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HBIM AND GIS INTEGRATION FOR PAMPULHA CULTURAL LANDSCAPE MANAGEMENT: CHALLENGES AND OPPORTUNITIES

HBIM E SIG PARA GESTÃO DA PAISAGEM CULTURAL DA PAMPULHA: DESAFIOS E OPORTUNIDADES

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Abstract

The challenges in documenting and managing architectural heritage at various scales, including cultural landscapes, are complex due to the unique characteristics of historic buildings, their construction systems, and cultural value. Managing a heritage ensemble becomes even more demanding, given its comprehensiveness. To overcome these challenges, new technologies have emerged, such as photogrammetry, 3D scanning, semantic modeling, and integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS). The application of BIM and GIS in heritage management allows for a comprehensive understanding of historic buildings' architectural and functional features. Integrating HBIM and GIS involves extracting and transforming geometric and semantic information; however, data loss during software transfers and the need to structure information through standards present challenges to ensure effective integration. This article addresses the integration of Historic Building Information Modeling (HBIM) and GIS in managing the cultural landscape of Oscar Niemeyer's Pampulha Complex, including the surrounding cultural protection area of Lagoa da Pampulha. The study focuses on Niemeyer's unique architectural works to assess the effectiveness of integration software and the benefits of the HBIM-SIG model in heritage management, establishing a workflow for preserving and maintaining these cultural assets using these technologies. This approach can provide a solid foundation for the conservation of architectural heritage, enabling detailed analysis, efficient decision-making, and a better understanding of the historical and cultural characteristics of the Pampulha protection area. The results demonstrate the importance of ensuring interoperability between BIM and GIS systems to manage this distinctive architectural heritage successfully.

Keywords: *Cultural heritage, HBIM, GIS, semantic information sharing.*

Resumo

Os desafios da documentação e da gestão do património arquitetônico a várias escalas, incluindo as paisagens culturais, são complexos devido às características únicas dos edifícios históricos, dos seus sistemas de construção e do seu valor cultural. A gestão de um conjunto patrimonial torna-se ainda mais exigente dada a sua abrangência. Para ultrapassar estes desafios, surgiram novas tecnologias, como a fotogrametria, a digitalização 3D, a modelação semântica e a integração da Modelagem da Informação das Construção (BIM) e Sistemas de informações Geográficas (SIG). A aplicação do BIM e do SIG na gestão do património permite uma compreensão abrangente das características arquitetônicas e funcionais dos edifícios históricos. A integração do BIM e do SIG envolve a extração e a transformação de informações geométricas e semânticas; no entanto, a perda de dados durante as transferências de software e a necessidade de estruturar as informações através de normas representam desafios para garantir uma integração eficaz. Este artigo aborda a integração da Modelagem Informação da Construção Histórica (HBIM) e do SIG na gestão da paisagem cultural do Complexo da Pampulha de Oscar Niemeyer, incluindo a área de proteção cultural do entorno da Lagoa da Pampulha. O estudo se concentra nas obras arquitetônicas únicas de Niemeyer para avaliar a eficácia do software de integração e os benefícios do modelo HBIM-SIG na gestão do patrimônio, estabelecendo um fluxo de trabalho para a preservação e manutenção desses bens culturais usando essas tecnologias. Esta abordagem pode fornecer uma base sólida para a conservação do património arquitetônico, permitindo uma análise detalhada, uma tomada de decisão eficiente e uma melhor compreensão das características históricas e culturais da área de proteção da Pampulha. Os resultados alcançados demonstram a importância de garantir a interoperabilidade entre os sistemas BIM e GIS para alcançar uma gestão bem sucedida e integrada deste património arquitetônico distinto.

Palavras-chave: Patrimônio cultural, HBIM, SIG, compartilhamento de informações semânticas

Authors' contributions:
RFD: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, validation, visualization, writing - original draft, writing - review & editing. EDK: conceptualization, formal analysis, investigation, methodology, supervision, validation, visualization, writing - review & editing.

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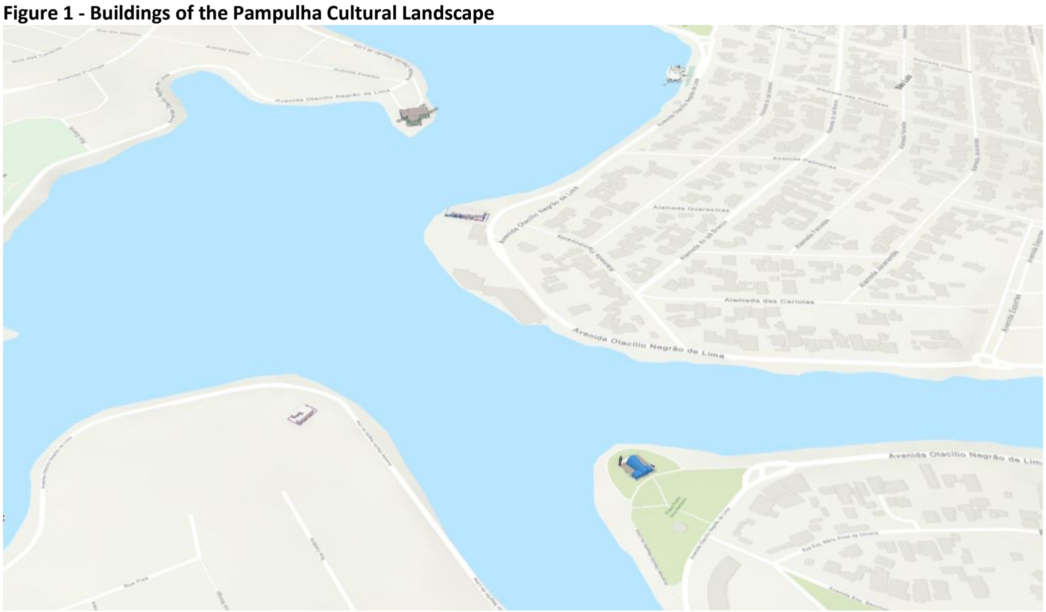
Introduction

Technological advances in the preservation of modern architectural heritage

According to Dezen-Kempter *et al.* (2020) and Vacca *et al.* (2018), architectural heritage management faces considerable challenges due to the unique characteristics of historic buildings, their components, and the construction technologies that differ from contemporary buildings. These challenges increase according to the scale of the listed architectural heritage, as is the case for architectural ensembles that comprise the cultural landscape.

Nascimento and Scifoni (2010) defines cultural landscape as a broader concept that involves not only individual architectural structures but also the spatial and cultural context in which these structures are embedded. The cultural landscape includes physical elements such as buildings, squares, gardens, and streets, as well as intangible features such as cultural practices, traditions, and histories associated with a particular place. Cultural landscape preservation involves protecting the built environment and its relationship to the natural environment and intangible cultural heritage. Vacca *et al.* (2018) state that when managing a large-scale area comprising several built specimens, we are committed to preserving the memory materialized in these BIM and GIS technologies that offer significant advantages. Among the examples of internationally recognized Cultural Landscapes, we highlight the Conjunto Moderno da Pampulha - CMP (the Pampulha Modern Ensemble) in Belo Horizonte, Brazil, which was recognized as a World Heritage Site by UNESCO in 2016. It consists of four buildings: the Casino (now the Museu de Arte da Pampulha – MAP - Pampulha Art Museum), Igreja São Francisco de Assis – ISFA (the São Francisco de Assis church), the Casa do Baile - CB (Ballroom), and the Iâte Tenis Clube – ITC (Yacht Tennis Club). Figure 1 illustrates Lake Pampulha with the Pampulha Modern Ensemble and the Casa Juscelino Kubitschek - CJK (Juscelino Kubitschek House) that comprise the Pampulha Cultural Landscape.

