DOI: 10.53660/CLM-4132-24S32

Development of BIM Models for Retrofit: Approaches and Challenges in a Case Study of Brasília

Received: 01-08-2024 | Accepted: 01-09-2024 | Published: 05-09-2024

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ABSTRACT

Retrofitting involves renovating or modernizing buildings or systems by integrating new technologies and concepts to increase property value, change its use, and improve operational and energy efficiency. The adoption of Building Information Modeling (BIM) in this process is still an emerging field, facing several challenges. This study aimed to develop a building retrofit using BIM methodologies. A case study of a 2,404.5 m² building in Brasília was carried out, divided into two stages: (1) BIM modeling based on surveys (AS-IS model) and (2) development of a BIM model for retrofitting. The results indicated that BIM facilitated project development, improving collaboration, transparency, and compatibility between architectural and engineering projects. However, challenges such as limited information about the project and difficulties monitoring electrical and plumbing systems were encountered. Although current data are sufficient, additional studies are needed to map building systems, adjust the budget for future retrofit changes, and identify potential research limitations.

Keywords: Retrofit; Building Information Modeling (BIM); AS IS Model; Building retrofit.

INTRODUCTION

Buildings classified as old or historic often exhibit poor operational and habitable conditions, including inadequate air quality and substandard thermal, visual, and acoustic comfort (Song et al., 2024). This may be related to these buildings being constructed before the current policies and standards defining the building performance requirement (Artino et al., 2019). In addition, the natural deterioration of the building elements and the need for maintenance or replacement of equipment with high energy consumption and inadequate functioning are highlighted (Marzouk et al., 2020). Also, due to the high social value of old buildings for an urban community and the importance of further studies for their rehabilitation, we can highlight the executive techniques, as well as the forecasts of these rehabilitations in terms of quality, deadlines, and costs (Gravagnuolo et al., 2024).

The demolition of these buildings results in a significant waste of resources and contributes to environmental pollution (Liang et al., 2017). In this sense, sustainability in the construction industry focuses on minimizing the use of resources and reducing environmental impact, aiming to obtain maximum return (Motalebi et al., 2022). According to these authors, there are two main strategies for achieving sustainability in the construction industry, being: (i) the construction of new sustainable buildings that are aligned with environmental goals and (ii) the adaptation of existing buildings to sustainable standards, representing an alternative more profitable to construct new green buildings. In some developing countries, improving the construction industry is considered significant progress that benefits the environment, aiming to reduce the adverse environmental impacts of buildings (Motalebi et al., 2022).

In this context, many researchers seek to frame the construction context by renovating some buildings instead of demolishing them. Thus, retrofit refers to a concept of remodeling, rehabilitation, or adjustment of the current conditions of an existing building to modernize and readapt its components and facilities to improve and adapt it to current requirements and extend its life cycle (Ma et al., 2012).

Thus, several studies indicate that the primary barrier to retrofit development is the lack of information about the built environment, as well as the absence of documentation on construction systems (Zhang et al., 2012; Ástmarsson; Jensen; Maslesa, 2013; Dauda; Ajayi, 2022). Consequently, it is crucial to grasp the current condition of the building to pinpoint the best retrofit intervention strategy (Basu et al., 2017). Some tools, such as Building Information Modeling (BIM), can assist in decision-making, provided that building information is more precise, to achieve this.

However, given its potential benefits, leveraging BIM for building retrofitting offers numerous advantages, particularly in overcoming challenges related to the absence of documentation or information regarding how the building was constructed, technical challenges associated with information surveys (as-is and as-built), cost management, organizational, legal, and maintenance challenges (Sardroud et al., 2018; Valero et al., 2018; Hossain; Yeoh, 2018; D'angelo et al., 2022). Additionally, the primary obstacle to retrofit development in buildings is the lack of projects, such as plant representation and specification of materials and facilities present in the building (Li et al., 2019; Negro et al., 2019; Oguntona et al., 2019). According to D'Angelo et al. (2022), the use of BIM in retrofit projects still faces some challenges that need to be overcome through applications in real-world contexts. Thus, aiming to overcome these barriers, this study aims to develop a BIM model for building retrofitting using BIM methodological processes.

