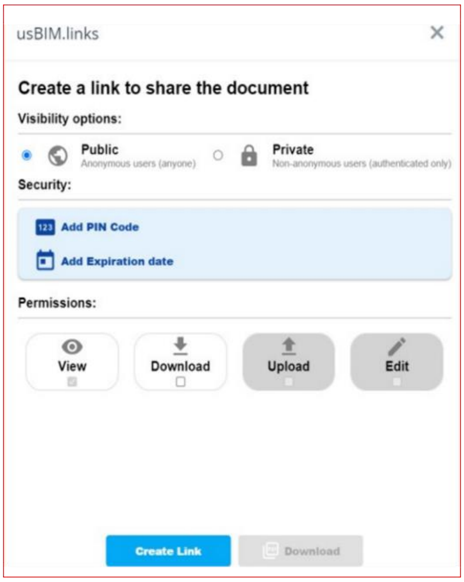

Figure 8. Workflow for sahred on UsBIm.Gis. Source: Authors, 2024

The IFC data is presented in a simplified manner, facilitating building analyses. An example of such analysis is the visualization of all IFC components with the application of filters. Additionally, we can incorporate data such as PDFs associated with these components. Assigned to these components, we can insert building documents, inspection reports, and preservation processes, making them readily available in a simplified manner. Figure 9 illustrates the HBIM model, including the PDF of the preservation dossier conducted by IPHAN for UNESCO, along with the selection of IFC components.

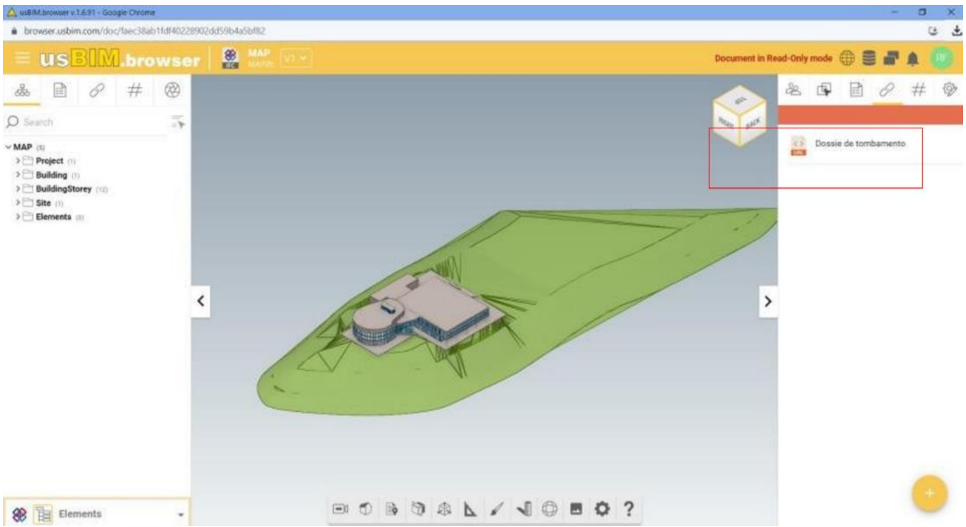

Figure 9. PDF integrated data in UsBIM.gis. Source: Authors, 2024

In addition to visualizing IFC components, it is possible to examine and select the metadata of IFC data, such as materials and textures. Figure 10 illustrates the IFC Materials function with the selected concrete material. Furthermore, we can incorporate data in PDF format.

These materials can be used as a form of structure monitoring, allowing the attachment of textual data, such as inspection reports or assessments of the building's physical condition.

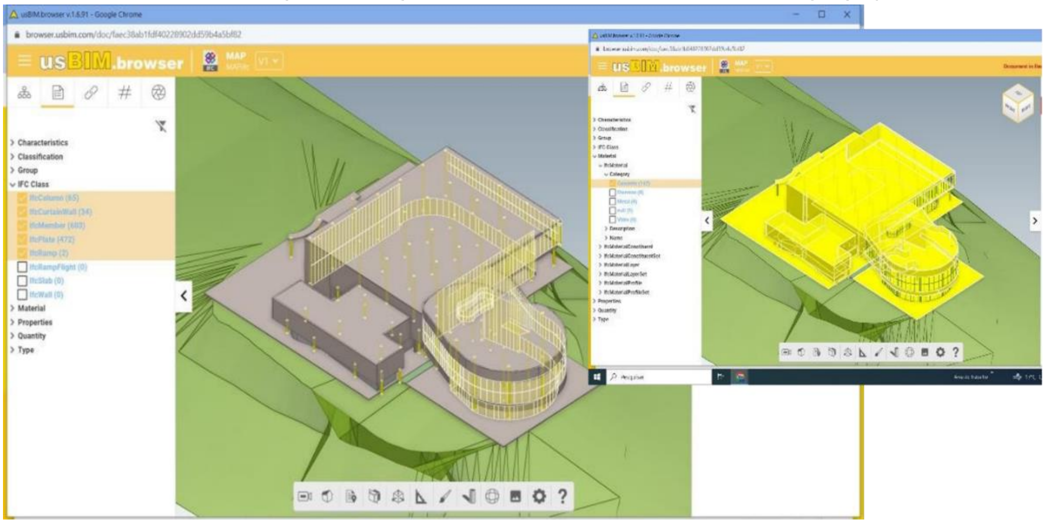

Figure 10. Selection filters for IFC data and metadata in UsBIM.gis.