Figure 1 - Buildings of the Pampulha Cultural Landscape



Source: the authors.

Eastman (2011) points out that applying BIM and GIS technologies has proven highly advantageous in several areas of Building, Construction, and Engineering Management. The BIM method has been developed to provide an efficient system throughout the life cycle of buildings, from architectural design, construction, and maintenance to demolition. This approach is based on the use of detailed and accurate parametric models, with information regarding their materiality, which even serves to simulate the performance of this building over time. BIM is not restricted to simple parametric and semantically oriented modeling of the building but represents a comprehensive transformation in Architecture, Engineering, Operation, and Construction (AEOC) processes. Therefore, the BIM methodology constitutes a paradigmatic change in construction process management, whose essence lies in integrating data and the systemic and holistic approach to buildings.

Regarding GIS, Dangermond and Goodchild (2020) highlights the effectiveness of this tool for geospatial data management, allowing spatial analysis and advanced territorial modeling. According to Goodchild (2000), GIS emerged in the 1970s and 1980s to simplify the processing of georeferenced data. GIS was developed in Canada to automate the processing of Land Inventory information, replacing manual activities. Similarly, the U.S. Bureau of Demographic Census Studies created an early GIS in 1970 to simulate and project population distribution and characteristics in specific areas. Nowadays, GIS is widely used in utilities, telecommunications, urban and regional planning, road system analysis, and any georeferenced data application.

Evolution from BIM to HBIM and integration with new technologies

According to Eastman (2011), BIM has experienced significant advancement and consolidation, focusing on seeking synergistic integrations with other technologies. A notable example is the development of Historic Building Information Modeling (HBIM) and its integration with GIS. According to Dezen-Kempter *et al.* (2020), Chenaux *et al.* (2019), and Matrone *et al.* (2019), this integration has been widely applied in conservation and restoration projects and maintenance activities of historic buildings.

The concept of Historic-BIM, introduced by Murphy, McGovern, and Pavia (2007), refers to a BIM approach that goes beyond modeling information of existing (tangible) buildings, including information related to their historical significance throughout their life cycle (intangible). HBIM involves collecting data using scanning technologies and structuring it within the BIM context. This approach has been used to document, preserve and manage information related to historic buildings, enabling more accurate analysis of their architectural, structural, functional, and cultural characteristics.

As highlighted by Dezen-Kempter *et al.* (2020), the advancement of BIM and the adoption of HBIM have enabled a more comprehensive and specialized approach to managing historic buildings, allowing for a deep and detailed understanding of the built heritage.

Dezen-Kempter *et al.* (2020) emphasize that correctly modeling information in the BIM environment is essential to promote interoperability between systems and tools. This facilitates efficient information sharing and reuse. It also integrates data from different sources and disciplines, contributing to the multidisciplinary management of architectural heritage.

According to Vacca *et al.* (2018), Dezen-Kempter *et al.* (2020), and Trisyanti *et al.* (2019), the integration between BIM and GIS requires additional interoperability efforts due to the differences in standards and semantics used in each system. In the HBIM-GIS integration process, it is necessary to extract and transform geometric and semantic information from the BIM model to a GIS. However, the model's lack of structured semantic enrichment can make this task difficult. While GIS does not model detailed building information, BIM does not model geographic information.

Murphy, McGovern, and Pavia (2007) point out that the semantically oriented approach of HBIM aims to define topological relationships and properties of entities (components) representing the knowledge and information of a historic building. This facilitates the capturing and structuring of detailed information, including historical, architectural, and material aspects.

In terms of interoperability, Vacca *et al.* (2018) and Trisyanti *et al.* (2019) highlight that checking and editing the data and metadata contained in the HBIM model ensures a more efficient data exchange between BIM software and a specific GIS, ensuring that all data from the BIM method is correctly transferred to the GIS.

To achieve more effective interoperability, two main steps are defined. The first is the definition of the level of detail (LOD), which establishes the degree of development and accuracy of the information in the model. The second step is the semantic enrichment applied to the HBIM model, which consists of adding contextual information and relationships relevant to the components of historic buildings.

Vacca *et al.* (2018) highlight the widespread use of the Industry Foundation Classes (IFC) export format, developed by BuildingSMART and the International Organization for Standardization (ISO), for sharing and exchanging BIM data between different software. This standardization aims to facilitate interoperability in AEOC and the exchange of information between those involved.

However, Vacca *et al.* (2018), Dezen-Kempter *et al.* (2020), and Trisyanti *et al.* (2019) point out that HBIM and GIS integration faces the challenge of data loss when transferring data between software. One solution is using structured semantic enrichment with a standardized structure for the information. A converter software, such as FME mentioned by Vacca *et al.* (2018) and Baik, Yaagoubi and Boehm (2015), can be applied to assist in data conversion.

This paper presents the results of two investigations addressing the integration of HBIM-SIG for a set of works recognized by UNESCO as Cultural Landscape, listed in 2016. The study was conducted on a group of buildings located in the cultural protection area of Belo Horizonte, more specifically in the cultural protection area around Lake Pampulha. These buildings include the Pampulha Modern Ensemble, the São Francisco de Assis church, the Pampulha Art Museum, the Yacht Tennis Club and the Ballroom.

The cultural protection area surrounding Pampulha, the Juscelino Kubitschek House, is also located there. These works are considered outstanding examples of modern national and international architecture. UNESCO listed the Pampulha Modern Ensemble as a World Heritage site, while the Juscelino Kubitschek House was listed by IEPHA in 2009.

The first part of the paper aims to provide the historical context of the buildings, which serves as a basis for structuring the information standards adopted in this research. The second part focuses on HBIM modeling using Revit software. In the third part, the integration of this HBIM model with a GIS-3D is performed, more explicitly using ArcGIS Pro (Esri) software. This study is justified by the importance of the conservation and promotion of cities' cultural, historical, and architectural heritage, aiming at safeguarding cultural identities and their due recognition, in line with the achievement of Goal 11 of the Sustainable Development Goals (SDGs) established by the United Nations.

This study starts from the hypothesis that integrating the HBIM model with a GIS system can provide relevant and structured information that supports heritage management, specifically in the context of the Cultural Landscape, during maintenance activities. To achieve this aim, the following specific objectives have been established:

1. Evaluate the attempted HBIM to GIS integration directly.

2. Evaluate the effectiveness of using data converter software (FME) applied to the HBIM-SIG model to capture, organize and visualize 3D data in a GIS.