LITERATURE REVIEW

The Building Information Modeling (BIM) is a holistic process of creating and managing information that enables AEC professionals to efficiently plan, design, build, and manage construction projects throughout their lifecycle (Autodesk, 2024). Although BIM is widely used in the early stages of construction, several studies have explored its application in retrofitting existing buildings (Li et al., 2021; Seghier et al., 2022; D'Angelo et al., 2022). However, BIM's use in modernizing these buildings remains an emerging field of research, facing several challenges. These challenges include the need for more accurate and up-to-date data, particularly in buildings constructed before 1990, which complicates creating as-built BIM models (Dauda; Ajayi, 2022).

In addition, there are technical barriers related to data capture and processing, which need to become more accessible and efficient to enable the use of BIM in modernization projects. The high cost of software and training also raises concerns about the return on investment for implementing BIM (Hossain; Yeoh, 2018). Finally, organizational and legal challenges, such as poor communication among stakeholders, the absence of contractual standards, and the complexity of maintaining updated information throughout the building's lifecycle, further complicate the effective application of BIM in modernization projects (Leśniak et al., 2021).

Previous studies have focused on using BIM to improve retrofit strategies. Zhang et al. (2021) applied a multi-criteria decision-making process based on BIM to retrofit external walls in an office building, identifying extruded and expanded polystyrene as the best options. Li et al. (2021) developed a multi-objective optimization model combining energy and thermal comfort, resulting in 4% energy savings and near-optimal comfort levels in a school. Similarly, Seghier et al. (2022) developed a method to optimize the thermal performance of building envelopes using BIM and visual scripts by modifying components such as windows and walls, which led to a 44.78% reduction in thermal transfer. Mughala et al. (2024) developed a green retrofit model for buildings using BIM to reduce energy consumption. They modified the design parameters of an inefficient building envelope using tools such as Autodesk Revit and Design Builder to optimize energy consumption. The analysis revealed a 46% energy consumption savings with the optimized design. The solutions were adjusted according to local environmental sustainability.

While these studies are essential for the spread of BIM in retrofit projects, there remains a significant gap in the application of such projects. The literature review highlights a shortage of studies addressing the initial phases of modernization and assessing a building's current conditions, underscoring the limitations in identifying this information. Furthermore, although most BIM-based retrofit studies focus on energy issues, it is equally important to advance scientific knowledge by exploring the implementation of retrofits and the involvement of stakeholders.

RESEARCH METHOD

The research strategy adopted in this work was the exploratory case study. This approach aims to identify research questions or procedures for future research (Yin, 2018). Therefore, the study will be developed in the following steps: (1) BIM modeling of the building from the surveys (AS IS model) and (2) BIM retrofit model. Before starting the modeling, inspections and non-destructive tests were carried out to assess the current conditions of the building and obtain data for the modeling. This information was collected from a point cloud generated by drones and by the survey with a terrestrial laser scanner (Silva et al., 2024).

The study object

The study was conducted at the headquarters of the Scientific and Technological Park of the University of Brasília (PCTec/UnB), located on the Darcy Ribeiro Campus in Brasília, at coordinates (-15.7719274, -47.8705796), as shown in Figure 1. Brasília's climate, including the study site, is classified as high-altitude tropical, characterized by a tropical climate with rainfall concentrated in the summer and high temperatures moderated by altitude. Relative humidity can drop significantly during the dry season. The building is a single-story structure constructed with conventional masonry, featuring a mixed roof composed of sandwich tiles and exposed slabs. It is surrounded by a solid brick wall, also known as exposed brick, and covers a built area of 2,404.5 m².

Figure 1 – The study object (PCTec/UnB)

The building has undergone adaptations over the years, according to its occupation, and today, it still needs to present the original characteristics of the project. The space is used to carry out research and to house some startups. Furthermore, the building is currently occupied by UnBTV, which occupies part of the building, and the PCTec UnB headquarters, which occupies the other half.

Development of the “as is” Model

Based on the surveys carried out as described in the previous sections, we started to model. We use Autodesk Revit® to develop the projects. This choice is due to performance, licenses, and its majority use within the Built Environment Innovation and Sustainability Platform (PISAC). Besides that, Revit was the best-integrated software with Recap® and presented the best performance in visualizing the point cloud generated by scanning the building. However, it should be noted that this work does not intend to focus on software tools, and the guidelines and conclusions can be worked on other platforms.

