

Proposal for a hierarchical requirements model to support BIM-based maintenance management in federal higher education institutions

Proposição de um modelo hierarquizado de requisitos para apoiar a gestão da manutenção baseada em BIM em instituições federais de ensino superior

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Abstract

The efficient management of public buildings is of utmost relevance to society, as the resources allocated for their operation and maintenance originate from taxpayers. A promising approach is the integration of Maintenance Management (MM) with Building Information Modeling (BIM), which, when applied throughout the building life cycle, can improve the efficiency and effectiveness of activities, contributing to the preservation of the built environment. This study proposes a process model for implementing BIM in the MM of public buildings. Following the Design Science Research methodological approach, this research study was divided into four phases: (a) a literature review; (b) an exploratory phase, during which attributes related to MM with BIM application were identified and organized; (c) a development phase, where the groupings were validated, prioritized, and connected to the phases of the building life cycle; and (d) a proposition phase, in which a Process Model for Information Requirements Management for Maintenance of Federal Higher Education Institutions was devised. The identification and formalization of the required information for MM can contribute to improving facilities management.

Keywords: Building Information Modeling (BIM). Operation and Maintenance (O&M). Facilities Management (FM). Maintenance management. Higher Education Institution.

Resumo

A gestão eficiente dos edifícios públicos é de extrema relevância para a sociedade, uma vez que os recursos alocados para sua operação e manutenção são provenientes dos contribuintes. Uma abordagem promissora é a integração da Gestão da Manutenção (GM) com a Modelagem da Informação da Construção (BIM), que, quando aplicada ao longo do ciclo de vida do edifício, pode melhorar a eficiência e a eficácia das atividades, contribuindo para a preservação do ambiente construído. Este estudo propõe um modelo de processo para implementar o BIM na GM de prédios públicos. Seguindo a abordagem metodológica da Design Science Research, este estudo de pesquisa foi dividido em quatro fases: (a) uma revisão da literatura; (b) uma fase exploratória, durante a qual os atributos relacionados à GM com aplicação do BIM foram identificados e organizados; (c) uma fase de desenvolvimento, na qual os agrupamentos foram validados, priorizados e conectados às fases do ciclo de vida do edifício; e (d) uma fase de proposição, na qual foi elaborado um Modelo de Processo para Gestão de Requisitos de Informação para Manutenção de Instituições Federais de Ensino Superior. A identificação e formalização das informações necessárias para a GM podem contribuir para melhorar a gestão de instalações.

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Introduction

Buildings are complex structures that play a fundamental role in the context in which they are situated. As durable products, the life cycle of a building comprises several phases, including planning, design, construction, operation and maintenance, and eventually, demolition (Chen; Tang, 2019). Throughout its service life, all components and materials that make up the building undergo an inevitable process of deterioration, caused by use and exposure to weathering agents, which can lead to a series of problems and wear (Algayer, 2019).

The Operation and Maintenance (O&M) phase tends to be the longest in the building life cycle, encompassing essential activities that aim to preserve and keep the proper functioning of the built environment, as well as directly influencing the return on investment (Crawford, 2011; Kensek, 2015; Ngwepe; Aigbavboa, 2015; Gao; Pishdad-bozorgi, 2019).

Owing to the extended lifespan of buildings, maintenance costs frequently surpass those incurred during the design and construction stages (Akacamet; Akinci; Garrett, 2010). Employing effective maintenance strategies can mitigate these expenses and enhance the longevity of building components, as appropriate management helps control deterioration processes (Chew; Tan; Kang, 2004; Cheng *et al.*, 2020).

In the case of public real estate assets, maintenance activities are crucial to prolonging the durability and functionality of these buildings (Viana *et al.*, 2022). It is not uncommon to find anomalies in the conservation status of these properties, often due to inadequate maintenance actions or even their absence, imposing new challenges on public authorities related to resource management and additional costs (Shen; Lo; Wang, 1998; Viana *et al.*, 2022).

The efficient management of public buildings is of great importance to society, given that the resources allocated for operation and maintenance come from taxes paid by the population. In this context, the effective conservation of these buildings is aligned with the principle of economy in public administration (Teixeira, 2022).

In order to properly manage these buildings, it is necessary to use best practices. In the O&M phase, Facility Management (FM) stands out, whose mission is to maintain and continuously improve facilities. It is a comprehensive process that encompasses various activities and competencies, and requires a wide range of criteria from different data sources, such as maintenance activities (Marmo *et al.*, 2020; Matos *et al.*, 2021).

Among the activities that make up FM, Maintenance Management (MM) stands out, mainly due to the fact that the costs associated with the building maintenance process represent the largest part of the total costs incurred by FM operations (65% to 85%), and the absence of efficient strategies and inadequate decision-making contribute to the increase in these expenses (Liu; Issa, 2013; Lavy; Jawadekar, 2014; Chen *et al.*, 2018; Sacks *et al.*, 2018).

Effective maintenance management requires the collection and provision of accessible information to decision-makers, as well as cooperation among experts at various stages of the building life cycle (Ceric *et al.*, 2019). The lack of detailed and organized information about a facility, both geometric and semantic, is one of the reasons for inefficient management (Valinejadshoubi; Moselhi; Bagchi, 2022).

Disregarding the use of available tools in the O&M of buildings can compromise the quality of MM, as the handling and exchange of information play a fundamental role in this process (Kameli *et al.*, 2020). In this context, Information and Communication Technologies (ICT), combined with decision support systems, become crucial for maintenance management (Kameli *et al.*, 2020; Youssefli; Nasiri; Moselhi, 2021).

Building Information Modeling (BIM) has transformed how facilities are designed and managed, contributing to increase the quality of buildings, and reduce the cost of project delivery (Abideen *et al.*, 2022). With an intelligent model-based approach, BIM makes it possible to track, update, and maintain essential information for decision-making throughout the construction life cycle (Chen *et al.*, 2018).

The integration of BIM into maintenance management practices enables collaborative coordination among various disciplines and serves as a structured foundation for information gathering, supporting decision-making and enhancing maintenance practices (Carbonari; Stravoravdis; Gausden, 2015; Leal; Salgado, 2019; Marmo *et al.*, 2019). Its features, such as data repositories, offer the possibility of MM through the organization, integration, and structuring of information used by the O&M team (Matarnah *et al.*, 2020; Kamal; Taghaddos; Karimi, 2021).