3. Investigate the combination of 2D and 3D data to manage heritage at the Cultural Landscape level.

This integrative HBIM-SIG approach aims to provide a solid and replicable framework that can be applied to other historic buildings to contribute to the preservation and effective management during architectural heritage maintenance activities.

Workflow, planning, and execution

For the integrative approach of HBIM to GIS, we used two methods. First, we directly integrated the HBIM model, modeled in Revit software version 2023, with ArcGIS GIS version 3.1. In the second approach, based on the studies of Vacca *et al.* (2018) and Trisyanti *et al.* (2019), we used the FME software version 2023.0 as a tool to integrate and convert the data from the IFC format following the standard version 4.2 of the Revit software to the Esri GDB (Geodatabase) format.

For HBIM modeling, we used the Scan-To-HBIM method, based on the extension of studies conducted by Cogima *et al.* (2020), and divided it into three main steps: capture, acquisition, and modeling. We used digital scanning tools in two buildings: Casa de Baile – CB (Ballroom), using a Faro Terrestrial Laser Scanner (TLS), model Focus3D X 130, and the Igreja São Francisco de Assis – ISFA (the São Francisco de Assis Church), where we used TLS and Unmanned Aerial Vehicle (UAV) model Spark, manufactured by DJI. For the Pampulha Art Museum - MAP, Casa de Juscelino Kubitschek – CJK (Juscelino Kubitschek House), and the Iate Tênis Clube – ITC (Yacht Tennis Club), we used the original existing 2D data as the parametric basis for HBIM modeling.

In the first attempt, we converted the RVT model through the ArcGis standard "BIM to geodatabase" function, and then the RVT model was inserted into a 3D layer. For the second, we exported the HBIM model to IFC format and inserted it into the DataInspector FME and WorkBench FME software, allowing editing and validation of data and metadata. After calibrating the data, we converted it to GDB and inserted it into a 3D layer in ArcGIS.

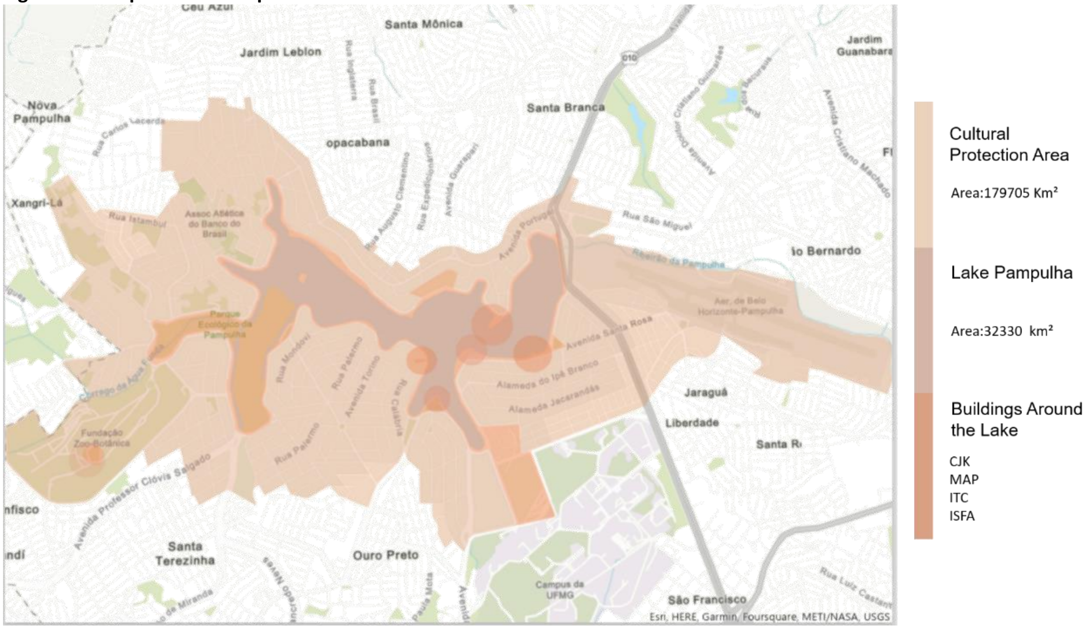
We collected the Shapefile (SHP.) data the Belo Horizonte-MG City Hall provided regarding the Pampulha Cultural Protection Area. Then, we imported these data into 2D layers in ArcGIS software and created specific attributes related to the Pampulha cultural protection area.

The Pampulha modern ensemble as a Cultural Landscape

Our study buildings are located in the Cultural Protection Area of Lake Pampulha surroundings, comprising the Pampulha Modern Ensemble and the Juscelino Kubitschek House totaling an area of 179,705 km2 (Figure 2).

According to Bruand (1999), the Pampulha Modern Ensemble refers to a set of 4 buildings in the Pampulha region of Belo Horizonte, Brazil. Brazilian architect, Oscar Niemeyer designed it with other artists such as Candido Portinari and landscape designers such as Burle Marx.

Figure 2 - Pampulha cultural protection area



Source: the authors.

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The buildings were built between 1942 and 1944, when the mayor of Belo Horizonte, Juscelino Kubitschek, sought cultural and architectural development. The project includes the São Francisco de Assis Church, the Ballroom, the Casino (now the Pampulha Art Museum), and the Yacht Tennis Club. Each of these buildings has distinct modernist characteristics.

Pampulha is a modernist architectural ensemble. The São Francisco de Assis Church has a curvilinear façade and sculptural elements that integrate harmoniously with the surrounding environment, and its roof stands out as a unique plastic element. On the other hand, the Ballroom is a circular building located on the shores of the lake, giving it a privileged position.

The Yacht Tennis Club was designed to evoke the image of a boat entering the lake, featuring a unique roof with inverted slopes. The Casino, intended as a leisure and entertainment space, had a distinctive horizontal structure and in 1946 ceased to function due to the ban on gambling in Brazil.

The Pampulha Modern Ensemble is considered modernist due to its architectural features, which reflect the five points of Le Corbusier's architecture, as exemplified in his iconic work, the Villa Savoye of 1929. The buildings feature organic shapes, and curved lines, use reinforced concrete, and integrate harmoniously with the surrounding natural environment.

The São Francisco de Assis Church was the first to be listed in 1947 due to the population's concern to preserve its original characteristics. In 1984, the entire architectural ensemble was listed by IEPHA and, in 1997, by IPHAN, recognizing its importance as a national architectural heritage. In 2016, it received the title of UNESCO World Heritage Site, highlighting its relevance as a historical and cultural symbol of universal value, protecting it for future generations (IPHAN, 2014).

The Juscelino Kubitschek House was conceived during the construction of Pampulha in 1945. Juscelino Kubitschek (JK) moved to Rio de Janeiro and took office as a federal deputy. This house stands out from Niemeyer's other projects in Pampulha due to its inverted roof, pioneering the design of the Yacht Tennis Club, and featuring a structure without curves.

Over time, Juscelino Kubitschek House has been home to several politicians. In 2013, Belo Horizonte inaugurated the site as a Museum (IPHAN, 2014).

Operating an integrated model of historical building data and geographic information: HBIM method.