An initial file was established with a defined coordinate system to model the current state of the building (as-is). This coordinate system allowed the insertion of the point cloud without the user having to perform any manual rotation during the modeling process. This practice was essential to ensure the consistency and accuracy of the model, as the point cloud needs to align with the modeling file's coordinate system correctly. This approach ensured that if the point cloud was accidentally removed from the project, it could be reinserted and automatically repositioned in the same location, maintaining the spatial consistency of the model.

After configuring the project coordinates, the Project Base Point was defined and agreed upon between the teams of complementary disciplines. This practice is fundamental to the effectiveness of interoperability between BIM programs and other software that can complement the model. The cloud axes had to coincide with the X and Y axes of the BIM software tools to align the project with the point cloud. This is essential to optimize Revit performance and ensure correct model orientation. Therefore, true north was kept to reality, while design north was adjusted for orthogonal modeling. This practice simplifies the modeling workflow and increases the efficiency of BIM tools.

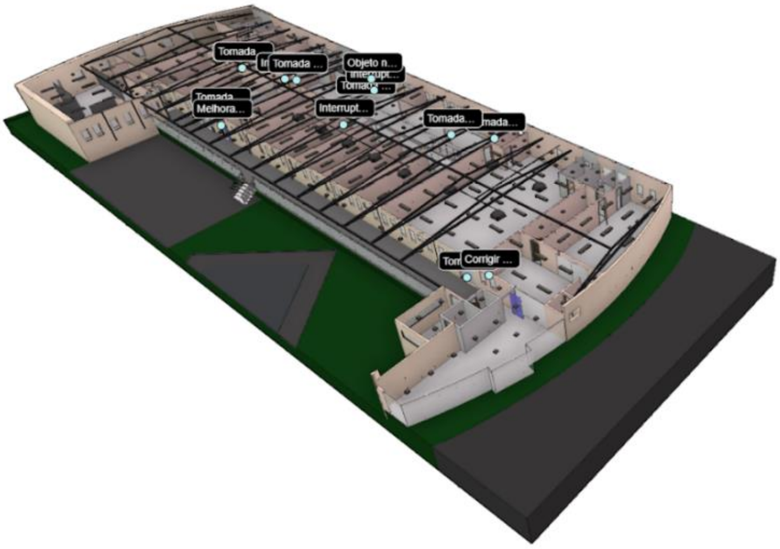
After completing the initial definitions, the Revit Cutting tool made a longitudinal section in the point cloud. This procedure made it possible to accurately establish project levels, such as street level, finished floor level, ceiling level, and roof level, using the point cloud as a reference. Levels represent horizontal planes that reference elements hosted in the project, such as walls, floors, and ceilings. Each level represents a specific height or an important reference in the construction. By establishing these levels based on the point cloud, we ensure an accurate representation of the model's height and arrangement of elements.

After defining the project levels, the architectural modeling process began, using the point cloud plan as a basis. This involved several stages, including dividing the building into intervention stages, parameterizing the families of architectural components, and understanding their relationships. We established standards to ensure accuracy and consistency and determine the level of detail required for each part of the building based on the planning strategy. Here, we decided which elements needed a more precise representation and which could be simplified according to the project objectives and the client's needs. The BIM model was thoroughly scrutinized on floor plans and sections to ensure compliance with these horizontal and vertical guidelines across the model. Continual verification of the model in all dimensions ensured that the digital representation accurately reflected the physical reality of the building.

Regarding the insertion of complementary disciplines, such as hydraulics, electrical, and structure, the team was divided, and each group had assignments for modeling the components based on the student's familiarity with each area. The components were modeled using a different BIM software, ArchiCAD. This choice sought to explore other platforms and deepen compatibility between programs, seeking to diversify the team's knowledge of different BIM software and improve interoperability between them. Revit IFC (Industry Foundation Classes) from the Retrofit stage were made available so each team could work in their designated area. IFC is an open file format used in the construction industry to exchange data between different BIM software, allowing platform interoperability. Furthermore, ArchiCAD offers Teamwork functionality, enabling real-time collaborative work, allowing multiple users to work on the same project simultaneously, sharing and updating information dynamically.