BIM therefore has the potential to support the O&M process, although its application is still largely focused on data collection, visualization, technical solutions, and cost optimization during the design and construction

phases (Godager; Onstein; Huang, 2021). However, the use of BIM as an information repository throughout the building life cycle and for data transfer and integration in the post-construction phases faces limitations (Naticchia; Corneli; Carbonari, 2020; Sadeghi; Elliott; Mehany, 2022).

One of the ways to overcome these limitations is by implementing it in a systemic way, so that it reflects the actual state of the equipment and provides information and documents that are relevant to operation and maintenance throughout the building life cycle (Wu; Wang; Wang, 2016). Delivering a well-structured BIM model not only facilitates ongoing property management, but also provides valuable historical information for future maintenance, renovation and expansion processes (Meng *et al.*, 2020).

The information collected and managed during the design and construction phases contributes to improving processes related to the O&M phase (Daniotti *et al.*, 2020). However, according to the same authors, data available in the initial stages often have limited content relative to O&M needs, and the definition of a structured information flow throughout the project life cycle is necessary.

Similarly, data overload in the BIM model is also a recurring problem, leading to increased time spent searching for relevant data and distractions at work (Ensafi; Thabet, 2021). Inadequate information management can be as detrimental as its absence, directly compromising the efficiency of maintenance tasks (Yang; Ergen, 2017; Chu; Matthews; Love, 2017).

To improve the implementation of BIM projects in the building maintenance process, it is necessary to define, in advance and carefully, the semantic information requirements to be incorporated into the model to optimize maintenance management (Ceric *et al.*, 2019; Matarneh *et al.*, 2020; Sadeghi; Elliott; Mehany, 2022). This includes establishing workflows for data capture, validation, retrieval, and documentation, assigning clear responsibilities, and directing efforts to deliver appropriate information in the ideal format for O&M (Sadeghi, 2019; Matarneh *et al.*, 2020).

The standardization of data to be included in BIM models contributes to improve the efficiency in the transfer of construction information, to facilitate asset management, and to promote a continuous workflow, being essential for effective syntactic and semantic interoperability between models (Ibrahim *et al.*, 2016).

The use of BIM by the Architecture, Engineering, Construction and Operation (AECO) industry is enhanced by the implementation of a project support structure capable of generating a well-structured information flow, contributing to the success and efficiency of the operational process (ABNT, 2022). Structuring information management transparently among stakeholders results in higher-quality data, which supports decision-making during building management (Borrmann *et al.*, 2018).

The NBR ISO 19650-1 (ABNT, 2022) standard defines essential concepts and principles that underpin information management and production throughout the lifecycle of built assets using BIM (ABNT, 2022). This standardization plays a key role in facilitating the adoption of Building Information Modeling and fostering effective collaboration (Catelani; Santos, 2016). Adherence to technical standards focused on BIM and interoperability, such as the NBR 15965 series, further supports these objectives.

In the context of government buildings, developing specific criteria throughout the different stages of their life cycle is fundamental to improve a maintenance process through BIM (Fatmasari; Latief, 2018). According to the same authors, this process aims to identify the necessary information flow, establish its prioritization, and determine appropriate organizational and legal criteria to support the application of Building Information Modeling.

In Higher Education Institutions (HEIs), the management of numerous buildings—combined with financial and staffing limitations—necessitates the implementation of an effective maintenance process (Uhm; Lee, 2021). University buildings serve multiple purposes and house a range of facilities and spaces that accommodate diverse activities. This leads to complex management requirements, involving various features and attributes as well as extensive participation from personnel in daily operations (Moreno *et al.*, 2022).

As some university buildings operate 24 hours a day, 7 days a week, such as university hospitals, managers face the challenge of maintaining continuous maintenance, with access to constantly updated information in dense databases subject to frequent changes (Moreno *et al.*, 2022). In this context, the implementation of BIM has much potential to enhance maintenance practices, contingent upon the successful resolution of challenges associated with the organization and standardization of information (Uhm; Lee, 2021).

The proper organization and integration of information, promoting a continuous flow throughout the life cycle of the built environment, through collaborative technologies, offers a significant opportunity to improve the management of building maintenance, especially in the case of public assets. Therefore, by adopting effective approaches and appropriate technological tools, it is possible to improve maintenance processes, ensuring

greater efficiency, reducing costs and extending the useful life of buildings. Maintenance management is thus consolidated as a strategic asset, contributing directly to the preservation and appreciation of public assets.

Accordingly, this study seeks to identify the key information requirements that should be integrated into the BIM model to effectively support the maintenance management of public buildings, with particular emphasis on those administered by Federal Higher Education Institutions in Brazil. The primary objective is to establish the flow of information across the building life cycle, systematically analyzing the organization and standardization of data within the BIM model, and propose a process model that structures the requisite level of information to streamline the maintenance activities of public buildings.

Methodology

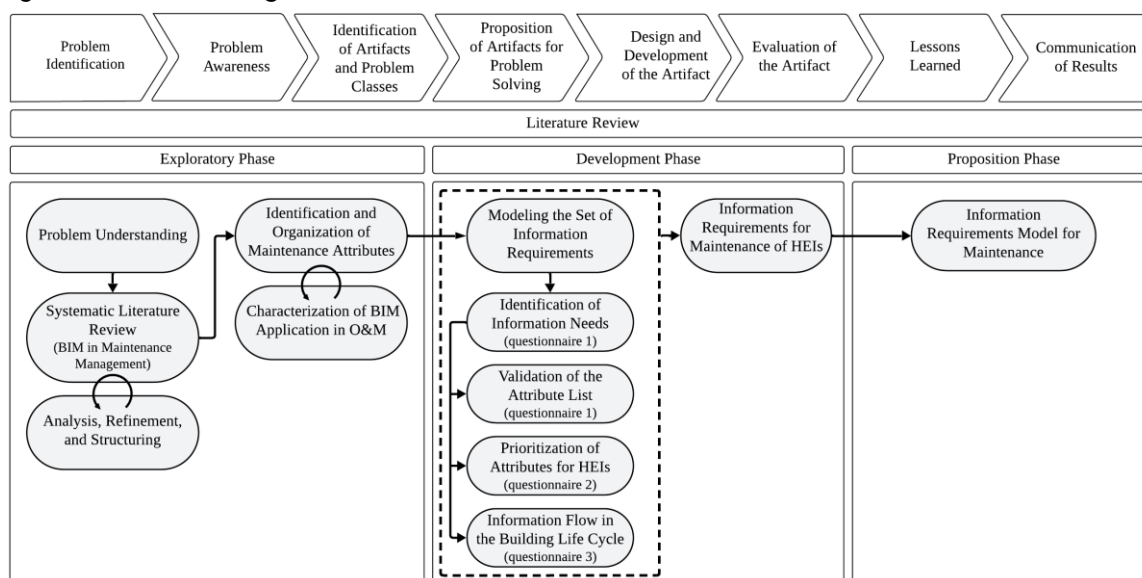
Given the practical nature of the research, which seeks to solve a specific problem through the development, implementation, and evaluation of applicable constructs, the Design Science Research (DSR) methodological approach was adopted (Dresch; Lacerda; Antunes, 2015).