We performed the MAP, ITC, and CJK modeling with the LOD200 development level, while for ISFA and CB, we used LOD400. We used the OmniClass structured standard, integrated with Revit, as a reference to standardize the assignment of information and identification of components.

To model MAP, ITC, and CJK, we used the Level of Detail (LOD) 200 as the basis for modeling. We decided to model only the external part of these buildings, making LOD 200 suitable to meet our objectives.

LOD 200 enables the representation of the essential architectural features of buildings, such as walls, windows, and roofs, at a level of detail that allows clear and understandable visualization of the external structure of the building.

While modeling the MAP in Revit software, we observed that the building has three types of pilotis with three different radii, measuring 0.17 cm, 0.20 cm, and 0.25 cm, respectively. The internal pilotis are clad in stainless steel, while the external ones are finished in exposed concrete.

We used the Architectural Column tool to represent these features in the BIM model to create the pilotis elements with their specific dimensions and finishes. This allowed for accurate and detailed modeling of the MAP structural elements, incorporating the particularities of Oscar Niemeyer's architectural design. We faced a significant challenge related to the distinctive features of Oscar Niemeyer's architecture, including organic forms in his designs. Specifically, the MAP multipurpose space block has circular and organic shapes and is at an elevated level, 93 cm above the rest of the building. The slab of the multipurpose space should be connected to the slab of the rest of the building, which is at a lower level.

To deal with these complex shapes, we used the Ramp function available in Revit. This approach allowed us to accurately model some of the forms of the slabs and floors of the multipurpose space, ensuring fidelity to Niemeyer's architectural proposal. The ITC and CJK works differ from the other CMP works because they do not have curves and complex organic shapes as the CB and ISFA do. During the modeling in Revit software, we observed that the ITC roof has the same architectural proposal as CJK and presents unique pilotis with oval shapes, measuring 30 × 60. Each pillar's height was calculated based on the average, considering the vertical limitations imposed by the sloping roof, resulting in varying lengths for each roof section. Each was designed with additional upper constraints, requiring several levels for each pillar. This complexity in the pilot design resulted in an extensive modeling process.

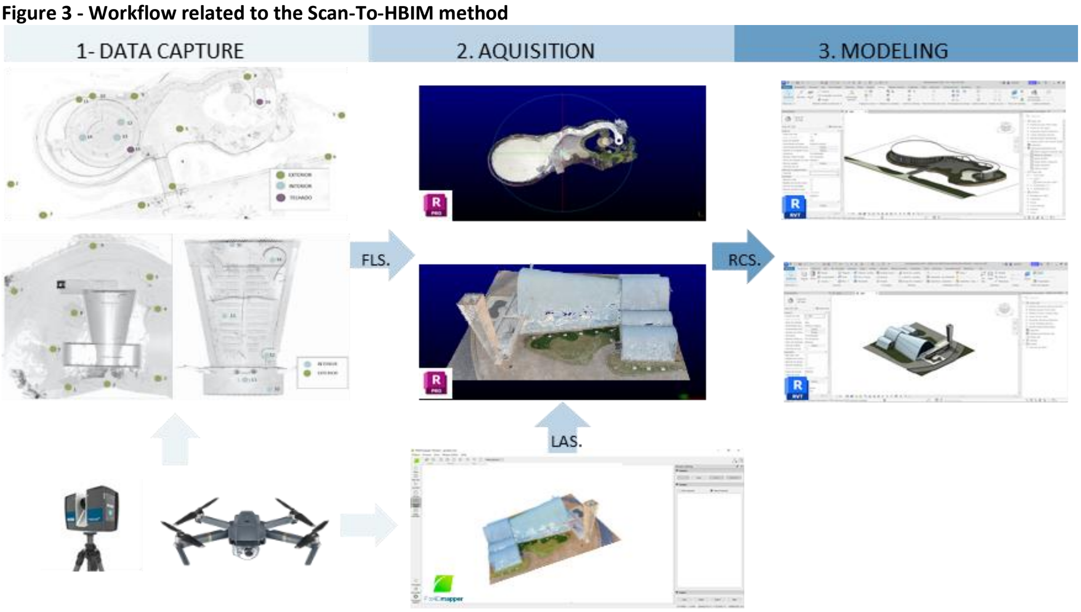
We chose to use the extrusion function to properly represent the ITC Brises elements, which are installed from the floor to the ceiling. This approach allowed us to model each

Brise individually, considering their measurements. As in MAP, ITC has curtain walls that are used as windows, but each amount has different measures for each building facade.

For the modeling of the ISA and CB buildings, we adopted the Scan-to-HBIM method. This process was subdivided into three essential steps, as illustrated in Figure 3, data capture, acquisition, and modeling. Both buildings, ISFA and CB, present remarkable architectural complexities and distinctive plastic characteristics of using reinforced concrete proposed by Oscar Niemeyer, which required highly reliable techniques and equipment to obtain the data needed for modeling accurately.

The point cloud is just a three-dimensional representation of points in space, with no attributes or semantic meaning associated with them. Conversely, BIM allows linking specific information to these points, enabling more advanced analysis and intelligent decision-making in AEOC. To add intelligence to this data, methods such as BIM should be used, or in this specific case, the Scan-to-HBIM method can be used.

Figure 3 - Workflow related to the Scan-To-HBIM method



Source: the authors.

In the Data Capture phase, it is essential to carry out detailed planning to operate the laser scans efficiently, quickly and with high quality, avoiding rework. Thus, we analyzed the shape and size of the building to position the TLS and conducted the aerophotogrammetric process of the scanning areas.

At ISFA, we performed a double grid flight with the camera perpendicular to the ground with a 900 axis. We used the UAV equipped with a 12-megapixel camera and a f/2, 12mm aperture lens. The flight was conducted at an altitude of 30 meters, and the camera was set to capture images every 5 seconds.

To perform terrestrial laser scanning, we used TLS equipped including a standard Faro camera with a resolution of 70 megapixels. This scanner has a range of up to 130 meters, allowing it to capture information over long distances. Its functionality covers a complete spatial coverage with vertical capture angles of 300° and horizontal capture angles of 360°, which made it possible to obtain data in all directions around the scanning point. During indoor operations, a total of 5 scans were obtained, while, in outdoor environments, 9 scans were performed. The Faro TLS generated scans in FLS format, which were aligned, unified and performed noise cleaning in the RecapPRO software version 2023.