To make architectural elements and complementary disciplines compatible, the common data environment, Kuara®, was used (Figure 2). This platform served as a centralized repository of project information, facilitating collaboration and coordination between multidisciplinary teams. This tool allowed different disciplines to share their models and information in a single digital environment. With Kuara, it was possible to identify clashes, that is, conflicts between different elements of the project, such as pipes that crossed beams and electrical installations that interfered with walls. After exporting the IFC models for all disciplines, with the parameters properly configured, the federated model was generated, marking the beginning of the compatibility phase. The verification team analyzed the model, looking for clashes and modeling failures. During this analysis, incompatibilities were observed between electrical points, lighting, and hydraulic pipes. All this information was recorded in the Kuara interface and communicated to the development teams so they could take appropriate action. There were relocations of sockets and switches, repositioning of lighting fixtures to avoid conflicts with the structure, and adjustments to the height of hydraulic pipes. The compatibility phase consists of an iterative process till the model is compatible and ready to be submitted for budgeting.

Figure 2 – Model compatibility in Kuara®



Retrofit proposal

After modeling the As-Is phase, the retrofit project began. This stage involved the requalification of the building to meet new demands and requirements, aiming to improve both the functionality and accessibility of the space. New rooms and environments were created, taking into account the specific needs of users and adapting the space to accommodate different activities and functions. Special attention was paid to accessibility, with new features to ensure the space was inclusive and accessible to all people, regardless of their physical needs. This included the creation of new toilets, such as toilets adapted for people with special needs (PNE), and implementation of ramps and other measures to facilitate access.

We classified the modeled architectural elements according to their condition, i.e., existing, built, and demolished. In the context of Revit, this classification is essential for planning and executing retrofit projects. Existing elements are those already present in the building and which will be maintained or adapted. They are preserved in the BIM model to ensure their characteristics and locations are considered throughout the project. The elements to be built represent the additions planned during the retrofit, such as new walls, floors, windows, and doors. These elements were incorporated into the model to represent the proposed changes. Finally, the elements to be demolished will be removed or replaced during the retrofit. They are identified in the BIM model to ensure they are removed as necessary during the construction phase.

Furthermore, this platform was fundamental in facilitating data exchange through information from SINAP (National System for Research on Civil Construction Costs and Indices). The inclusion of this data on civil construction costs and indices in the project was a need identified by the research. It was important to transmit project information in detail, as this will be used by the team in charge of budgeting for the retrofit. To do this, it was necessary to configure the IFC exporters of the Revit and ArchiCAD software, ensuring the efficient integration of SINAP information into the project data model. However, BIM software offers a wide variety of construction elements and standard parameters for projects. In some specific situations, more than these parameters may be required to capture all the necessary information. Therefore, there was a need to create new parameters for SINAP to meet budgeting demands and guarantee data completeness.

RESULTS AND DISCUSSION

This section presents the main results and discussions.