The research was structured into four main phases (Figure 1), incorporating the stages suggested by Kasanen, Lukka and Siitonen (1993) and Lukka (2000¹ *apud* Lukka, 2003):

- (a) literature review, conducted throughout the entire research;
- (b) exploratory phase;
- (c) development phase; and
- (d) proposition phase.

In the first phase of the research, the aim was to understand the topic through an initial literature review, with the objective of outlining the research problem to be explored and identifying existing studies on the application of BIM in maintenance management. This phase is aligned with the first stage of DSR, which involves identifying a problem with practical relevance and potential theoretical contribution. The literature review focused mainly on recent studies on BIM, aiming to assess its level of application in the O&M phase of buildings, with an emphasis on processes related to maintenance management. These aspects enabled the definition of the research problem addressed in this study.

Figure 1 - Research design



¹LUKKA, K. The key issues of applying the constructive approach to field research. In: REPONEN, T. (ed.). **Management expertise in the new millennium**. Turku: Turku School of Economics and Business Administration, 2000. Series A-1. p. 113-128.

In the exploratory phase, the research focused on raising awareness of the problem and identifying artifacts and classes of problems. This enabled a deeper understanding of the topic and the problem itself, characterizing the use of BIM in processes related to the O&M phase. In this phase, attributes related to maintenance management using BIM were identified through a Systematic Literature Review (SLR), which were analyzed, refined, and structured, enabling them to be organized into a list of attributes.

In the development phase, the stages of proposition, design, and artifact development were presented, aiming to generate applicable and useful knowledge to solve the identified problem.

The development phase involved the participation of specialists and professionals related to maintenance management, who contributed to data collection by responding to a series of questionnaires. Considering the characteristics of this phase of the work, ethical and legal aspects related to research involving human subjects were observed. Thus, the project was submitted to *Plataforma Brasil*² and was previously evaluated and approved by the Research Ethics Committee on Human Subjects of the Federal University of Pelotas, under the Ethical Review Submission Certificate No. 75117123.3.0000.5313.

During the development phase, the list of information attributes defined to support building maintenance management using BIM underwent processes of identifying information needs, validation, prioritization, and defining the information flow of the main attributes employed in BIM models used in the O&M phase, resulting in a set of information requirements for maintenance of HEIs.

Finally, the fourth phase concerns the reflection and discussion of the results in an attempt to disseminate the knowledge generated in this work and contribute to the advancement of the field of study. The proposition phase involved explaining the lessons learned and communicating the results.

Considering the results obtained and the comparison with evidence found in the literature, we sought to refine the set of information requirements and identify the level of applicability to achieve the proposed objective. As a result of these analyses and modifications, the Maintenance Information Requirements Model was developed, which can be implemented in projects developed in BIM by HEIs.

It is worth noting, as a limitation of this study, that the proposed model was not subjected to a practical evaluation stage through its application in an empirical study. Although it was developed based on data obtained from professionals in the field and structured according to DSR principles, the usefulness and applicability of the artifact have not yet been evaluated in a real-world context. This stage, considered fundamental in the DSR approach to verify the effectiveness of the proposed solution, remains an opportunity for future research.

Identification and organization of maintenance attributes

The SLR was conducted with the aim of identifying primary studies that have explored the application of BIM in Maintenance Management and analyzing the approaches used regarding the development and implementation of BIM in this context.

The SLR was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology, which consists of a checklist to facilitate the preparation of searches, the development of a research protocol, and the presentation of a consistent and detailed report (Moher *et al.*, 2015). The entire selection process and its stages are presented in the PRISMA flow diagram (Figure 2).

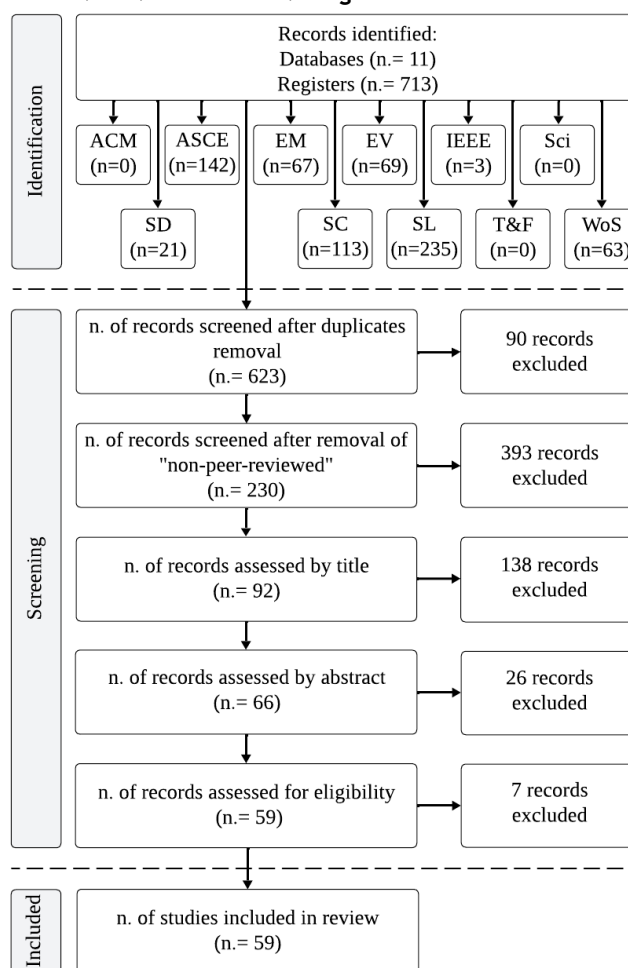
The selection of the timeframe for analysis, from 2008 to 2022, was based on preliminary mapping from the narrative literature review. This provided an opportunity to explore historical and recent advances in the use of BIM in Maintenance Management. The search was not restricted to HEIs, thus increasing the number of studies obtained for analysis.