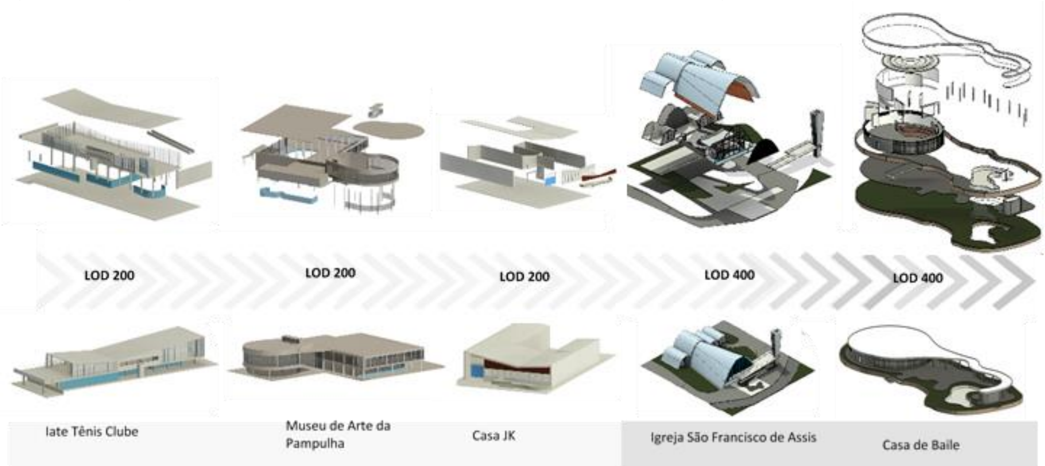
After capturing ISFA data, we performed photogrammetric processing with Pix4DMapper software, version 4.8. This procedure inserted images in JPEG format, and the coordinate system was appropriately specified. Pix4DMapper offers three processing options: fast; advanced; and standard, which took a total of 13hr to process 300 images.

As a result of this processing, the software generated a point cloud containing 7,063.9 points in total, with a density of 3006.3 points per cubic meter. Subsequently, the point cloud was exported in LAS. format to the RecapPro software, where the alignment with the point cloud obtained through TLS was performed.

For the CB data collection, we chose not to use the UAV, as it was feasible to perform the acquisition by TLS on the roof itself. The TLS was positioned at strategic points to cover the largest possible area of the building. We obtained 11 exterior scans, 3 interior scans, and 2 scans on the roof of the building. The data captured through the TLS were later inserted into the RecapPRO software. This procedure resulted in approximately 360 million points, representing a significant amount of information about the environment with millimeter precision. We exported the point cloud to the RCS format compatible with Revit software.

We use standard modeling to create the overall CB structure in Revit. We employed the family system to insert elements such as walls, columns, floor, ceiling, and sealing walls. In addition, the ceiling was modeled in-place, and the walls and windows were hosted in specific system elements designated for that purpose. Figure 4 shows the HBIM models at different LODs.

Figure 4 - Comparison of the level of detail between the HBIM models of the Pampulha Cultural Protection Area



Source: the authors.

For the modeling of the ISFA, we faced a significant challenge due to the curvilinear shape of the church. To represent the walls and the roof, we had to treat them as a single piece, using the vaulted structure. Thus, we called this element "roof" in the Revit modeling environment to connect it to the interior walls and facade elements. To deal with the connections between the vaults, we used the "mass" tool as there was variation in thickness and the lack of dedicated standard elements.

Integration of the HBIM model into a GIS 2D-3D

In the first approach, we used the "BIM to geodatabase" tool available in ArcGIS Pro to incorporate the Revit model directly. We started the georeferencing process of the RVT model using the "Location" function in the "Manage" tab, configuring georeferencing points through the "Topographic base points" and "Survey points" functions. It is important to note that Revit and ArcGIS use the GPS system as a standard for georeferencing, facilitating compatibility between the two systems.

Subsequently, in the "Geoprocessing" tab of ArcGIS Pro, we selected the RVT. model and specified the geodatabase in which the RVT. file was stored after conversion. We emphasize that ArcGIS Pro has its standard data conversion system, requiring the input RVT. file to be linked to a folder within a geodatabase previously created in ArcGIS.

After performing the conversion task, which lasted 1 minute and 23 seconds, the Revit model was visualized on the map in ArcGIS Pro. However, we found that the model did not contain BIM information, as it was recognized by ArcGIS as a single block without associated semantic data. Colucci *et al*. (2020) report this same challenge of data loss when inserting BIM models directly into the GIS.

However, the initial attempt did not result in incorporating the BIM information we desired, requiring the consideration of other strategies to achieve a more comprehensive and efficient integration between the HBIM and GIS models.

To overcome the challenge of data loss, we chose to adopt well-established methodologies, such as those proposed by Vacca *et al.* (2018) and Trisyanti *et al.* (2019). In this second approach, we used FME software as a solution. FME allows us to visualize, edit and validate the data and metadata contained in the HBIM model, as well as convert them into GDB for ArcGIS.

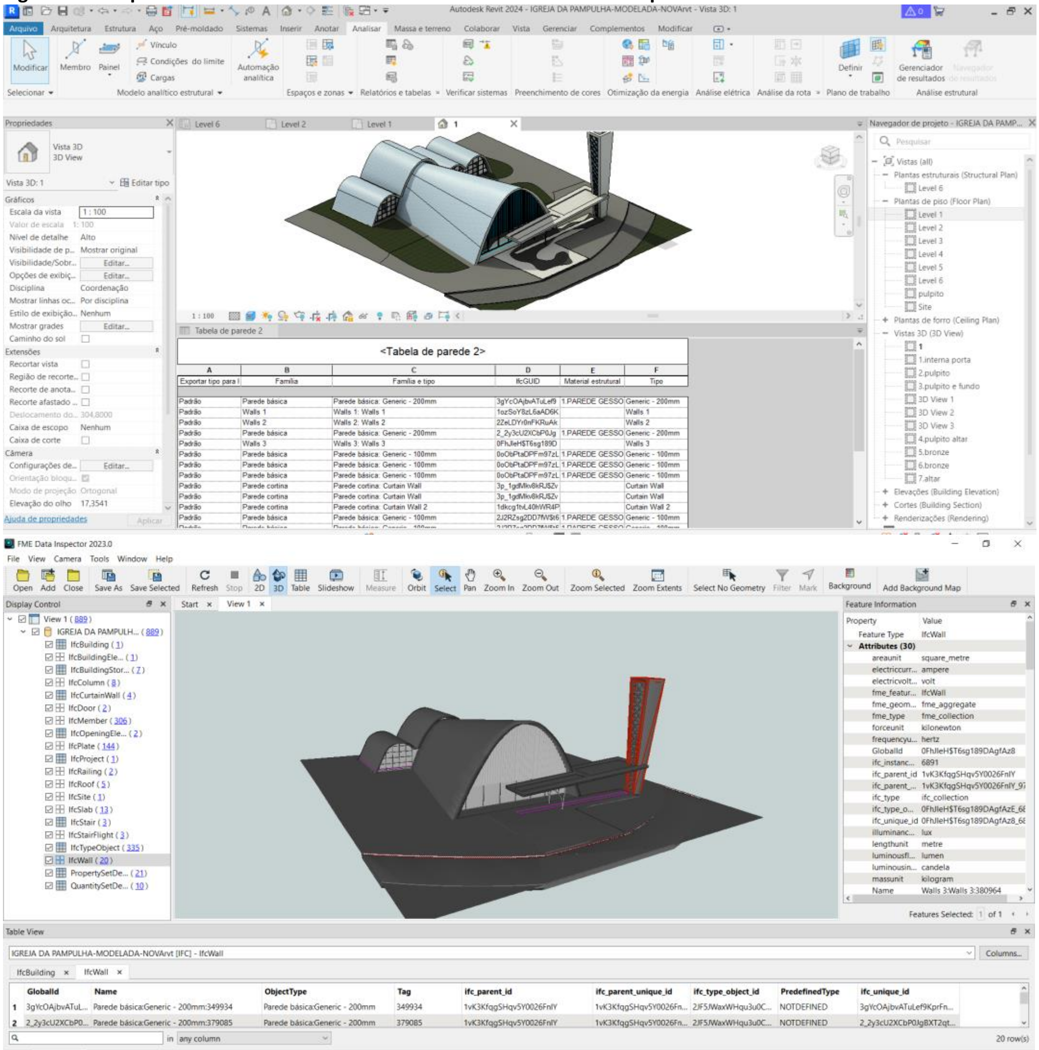
Within FME, we have two extensions: the FME Data Inspector and the FMW Workbench. The Data Inspector allows for the visualization of missing information, enabling us to analyze and make edits to the information patterns in the input files using the FME Workbench. These steps are essential to ensure the quality and completeness of the data before conversion to GDB format.