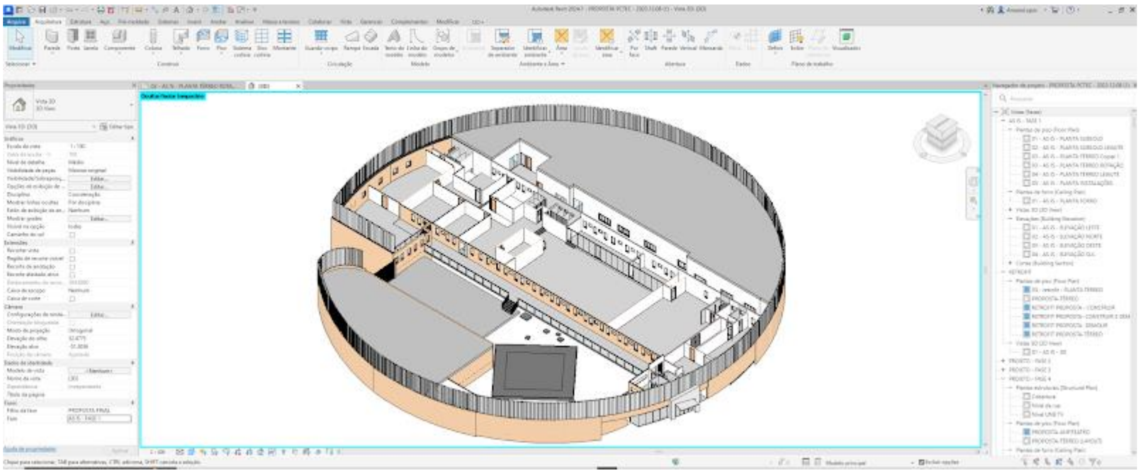
3D point cloud processing

The points collected by the laser scanner and the drone were processed in the Recap® software and generated the 3D model of the building. The collected points were processed and resulted in a textured mesh that allowed the manipulation of the 3D model of the building. After generating this model, it was possible to start modeling in Revit, from the manipulation of the building it was possible to extract measurements that provided subsidies for the modeling.

It is possible to observe that point clouds record the position and dimensions of all visible surfaces outside the context of a building. Besides that, it is critical to understand that these records must be improved to capture deeper information about the building. Everything that is within the surface needs to be addressed through other techniques. The information extracted from point clouds for modeling buildings is mainly related to geometry.

The as-is modeling was important for us to understand the spaces better, considering that the building has undergone many modifications and no longer maintains the original design characteristics. This survey was essential to identify how the partitions would be modified and which could easily be repositioned, readjusting the spaces to new uses. Another point to highlight is the need for PCTec management to adapt spaces, ensuring user accessibility to all internal spaces (Figure 3).

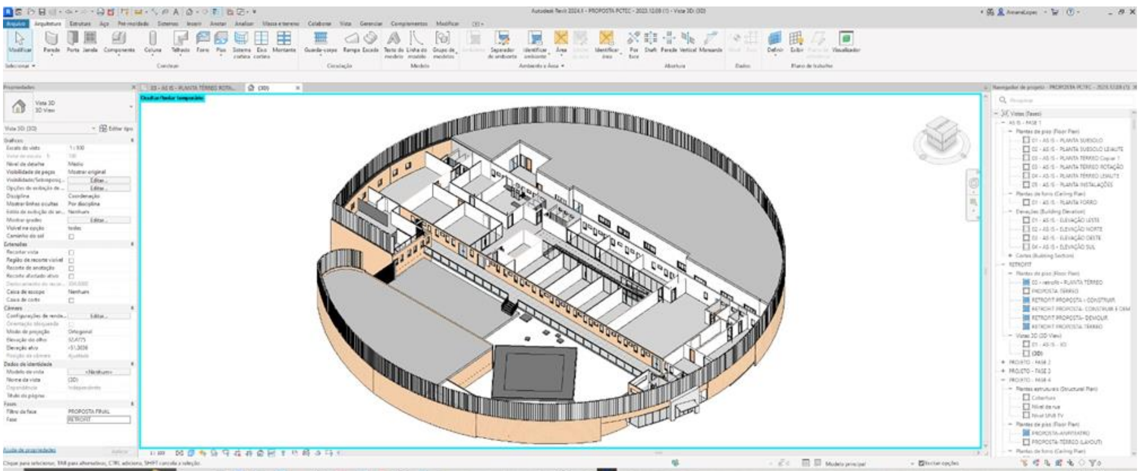
Figure 3 - As-is model



Retrofit project

After modeling the As-Is phase, the retrofit project began. The retrofit project involved a significant building transformation to meet new functional and accessibility requirements. This included the creation of new optimized spaces, the addition of bathrooms compliant with accessibility standards, the implementation of ramps, and overall improvements to the usability of the space (Figure 4). BIM proved indispensable in this process, facilitating visualization, clash detection, and the accurate classification of existing, new, and demolished elements. This streamlined project development and enhanced communication among stakeholders ultimately led to a successful retrofit outcome that closely aligned with the expectations and needs of the building's users.

Figure 4 - Retrofit model



Regarding the use of BIM in retrofit projects, we noticed that the association between the point cloud and the BIM model was fundamental for understanding the as-is condition of the building. Combining these data sources allowed for an accurate representation of the existing building, which was critical for defining appropriate retrofit strategies.