To maximize comprehensiveness, several databases were explored, including the ACM Digital Library (ACM), ASCE Library (ASCE), Emerald (EM), Engineering Village (EV), IEEE Digital Library (IEEE), SciELO (Sci), Science Direct (SD), Scopus (SC), Springer Link (SL), Taylor & Francis (T&F), and Web of Science (WoS).

The keywords and Boolean operators used were: (“BIM” OR “Building Information Model*”) AND (“Facilit* Maintenance” OR “Building Maintenance”). These strings were used to search the titles, abstracts and keywords of the articles. As a result, a total of 713 articles were identified.

²A Brazilian unified platform for registering research involving human subjects, enabling the monitoring of projects at all stages, from submission to final approval by the Research Ethics Committees and the National Research Ethics Commission.

Figure 2 - PRISMA diagram - BIM in Maintenance Management



The articles were screened according to the inclusion criteria, which required the articles to be scientific, within the research field of AECO, written in English, published within the defined time frame, and with full-text availability. The exclusion criteria eliminated texts that did not address the topic of BIM in Maintenance Management or had not undergone peer review. Data extraction and quality assessment of the selected articles were then carried out.

In the end, 59 eligible articles were selected and classified as the final sample to proceed with the research. These selected articles underwent a qualitative synthesis, being critically reviewed and analyzed to map the current state of research on BIM applied to MM, thus providing support for the development of this study.

Based on the results of the SLR, the attributes used in BIM models to support the Maintenance Management process in buildings were identified and extracted, aiming to deepen the understanding of the research problem.

The attributes related to BIM models, identified and collected from previous studies, were organized into a matrix for comparison. The objective was to analyze the frequency of occurrence of these attributes and identify similarities among the various mapped elements, aiming to support MM practices in the BIM context.

These attributes collected in the SLR represent individual characteristics that contribute to the description and representation of maintenance elements in a BIM model. To facilitate analysis, these attributes were grouped into clusters.

The organization of the attributes and the definition of requirement groups were carried out based on the structure of the Construction Operations Building Information Exchange (COBie³) standard. The grouping

³COBie is a performance-based specification that standardizes the capture and delivery of BIM model information to FM systems during the O&M phase (East; Carrasquillo, 2013). The format is widely recognized as an international data exchange standard, using a formal spreadsheet format (Alavi; Bortolini; Forcada, 2022).

process consisted of combining attributes with similar characteristics and organizing them into the 18 categories that make up COBie.

Based on East (2007), COBie spreadsheet can be described as follows:

- (a) contact: list of project stakeholders, companies, suppliers, and manufacturers, along with their respective contact information;
- (b) facility: project name, location, function, and description of the facility in question;
- (c) floor: detailed information about the floors belonging to the facility;
- (d) space: information about individual spaces within the project, including floor, category, area, and other data;
- (e) zone: identification of zones, referring to groups of organized spaces and defining their respective functions;
- (f) type: details of equipment and furniture, including manufacturer specifications, model, warranty, costs, and associated dates, covering information on assets present in the facility;
- (g) component: listing of assets described in the “*Type*” category, indicating the space where they are located, serial number, and other information;
- (h) system: organization of systems created in the model, categorized according to their configurations;
- (i) assembly: data sets related to “*Component*” and “*Type*”, organized to facilitate configurations and describe their assembly form;
- (j) connection: records of logical connections between components;
- (k) spare: information about spare parts;
- (l) resource: data sets on materials needed, tools, and instructions for processes;
- (m) job: procedures associated with building operation, such as maintenance, repair, inspection, safety, emergency, or other activities;
- (n) impact: record of impacts generated by the building (economic, environmental, and social) during the life cycle phases;
- (o) document: organization of documents related to the building, such as warranties, O&M manuals, or other materials relevant to FM;
- (p) attribute: specific information about a particular space, floor, or component;
- (q) coordinate: coordinates and spatial locations of construction elements, systems, or equipment present in the building; and
- (r) issue: information about additional issues related to the work.

Identification of information needs and validation of the attribute list

To promote a critical and relevant analysis of the attributes in terms of their usefulness for the maintenance process, the groupings were submitted to analysis by experts in the field of building maintenance, with the aim of identifying information needs and validating this structure in terms of its scope and depth.

The analysis of the list of BIM model attributes for maintenance management was carried out through a survey, in which digital questionnaires were sent by email to the participating experts, entitled “*Questionnaire 1*”. The attributes were divided and presented in the questionnaire according to the pre-established groups (18 categories).

In this research, university professors and researchers with expertise in building maintenance management were invited to participate. To broaden expert participation, no restriction was placed on affiliation with HEIs. The invitation was sent to 22 specialists linked to different Brazilian universities, of whom 13 agreed to participate. However, only 9 completed all the established stages.

The survey was conducted online using the *LimeSurvey* tool. The importance of each attribute for maintenance management was rated by experts using a five-point Likert Scale (1 = dispensable, 2 = slightly useful, 3 = neutral, 4 = very useful, and 5 = indispensable). According to Joshi *et al.* (2015), the Likert Scale is widely used in research to measure participants’ attitudes, opinions, and perceptions, allowing respondents to express

their level of agreement with a series of statements. The average of the responses provides an overall measure of the perceptions analyzed concerning the studied problem (Joshi *et al.*, 2015).

To explore the quantitative variables, Frequency Analysis was employed, a statistical method that uses descriptive measures to summarize the main characteristics of the data's frequency distribution (Barbetta, 2024). Through classic descriptive measures (mean, mode, and standard deviation), it was possible to identify the attributes with the highest and lowest degrees of usefulness for the intended application.

During the frequency analysis, minimum thresholds were established for attribute validation: a mean greater than 3, a mode equal to or greater than 3, and a standard deviation less than 1, ensuring data consistency. The adoption of these criteria allowed the selection of attributes with moderate relevance, avoiding consideration of only the extremely useful attributes, which could excessively reduce the list and compromise the number of items for subsequent phases.