In Revit software, we exported the HBIM model into IFC. format. Then, we used the FME Data Inspector software to visualize the information in the exported IFC file. Using the Display Control tool, specific filters can be applied for each type of IFC. data in the model, allowing a detailed analysis of the materials table generated by Revit. Thus, we verified if all the information was successfully exported and if it correctly matched the data of the original model in Revit. This step was crucial to ensure the quality and integrity of the data during the export process and to facilitate the identification of any discrepancies that could arise in the conversion to IFC. format. Figure 5 shows the "walls" table in the Revit model. We note that all the information in the RVT. model is contained in the IFC. file. We note that the ifcBuilding and ifcProject data included missing information.

After validating the information in the FME Data Inspector, we inserted the IFC. file into the FME Workbench to deal with previously identified missing information. In the Workbench, we obtained 10 information patterns in HBIM models with LOD200 and 18 in HBIM models with LOD400. The amount of information patterns is directly related to the level of detail of the HBIM model, i.e., the more information is modeled, the more information patterns are obtained.

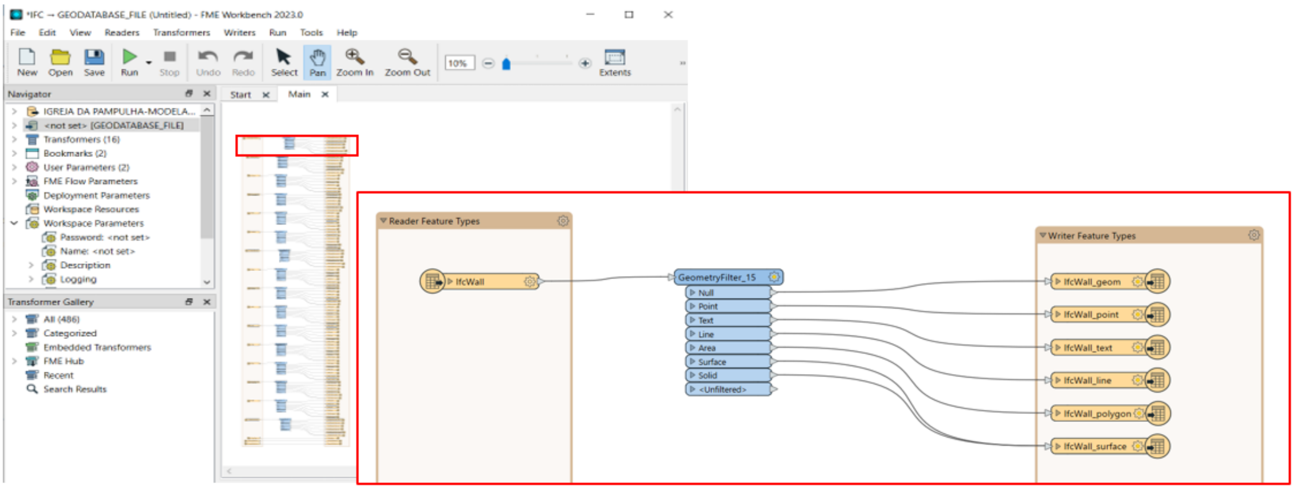
Figure 6 illustrates the main information pattern based on the IFCwall. Within the IFCwall data, its metadata can be observed, such as Points, Text, Lines, Surface, area, and solid. This visualization allows a better understanding of the information contained in the model. After checking all the data in Workbench, the IFC. model can be converted into GDB. (Geodatabase) format using the Read and Writer functions available in FME.

Figure 5 - Comparison between Revit information table and FME Data Inspector



Source: the authors.

Figure 6 - Patterns created in the FME WorkBench and extension of an information structure and paths adopted as a pattern



Source: the authors.

After collecting the data provided by the Belo Horizonte City Hall, regarding the cultural protection area, movable and immovable cultural assets, and intangible cultural assets located around Lake Pampulha, we proceeded to insert these data in shapefile format (SHP) as 2D layers in ArcGIS. We used ArcGIS as a working environment to import the shapefile files containing the geospatial information of the cultural elements. The 2D layers were loaded and overlaid on the map.

Results and discussion

We opened a local scene in ArcGIS Pro software and created a new layer using the "3D layer" function. We then inserted the GDB. file containing the HBIM model for each building, repeating this process for all facilities. ArcGIS and Revit use the global positioning system (GPS), which has an accuracy of 20 meters. However, we noticed that it may be displaced by a few meters when inserting the HBIM model into ArcGIS. To solve this problem, we used the "move layers" function to adjust the coordinates accurately and ensure that the models were within the correct boundaries of each terrain.

By entering coordinates directly into Revit, we obtained more accurate results than in WorkBench FME. However, the WorkBench FME approach allows analysis of HBIM model components and assigns qualitative and quantitative attributes through the 3D analysis function.

This approach of integrating and analyzing HBIM models in ArcGIS Pro and WorkBench FME provides a more comprehensive and detailed view of the data, allowing spatial analysis to be performed and relevant information to be assigned to model components.

In the case of a cultural landscape with five buildings, an efficient way to manage the heritage is through the HBIM-SIG model. In ArcGIS software, we can insert customized attributes that are not possible in Revit, and we can visualize several buildings in a georeferenced way. In the layers function, data can be added such as lines and polylines referring to the original projects and construction levels, ensuring a better understanding of the buildings.

In the first integration approach, when we inserted the RVT model into ArcGIS for conversion into GDB, the software did not separate the data as in the IFC standard, resulting in the impossibility of applying filters to the buildings. However, in the second attempt, based on methodologies such as Vacca *et al.* (2018), the FME software separated the data and metadata of the IFC standard in an organized and structured way. This enabled the visualization of lines, surfaces, volumes, and areas, allowing the insertion into ArcGIS in 3D layers to separate each group of components. In Figure 7, we represent the filters created for each building component. This integration approach provides a better understanding of the building, its construction system, and its connections.