Integrating diverse data sources, including records from other building systems such as the structure, into the As-is BIM model is crucial (Gu et al., 2014). This data enrichment enabled a more comprehensive understanding of the building's systems, facilitating the development of informed proposals for the transformations necessary to achieve the desired retrofit outcomes.

Beyond its visualization capabilities, BIM fostered a collaborative environment among stakeholders. The model served as a centralized information hub, facilitating seamless communication and decision-making across coordination, architecture, engineering teams, and the client. The successful integration of data further increased the model's utility, showcasing the transformative potential of BIM, and demonstrating its efficacy in visualizing, planning, in executing complex retrofit initiatives. Furthermore, the collaborative environment fostered by BIM highlights its broader role in driving informed decision-making and collaborating for project success.

Challenges

Several barriers and limitations were identified during the development of the projects in the case study. One of the main challenges was the need to use Autodesk Revit due to its performance and integration with Recap, especially for handling point clouds. Although Revit facilitated the visualization and manipulation of these clouds, the modeling process was challenging, particularly in creating a coordinate system and accurately inserting the point cloud to ensure model consistency. Despite providing precise geometric data, the point clouds presented significant limitations, such as occlusion and unwanted data, including reflections, temporary elements, and objects that complicated terrain modeling. Interpreting these clouds required specific analytical skills to filter and extract relevant information.

During the retrofit phase, classifying architectural elements into "existing," "to build," and "to demolish" was essential but required careful attention to ensure the BIM model accurately reflected the planned changes. The insertion of complementary disciplines, such as plumbing, electrical, and structural, presented another challenge when using ArchiCAD, exploring compatibility between different BIM software. The use of the IFC format and the Kuara® platform facilitated collaboration. Still, it was necessary to properly configure IFC exporters and create new parameters to integrate SINAP data, ensuring that all information needed for budgeting was available. Finally, the coordination phase revealed incompatibilities, such as conflicts between electrical points, lighting, and plumbing, which needed to be resolved to ensure the integrity of the final model.

Moreover, during this research, we encountered challenges related to the need for more information about the studied building, as highlighted by Li et al. (2019). The absence of accurate data on materials, dimensions, and modifications, as well as information about the electrical system, hindered the analysis and characterization of the building, requiring additional studies and tests. This study aligns with the findings of D'Angelo et al. (2022), which emphasize the potential of BIM for retrofit development, overcoming these limitations and enhancing collaboration among professionals.

While many studies focus on BIM-based retrofit to improve energy efficiency, this research went further by using BIM to model the building's current state with data from drones and laser scanning and developing retrofit proposals based on client information. This approach supports the conclusions of Zhang et al. (2021) and Li et al. (2021), demonstrating that BIM facilitates modeling and collaboration among designers.

CONCLUSION

This work analyzed the development of building retrofits using BIM through the assessment of the current state of the building with digital technologies. Detailed information on the building's main systems was collected, and an AS-IS model was created. During the research, it was identified that clearly defining the purpose of the retrofit is crucial for planning data collection and avoiding rework. The AS-IS modeling noted that not all systems, such as the plumbing, needed to be meticulously detailed, as they were not the focus of the intervention. The model must be aligned with the requirements of the BEP (BIM Execution Plan) to support decision-making. It was found that BIM methodology is essential in planning and organizing workflows, defining responsibilities, and preventing rework and information loss.

The BIM retrofit process highlighted the importance of collaborative work and knowledge dissemination within the university, involving many students. Software and model compatibility techniques were tested, but challenges such as constant changes in client demands, alterations in space usage, and budget constraints affected the level of intervention. This pilot project, conducted at a public university with limited resources, was significant for addressing the innovative topic of BIM retrofit. Coordinated workflows were created and tested, consolidating a BIM retrofit methodology manual, which will be the subject of a future article. This project marked the beginning of this methodology application, which will be refined in future projects. Future studies should consider budgeting for modernization, process development, and identifying limitations that could inform new research.

ACKNOWLEDGMENTS

The researchers would like to thank the Federal District Research Support Foundation FAP-DF for supporting the research.

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