Statistical analyses were performed using *jamovi*⁴. To validate the consistency of the questionnaire, Cronbach's alpha test was applied to assess the reliability of the responses obtained with the Likert scale, with the minimum acceptable value considered in the literature to be 0.70 (Hora; Monteiro; Arica, 2010).

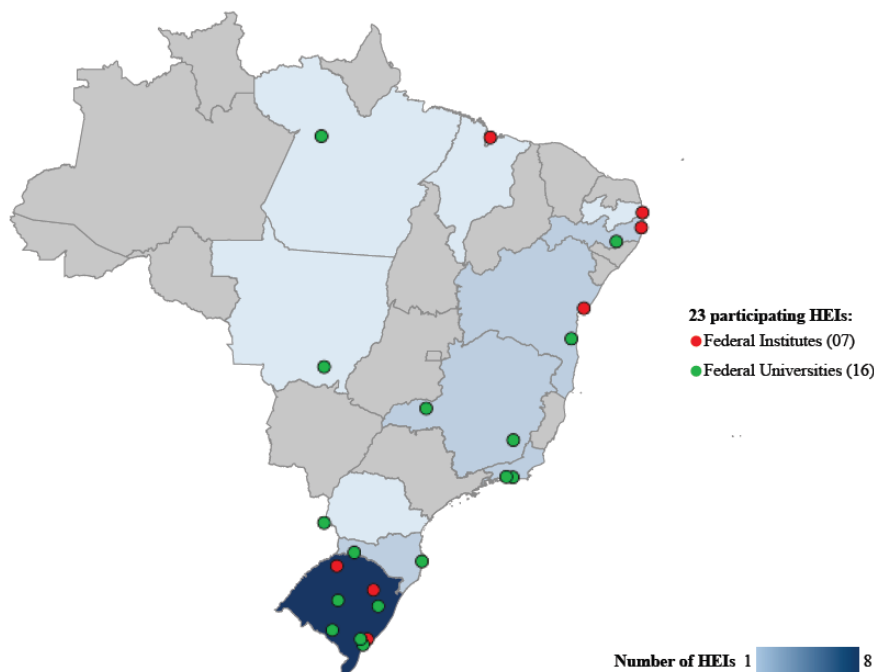
Prioritization of attributes for HEIs

After establishing the preliminary group of attributes based on their overall usefulness for building maintenance, the following step was to identify the most relevant attributes for facility management in a more specific context – namely, the case study involving Federal HEIs. This was done by organizing the attributes according to the practical experience of professionals associated with these institutions.

Then a new questionnaire – referred to as “*Questionnaire 2*” – was applied to prioritize the information required to support maintenance management in Federal HEIs. This questionnaire was directed at professionals responsible for maintenance in the aforementioned institutions. The building maintenance departments of all 110 Federal HEIs in Brazil were invited to participate in this phase. A positive response was obtained from 23 institutions. Of those, 16 were federal universities and 7 were federal institutes of education, geographically distributed as shown in Figure 3.

With the aim of increasing the number of professionals involved in maintenance management at the selected HEIs in this investigation, all professionals related to the maintenance process of each HEIs were invited to participate.

Figure 3 - Geographically distributed HEIs



⁴*jamovi* is a free and intuitive statistical platform designed to provide the latest advances in statistical methodologies.

The questionnaire containing the preliminary set of attributes was administered online using the *LimeSurvey* tool. A total of 27 complete responses were collected. Participants rated the importance of the attributes for maintenance management in Brazilian Federal HEIs using a five-point Likert Scale (1 = dispensable, 2 = slightly important, 3 = neutral, 4 = important, 5 = very important). The same statistical methods described in the previous section were applied to determine the prioritization of the data, ranking the attributes according to their relevance for building maintenance management in HEIs.

The responses collected were analyzed using the *jamovi* software, and the attributes were selected based on the following Frequency Analysis criteria: mean equal to or greater than 4 (important to very important), mode equal to or greater than 4, and standard deviation less than 1, ensuring data consistency. This approach aimed to guarantee that only attributes with the greatest impact on building maintenance management in HEIs were prioritized for incorporation into the BIM model, optimizing the efficiency and effectiveness of the process.

Identification of information flow in the building life cycle

Establishing the relationship between the attributes needed to support building maintenance management and the different phases of the building life cycle helps track project information and continuously improve operation and maintenance, especially in public buildings.

Based on the responses obtained in Questionnaire 2, where the attributes were ranked according to their level of importance, the research advanced to establish the relationship between the key identified attributes and the different phases of a building life cycle, from conception through to operation and maintenance phases.

To achieve this level of correlation, the same professionals were asked to answer Questionnaire 3, which contained a comparison matrix relating the prioritized key attributes to the life cycle phases for their evaluation. From the 27 professionals who participated in the previous survey, 19 were able to participate in this stage. The questionnaire was administered online using the *LimeSurvey* platform, with invitations sent by email to the responsible departments. Statistical analysis values were obtained using the *jamovi* software.

The questionnaire presented a list of attributes, asking professionals to correlate, in a comparative matrix, the 122 attributes to the phases of the building life cycle: Concept Design, Design, Construction and Pre-operation, and Operation and Maintenance.

Information requirements for maintenance of HEIs

The identification, prioritization, and definition of the information flow of the key attributes used in BIM models during the Operation and Maintenance phase resulted in a set of information requirements for maintenance of Federal HEIs. This set was developed to support teams responsible for maintenance management of public buildings affiliated with HEIs, serving as a knowledge base for the development of BIM models and for automating information exchange throughout all phases of a building life cycle, thereby enhancing the model's efficiency, especially during use and maintenance.

The adoption of semantic information requirements contributes to the standardization and organization of data needed for the maintenance process. The attributes within these groups represent individual characteristics that assist in the understanding and representation of maintenance-related elements within the BIM context. These groupings enhance interoperability among different BIM systems by presenting the key information necessary for maintenance, promoting more efficient communication and more integrated collaboration among those involved in building maintenance management.

Furthermore, identifying the most appropriate time to capture attributes throughout the stages of the building life cycle enables the development of these requirements from the initial phases of the project.