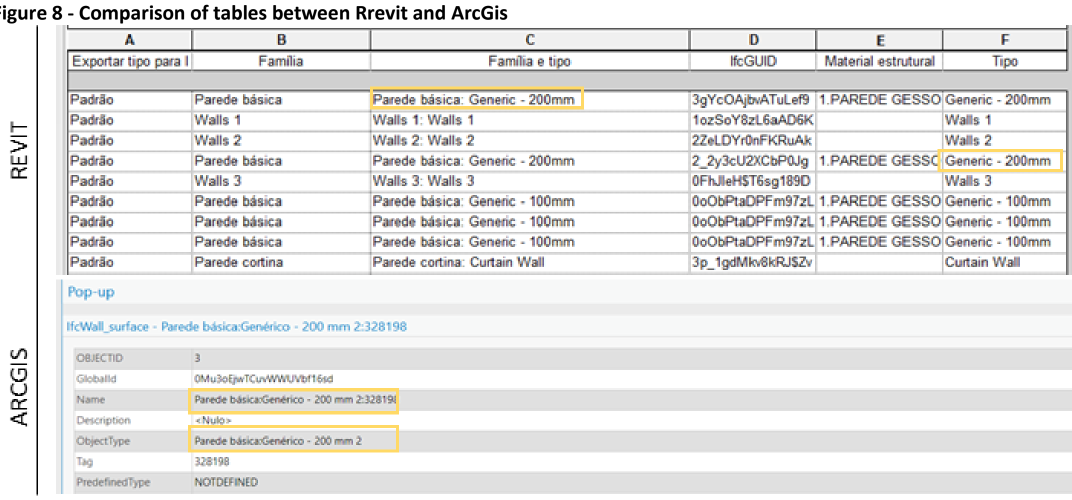
Through 3D analysis, quantitative and qualitative attributes of buildings can be created, including conservation data and the need for maintenance or restoration. This approach enables more comprehensive and detailed management of cultural heritage, allowing for more informed decision-making regarding the preservation and care of historic buildings.

After creating and converting the HBIM (IFC.) models into GDB., we developed individual 3D layers for each Pampulha cultural protection area building. Although all components were entered, texture data was not included in the conversion. When selecting a building component, a dialog box is opened, allowing the visualization of all data in table format and its comparison with the Revit material table. Figure 8 illustrates a comparative part of the materials table in ArcGIS and Revit.

Figure 7 - Filters applied to visualize columns and walls (IFCWall and IFCColumns)

Source: the authors.

Figure 8 - Comparison of tables between Rrevit and ArcGis



A	B	C	D	E	F
Exportar tipo para I	Família	Família e tipo	IfcGUID	Material estrutural	Tipo
Padrão	Parede básica	Parede básica: Generic - 200mm	3gYcOAjbvATuLef9	1.PAREDE GESSO	Generic - 200mm
Padrão	Walls 1	Walls 1: Walls 1	1ozSoY8zL6aAD6K		Walls 1
Padrão	Walls 2	Walls 2: Walls 2	2ZeLDYr0nFKRuAk		Walls 2
Padrão	Parede básica	Parede básica: Generic - 200mm	2_2y3cU2XCbP0Jg	1.PAREDE GESSC	Generic - 200mm
Padrão	Walls 3	Walls 3: Walls 3	0FhJleH$T6sg189D		Walls 3
Padrão	Parede básica	Parede básica: Generic - 100mm	0oObPtaDPFm97zL	1.PAREDE GESSO	Generic - 100mm
Padrão	Parede básica	Parede básica: Generic - 100mm	0oObPtaDPFm97zL	1.PAREDE GESSO	Generic - 100mm
Padrão	Parede básica	Parede básica: Generic - 100mm	0oObPtaDPFm97zL	1.PAREDE GESSO	Generic - 100mm
Padrão	Parede cortina	Parede cortina: Curtain Wall	3p_1gdMkv8kRJ$Zv		Curtain Wall

Pop-up

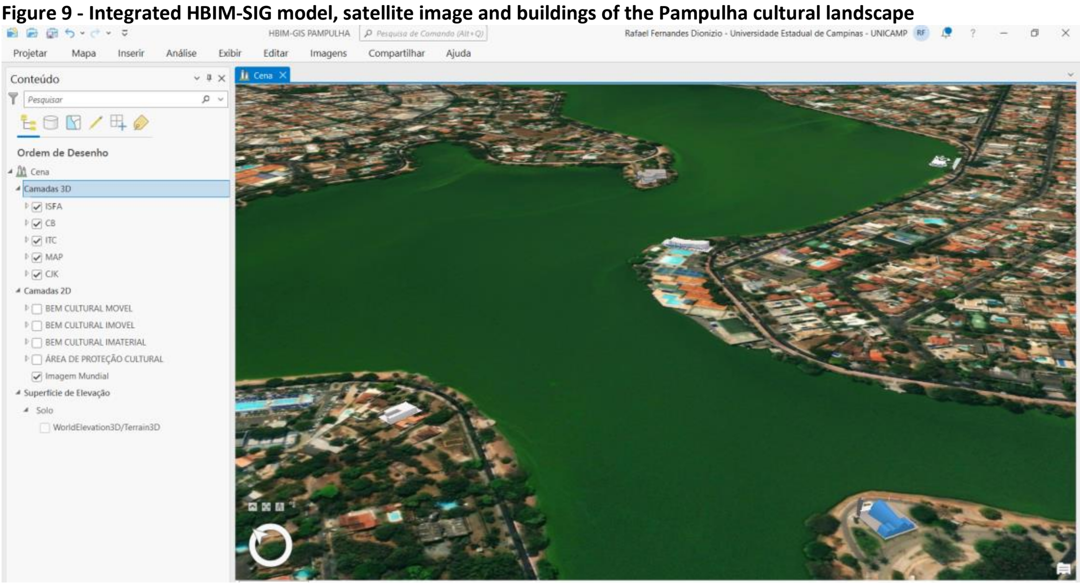
IfcWall_surface - Parede básica:Genérico - 200 mm 2:328198

OBJECTID	3
GlobalId	0Mu3oEjwTCuvWWUVbf16sd
Name	Parede básica:Genérico - 200 mm 2:328198
Description	<Nulo>
ObjectType	Parede básica:Genérico - 200 mm 2
Tag	328198
PredefinedType	NOTDEFINED

Source: the authors.

Figure 9 illustrates the models integrated into a local scene with the selected 3d layer.