The interaction of the HBIM-GIS model, coupled with the subsequent insertion of this data for simplified access across different technologies and scales, allows for a more comprehensive and detailed analysis of the building and its surroundings. This significantly contributes to the management and preservation of cultural heritage at the level of a cultural landscape.

Interoperability between BIM and GIS data is indeed a complex issue that requires in-depth knowledge in the involved areas. To enable the management of the building to visualize the HBIM-GIS model, a multidisciplinary team and the use of computers with advanced hardware become essential. While the use of a web database can address part of this challenge, dedicated software, such as ArcGIS, should enhance interoperability between BIM systems.

It is crucial to note that changes made in Revit are not automatically reflected in ArcGIS, requiring manual synchronization that is time-consuming and demands expertise to operate the HBIM-GIS model. However, Esri offers the ArcGIS Online extension, enabling the use of the HBIM-GIS model in the cloud and facilitating data visualization among involved parties. Studies, as presented by authors like [17][16], highlight this utilization.

As highlighted by authors such as [20], [21], [22] and [23], relatively recent applications of HBIM- GIS face notable challenges. One challenge involves the shortage of specialized workforce within the team responsible for cultural heritage, often encountering difficulties even in operating the necessary software for visualizing the informative model. Additionally, the complexity of managing various buildings stored in different files presents a significant obstacle. To overcome these challenges, there has been exploration into the possibility of consolidating all BIM data in a single location, aiming not only for simplicity in storage but also for integrating these models into a GIS system. This approach allows for georeferencing all BIM data at a unified point of access, streamlining the management and analysis of architectural heritage.

As highlighted by [5] [8], HBIM has evolved into various applications, with GIS being one

of them. The approach developed in this study represents an effective way to streamline processes and support heritage management in activities ranging from maintenance to decision-making, all based on an integrated information model that combines BIM and GIS data. In this scenario, it is crucial to conduct in-depth studies on interoperability to ensure data integrity during information exchange without relying on additional conversion software. Additionally, promoting the use of open-source software can enhance access and data manipulation among stakeholders.
Figure 11 illustrates the workflow, emphasizing the data input capability of GIS and BIM. GIS covers the macro scale, ranging from territorial scales to district mesoscale, and finally, to the micro scale of the building. The workflow depicts the collection of GIS and BIM data, the conversion of BIM data using FME software, and the insertion of converted data into ACCA software to make the data available in a web database.

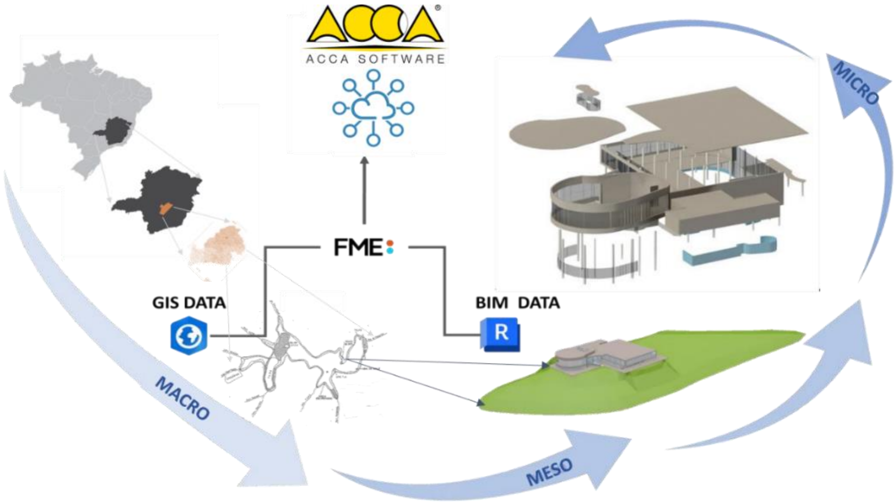

Figure 11. Final Workflow. Source: Authors, 2024

4 Conclusion

Evaluating the attempt to integrate HBIM into SIG directly revealed that the initial method of direct interaction from the HBIM model to ArcGIS Pro has limitations. Despite the ability to visualize the HBIM model in ArcGIS Pro, the BIM data is not successfully applied, indicating the need for additional approaches to ensure the successful transfer of Revit BIM data to ArcGIS.
The data integration software demonstrated effectiveness in integrating BIM data into a GIS, such as ArcGIS Pro. In addition to performing a complete conversion of the HBIM model into GIS, the HBIM model in ArcGIS presented a practical advantage for managing architectural heritage in maintenance activities, documentation, and decision-making.
The utilization of usBIM.gis software for streamlined data provision has proven to be effective. While GDB data cannot be directly viewed, the software enables stakeholders to acquire the data and open it later in ArcGIS Pro. Moreover, it simplifies the provision of IFC data, allowing for analyses using the IFC data visualization platform. This eliminates the

necessity for users to possess expertise in BIM modeling software and high-performance hardware.
For future research, studying the integrated application in a web database is imperative. The author should act as a proponent of the application of the HBIM-GIS model in a web database alongside heritage management to validate how and where this web database would be utilized. Additionally, exploring tasks beyond decision-making and maintenance scheduling that could be optimized is essential.
In terms of future research, it is crucial to emphasize interoperability between BIM and GIS software. This involves leveraging high-reliability data techniques and tools for capturing and modeling in both BIM and GIS environments. Exploring simplified data visualization methods is also fundamental, serving not only to present data in an accessible manner but also to enhance the overall visualization experience.

5 **Citations**

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