Results and discussion

Identification and organization of maintenance attributes

This approach enabled an in-depth analysis of the topic and the presentation of a list of information attributes for BIM models that can serve as a support tool for maintenance practices. As a well-established format in the field of Facility Management, aligning the identified attributes with the COBie spreadsheet provides a more organized and comprehensible structure for analysis. This approach also facilitates the comparison of the requirements for these attributes across the different phases of the building life cycle.

In total, 2,602 attributes were collected, distributed across 18 pre-established categories to begin the

refinement process. This activity consisted of grouping and consolidating similar information, occurring over 11 successive refinement cycles. For example, the attributes “*Post Office Box*”, “*City*”, “*Postal Code*”, “*Country*”, “*Region/State*”, and “*Street*”, initially listed separately, were grouped and integrated into a single attribute called “*Address*”.

At the end of the process, 187 attributes remained. The result of this stage was the creation of a generic list of attributes for BIM models, intended to support maintenance management practices, grouped according to their similarity.

Identification of information needs and validation of the attribute list

The aim was to establish a balance between an in-depth analysis and the overall quality and applicability of the attributes in building maintenance management. Based on the statistical analyses performed, all 187 attributes met the established criteria, presenting an overall mean of 4.24, a mode of 5, and a standard deviation of 0.70.

Overall, the experts considered the set of attributes presented to be satisfactory in terms of scope and depth. In the same questionnaire, specialists could suggest new attributes or adjustments to the existing groupings; however, during the analysis process, no additions to the groups or reorganizations of the data were recommended, thus validating the list of attributes.

The internal consistency of the questionnaire was assessed using Cronbach's alpha coefficient, which reached a value of 0.988 for the items presented—well above the minimum acceptable threshold.

The final outcome of this stage was the validation of all attributes extracted from the SLR included in the list presented to the specialists, consolidating them into a preliminary set of attributes and their respective categories.

Prioritization of attributes for HEIs

At the end of the analysis and refinement process for the prioritization of attributes for HEIs, 122 attributes remained, presenting an overall mean of 4.30, a mode of 4, and an average standard deviation of 0.71. As a result of this prioritization, a final list of information attributes was obtained for BIM models, aimed at supporting maintenance management practices in buildings belonging to HEIs.

Based on the predefined statistical criteria, 65 attributes were excluded. All of them had a mean and mode equal to or greater than 3. Of these, 56 did not meet the cutoff point for the mean (equal to or greater than 4), and 9 exceeded the cutoff point for the mean but had a standard deviation greater than 1.

Although attributes classified as “*neutral*”, “*slightly important*”, or “*dispensable*” were not prioritized, it is important to highlight that, in specific operation and maintenance contexts, they may hold relevance. These attributes can become useful depending on the needs of each institution or aspects not covered by the research. For example, the attributes “*Address*” and “*Company*”, belonging to the “*Contact*” category, may be essential to identify the exact location where maintenance intervention is needed or the company responsible for the faulty equipment, to name just one case. Nonetheless, the cutoff criterion was applied to focus attention on the most critical aspects for maintenance management in HEIs.

The reliability of the factors extracted from the items was assessed using Cronbach's alpha coefficient, which yielded a value of 0.990, indicating very good internal consistency of the questionnaire.

Even though institutions from all Brazilian states did not participate, this situation is not considered a limitation for the research, as there is broad coverage of different states and regions. Additionally, future studies could extend this research by expanding its scope and incorporating institutions that have not participated in this investigation.

Identification of information flow in the building life cycle

The responses collected were statistically analyzed by using Frequency Analysis to determine the most appropriate phase for incorporating each attribute into the BIM model. The mode was used as the main criterion to establish this correlation, while the standard deviation was employed to assess the consistency of the responses. Figure 4 shows the number of attributes associated with each phase, with further details provided in Table 1.

Figure 4 - Number of attributes per building life cycle phase

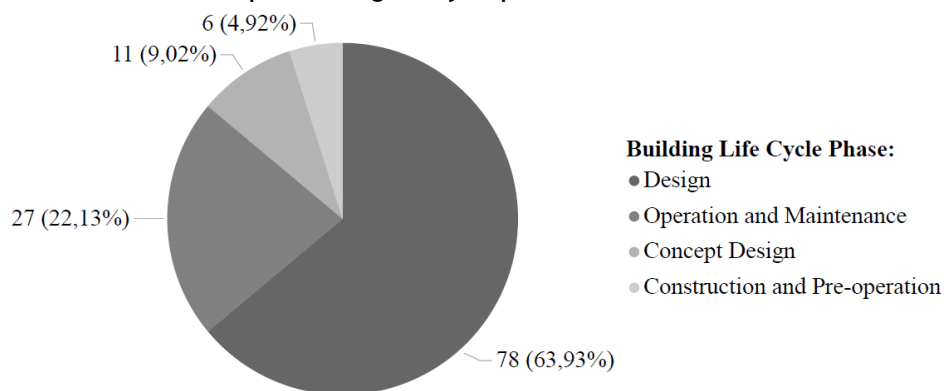


Table 1 - Set of information requirements and building life cycle phases (Continues...)

Group	Attribute	Phase
Contact	Contact Information	Conceptual Design
	Contact Category	Conceptual Design
Facility	Facility Name	Conceptual Design
	Facility Description	Conceptual Design
	Facility Category	Design
	Project Description	Design
	Facility Stage	Construction and Pre-operation
	Site Description	Conceptual Design
	Facility Type	Conceptual Design
	Construction Specifications	Design
	Facility Area	Conceptual Design
	Units of Measurement	Conceptual Design
	Current Condition Classification	Operation and Maintenance
	Structure Type	Design
	Facility Components	Design
Floor	Floor Name	Design
	Floor Description	Design
	Floor Location	Design
	Components on Floor	Design
Space	Space Name	Conceptual Design
	Space Description	Design
	Space Category	Design
	Space Function	Design
	Space Location	Conceptual Design
	Floor Name	Design
	Space Type	Design
	Space Dimensions	Design
	Occupancy Pattern	Design
	Space Importance	Design
	Components in Space	Design
Zone	Zone Name	Conceptual Design
Type	Type Name	Design
	Type Description	Design
	Type Category	Design
	Class	Design
	Brand	Design

Table 1 - Set of information requirements and building life cycle phases (continued)