Figure 9 - Integrated HBIM-SIG model, satellite image and buildings of the Pampulha cultural landscape

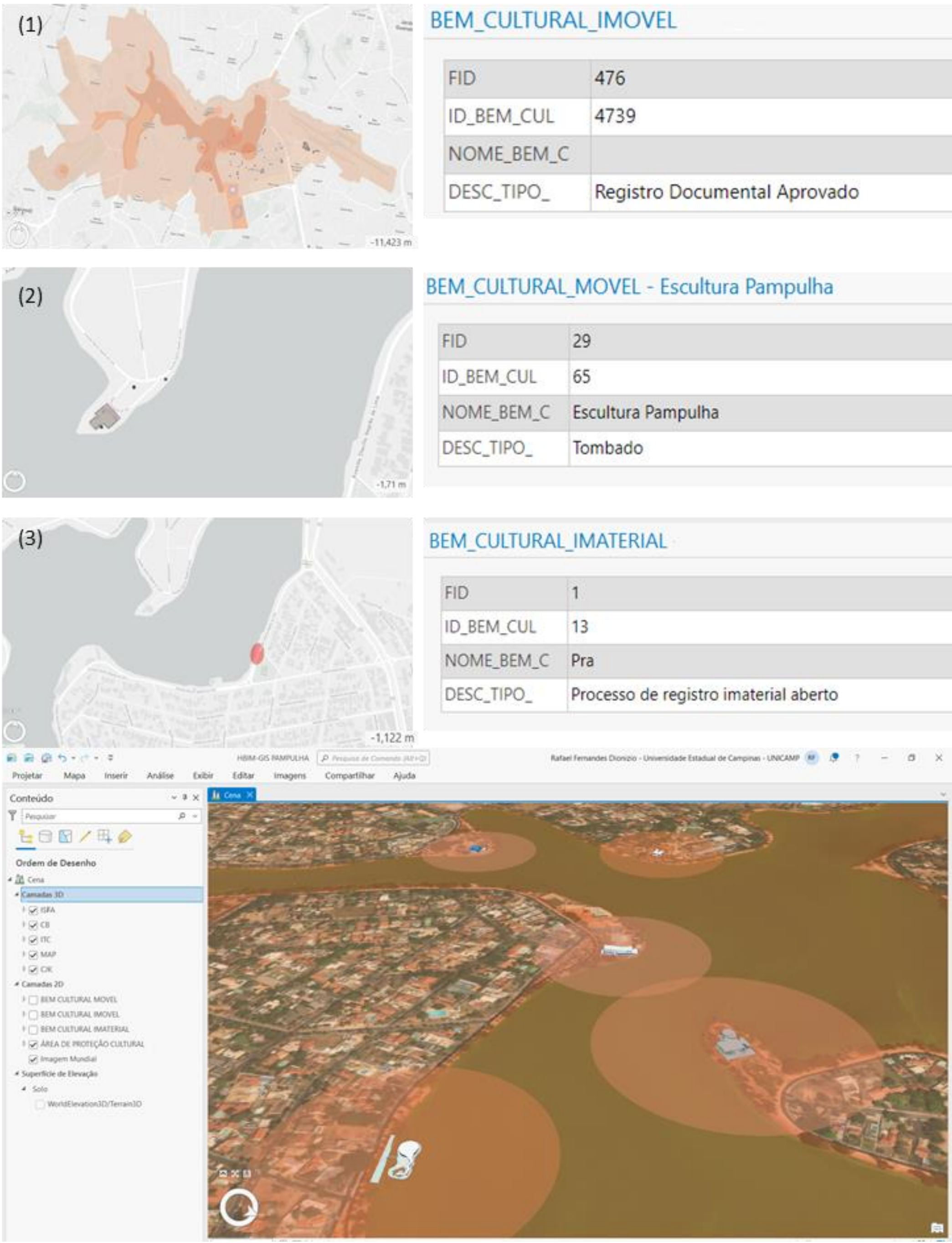


Source: the authors.

After creating the 2D layers in SHP format, we incorporated attributes based on the Belo Horizonte City Hall data. Integrating the buildings with the 2D data allowed quantitative and qualitative analysis. We inserted attributes, such as lines and polylines, to restrict the cultural protection area that composes the cultural landscape.

In addition, we included information on all immovable cultural assets (1) (architectural constructions) and movable cultural assets (2) (monuments). It was also possible to add attributes related to intangible cultural property (3). Figure 10 illustrates all these attributes and the tables generated with quantitative and qualitative data. All these data make up the surroundings of Lake Pampulha. Figure 10 also represents the HBIM models integrated with the 3d layer referring to the Pampulha cultural protection area.

Figure 10 - Attributes created and an example of an attribute table for these 2D layers. HBIM models in 3D layers next to the attributes



BEM_CULTURAL_IMOVEL

FID	476
ID_BEM_CUL	4739
NOME_BEM_C	
DESC_TIPO_	Registro Documental Aprovado

BEM_CULTURAL_MOVEL - Escultura Pampulha

FID	29
ID_BEM_CUL	65
NOME_BEM_C	Escultura Pampulha
DESC_TIPO_	Tombado

BEM_CULTURAL_IMATERIAL

FID	1
ID_BEM_CUL	13
NOME_BEM_C	Pra
DESC_TIPO_	Processo de registro imaterial aberto

Source: the authors.

Concerning movable cultural assets around Lake Pampulha, four listed statues are part of the MAP. Regarding immovable cultural assets, we have 43 assets, including those listed, in the process of being listed or with documentation requested for listing. Regarding intangible cultural property, the area destined for Iemanjá stands out, which is currently listed as intangible property.

This integration of information and attributes in different layers allowed a more comprehensive and detailed analysis of the surroundings of Lake Pampulha, contributing to the management and preservation of the region's cultural heritage.

The interoperability between BIM and GIS data is a complex issue that requires in-depth knowledge of the areas involved. A multidisciplinary team and computers with advanced hardware are indispensable to enable the visualization of the HBIM-GIS model by the building management.

It is worth noting that changes made in Revit are not automatically reflected in ArcGIS, requiring manual synchronization that is time-consuming and requires specialized labor to operate the HBIM-SIG model. However, Esri offers the ArcGIS Online extension, allowing the use of the HBIM-GIS model in the cloud and facilitating data visualization between the parties involved.

However, in-depth studies on interoperability are needed to ensure data integrity during cloud-based information exchange. Authors such as Zhu and Wu (2022) and Barazzetti and Roncoroni (2021) have contributed to recent research, presenting different approaches and strategies to overcome interoperability challenges.

Final considerations

In conclusion, integrating the HBIM model and GIS has proven to be a promising approach for managing and preserving cultural landscapes, as is the case of the Pampulha region. This integration allows a comprehensive and detailed view of 2D and 3D data, enabling spatial analysis and the assignment of qualitative and quantitative information along the components of historic buildings in a personalized way which Revit software does not allow.

During the integration process, we faced significant challenges. One of them was the direct insertion of the RVT model into ArcGIS, which resulted in the loss of data and information. Recent initiatives to insert BIM data directly into a GIS have been widely studied. Moreover, a considerable challenge is the loss of BIM data during data exchanges between BIM and GIS, as mentioned by Colucci *et al*. (2020). This limitation led us to look for alternatives in software that could structure and organize the information and ensure efficiency during data exchange.

Modeling all buildings in the Pampulha surrounding area, which is part of the cultural landscape, would be a more comprehensive strategy for integrated management. By expanding the scope of the HBIM-SIG model to include all relevant buildings, we were able to obtain a complete and detailed representation of the cultural landscape as a whole. Furthermore, this modeling activity takes extensive manual modeling and data integration work. Future work should focus on improving the interoperability between BIM and GIS, looking for automated and more efficient solutions to exchange information between software. In addition, it is essential to explore new technologies and tools, such as using the cloud for data storage and processing, to optimize the visualization and analysis of the HBIM-SIG model among stakeholders.

In summary, using the HBIM-SIG model in cultural landscape management is promising. However, it requires continuous research, innovation, and collaboration efforts to overcome the challenges and maximize the benefits of this integration in cultural heritage management.

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