Group	Attribute	Phase
Type	Model	Design
	Asset Type	Design
	System Type	Design
	Type Characteristics	Design
	Type Dimensions	Design
	Material	Design
	Power	Design
	Asset Operation	Design
	Asset Importance	Design
Component	Component Name	Design
	Component Description	Design
	Type Name	Design
	Component Classification	Design
	Component Composition	Design
	Component Type	Design
	Anomalies	Design
	Component Status	Operation and Maintenance
	Functionality	Operation and Maintenance
	Fault Location	Design
	Degree of Deterioration	Operation and Maintenance
	Component Dimensions	Operation and Maintenance
	Component Voltage	Design
	Component Location	Design
	Sensor Identification	Design
System	System Name	Design
	System Description	Design
	System Category	Design
	Associated Components	Design
	Component Names	Design
	System Type	Design
Assembly	Assembly Name	Design
	Assembly Description	Design
	Sheet Name	Design
	Fabrication Data	Design
Connection	Connection Name	Design
	Connection Description	Design
	Sheet Name	Design
	Row Name	Design
	Performing Element	Design
	Associated Systems	Design
	Connection Type	Design
Spare	Spare Name	Operation and Maintenance
	Spare Description	Operation and Maintenance
	Spare Category	Operation and Maintenance
	Type Name	Operation and Maintenance
	Part Number	Operation and Maintenance
	Assembly Number	Operation and Maintenance
Resource	Resource Name	Operation and Maintenance
	Resource Description	Operation and Maintenance
	Resource Category	Operation and Maintenance

Table 1 - Set of information requirements and building life cycle phases (continued)

Group	Attribute	Phase
Resource	Resource Type	Operation and Maintenance
Job	Job Name	Operation and Maintenance
	Job Description	Operation and Maintenance
	Job Category	Operation and Maintenance
	Job Type	Operation and Maintenance
	Job Location	Operation and Maintenance
	Job Start	Operation and Maintenance
	Job Status	Operation and Maintenance
	Resource Name Used	Operation and Maintenance
Impact	Impact Name	Design
	Impact Description	Design
	Affected Components	Design
	Asset Served Locations	Design
	Job Number	Design
	Impact Type	Construction and Pre-operation
Document	Document Name	Construction and Pre-operation
	Document Description	Design
	Document Category	Construction and Pre-operation
	Stage	Design
	Document Access Link	Construction and Pre-operation
	Sheet Name	Construction and Pre-operation
Attribute	Attribute Name	Design
	Attribute Description	Design
	Attribute Category	Design
	Unit	Design
	Value	Design
	Allowed Values	Design
	Reference	Design
Coordinate	Coordinate Name	Design
	Coordinate Category	Design
	Coordinates	Design
	Yaw Rotation	Design
Issue	Issue Name	Operation and Maintenance
	Issue Description	Operation and Maintenance
	Issue Type	Operation and Maintenance
	Owner	Operation and Maintenance

For the attributes that presented more than one mode (six attributes), only the earliest phase of the life cycle was considered. This choice is based on the premise that the earlier the data is captured, the more effective the process will be (Table 2).

This study aimed to facilitate continuous collaboration among design, construction, O&M teams, as well as other stakeholders. Additionally, it sought to contribute to the use of BIM by HEIs in project management throughout the building life cycle, aiming for more efficient maintenance management.

Information requirements for maintenance of HEIs

After analyzing the responses obtained during the exploratory phase and refining the collected, validated, and prioritized information, a final list comprising 122 attributes was established. The study identified the data required to serve as specific information requirements, supporting maintenance management practices in HEIs and serving as references for BIM projects aimed at this purpose.

Table 2 - Attributes with more than one mode

Group	Attribute	Phases
Facility	Site Description	Conceptual Design - Design
Impact	Impact Name	Design - Construction and Pre-operation - O&M
	Impact Description	Design - O&M
	Affected Components	Design - Construction and Pre-operation
	Asset Served Locations	Design - O&M
Document	Stage	Design - Construction and Pre-operation - O&M

The information attributes were organized and divided into 18 categories, forming a set of information requirements for maintenance of Higher Education Institutions that serve as a support base for most maintenance practices in Brazilian HEIs, as detailed in Table 1. Each category consists of specific attributes that assist in defining and describing the essential information for maintenance management.

Process model for information requirements management for maintenance of HEIs

The results obtained contributed to the development of the process model for managing maintenance information requirements, designed to be integrated within the BIM context. This approach tends to facilitate the adoption of such information by the maintenance departments of Brazilian HEIs. The Process Model for Information Requirements Management for Maintenance of Federal HEIs is divided into two parts and can be incorporated into BIM projects, both new and existing.

The Process Model for Information Requirements Management for Maintenance of Federal HEIs, illustrated in Figure 5, is designed for new buildings and aims to identify the attributes needed for maintenance management from early stages, as well as to verify whether these requirements are properly addressed throughout the building life cycle. This approach helps support the successful transfer of facility information in BIM-based projects.

The professionals responsible for maintenance management at HEIs, in collaboration with the project development or contracting team, should consult the information requirements identified in Table 1 to add the necessary attributes to the BIM model, so as to support building maintenance activities. During the concept design phase, these professionals forward the final information requirements to the design team.

Designers must carefully incorporate information requirements into design models. At the end of the design phase, maintenance managers, working with designers, verify that the previously identified requirements have been addressed, using common practices such as collaborative reviews in a Common Data Environment (CDE) or the use of checklists. Designers then deliver the BIM models to the construction team.

The construction team, in turn, develops additional BIM models and ensures that the information requirements are properly incorporated into the executive models. After validation, the construction team delivers the as-built BIM model to the contracting Higher Education Institution during project delivery.

The maintenance management team of the contracting HEI reviews the delivered model to ensure that all information requirements have been included. They also assess the need to add any other maintenance-related information. Finally, the maintenance management teams map the attributes incorporated into the BIM model and, if using FM systems⁵, integrate the necessary data outputs into these systems using an open data standard.

The characterization of the information necessary to support the maintenance of HEIs buildings, combined with the understanding of information exchange throughout the building life cycle and the application of interoperability between BIM tools, enables progress in studies aimed at identifying these groups of maintenance requirements already at the public works bidding stage, becoming an important reference term.

By clearly establishing the contractor's duties and responsibilities in the contract, regardless of the execution regime, the operation and maintenance of public buildings will occur in an organized manner, based on a relevant information repository.

For existing buildings, the incorporation of information into the BIM model occurs only during the operation and maintenance phase, requiring adaptation. Illustrated in Figure 6, the Process Model for Information

⁵FM systems are technological platforms that serve as data repositories or database management systems, developed to support the decision-making process of facility managers based on accurate, comprehensive, and real-time information. (Matarneh et al., 2020).

Requirements Management for Maintenance of Federal HEIs for existing buildings is proposed to identify the attributes necessary for maintenance management starting from the O&M phase. This approach aims to enhance the transfer of both new and existing facility information into BIM projects.

Figure 5 - Process model for information requirements management for maintenance of federal HEIs for new buildings

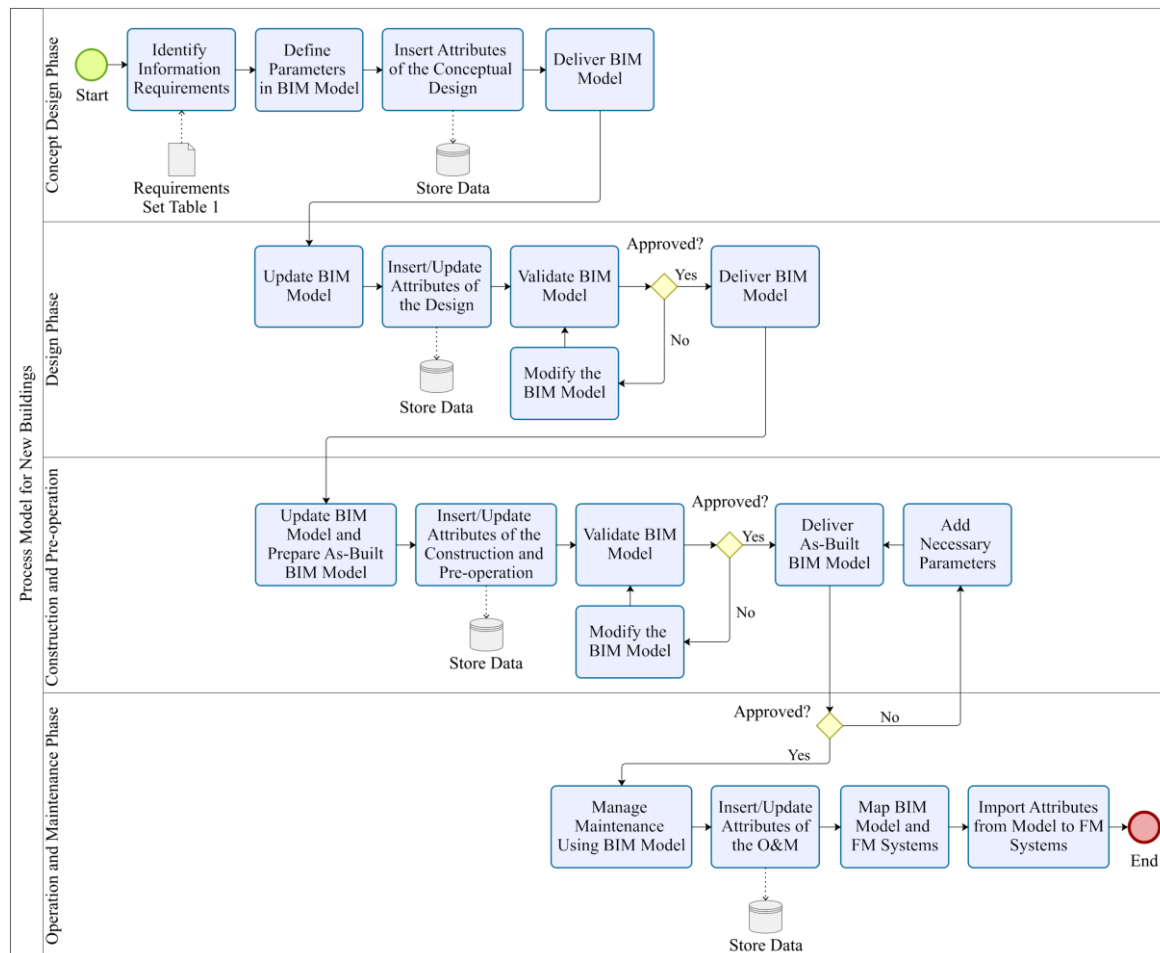
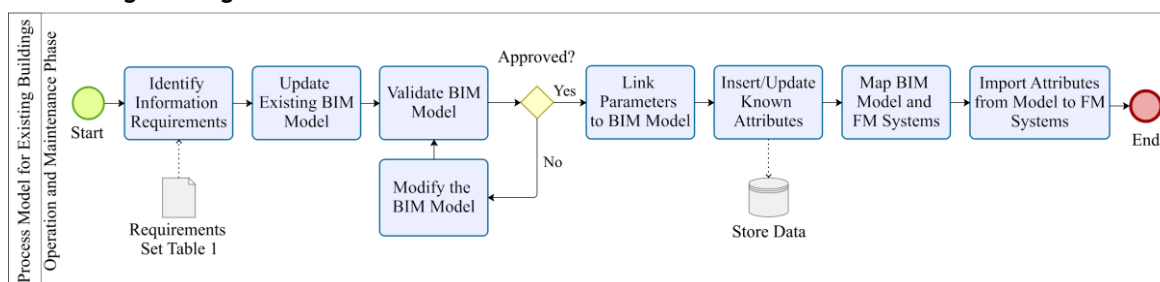


Figure 6 - Process model for information requirements management for maintenance of federal HEIs for existing buildings



In this case, the professionals responsible for maintenance management at the HEIs will be involved starting from the O&M phase. The management teams carry out the mapping of existing project and construction information.

The attributes must be inserted into the existing BIM model, enabling data-driven management of building information. If the HEI uses an FM system, the data outputs required for that system are integrated using an open data standard.

The main difference between the proposed models for new and existing buildings lies in the timing of the insertion of information requirements and the origin of the data. While the model for new buildings proposes the definition and monitoring of attributes from the initial stages of the life cycle, with the integrated participation of designers, builders, and maintenance managers, the model for existing buildings focuses its actions starting from the O&M phase, requiring efforts in surveying, verifying, and adapting the available information. In both cases, the use of open standards and integration with FM systems aims to ensure the continuity and effective use of data over time, promoting more efficient maintenance management based on structured information within the BIM environment.

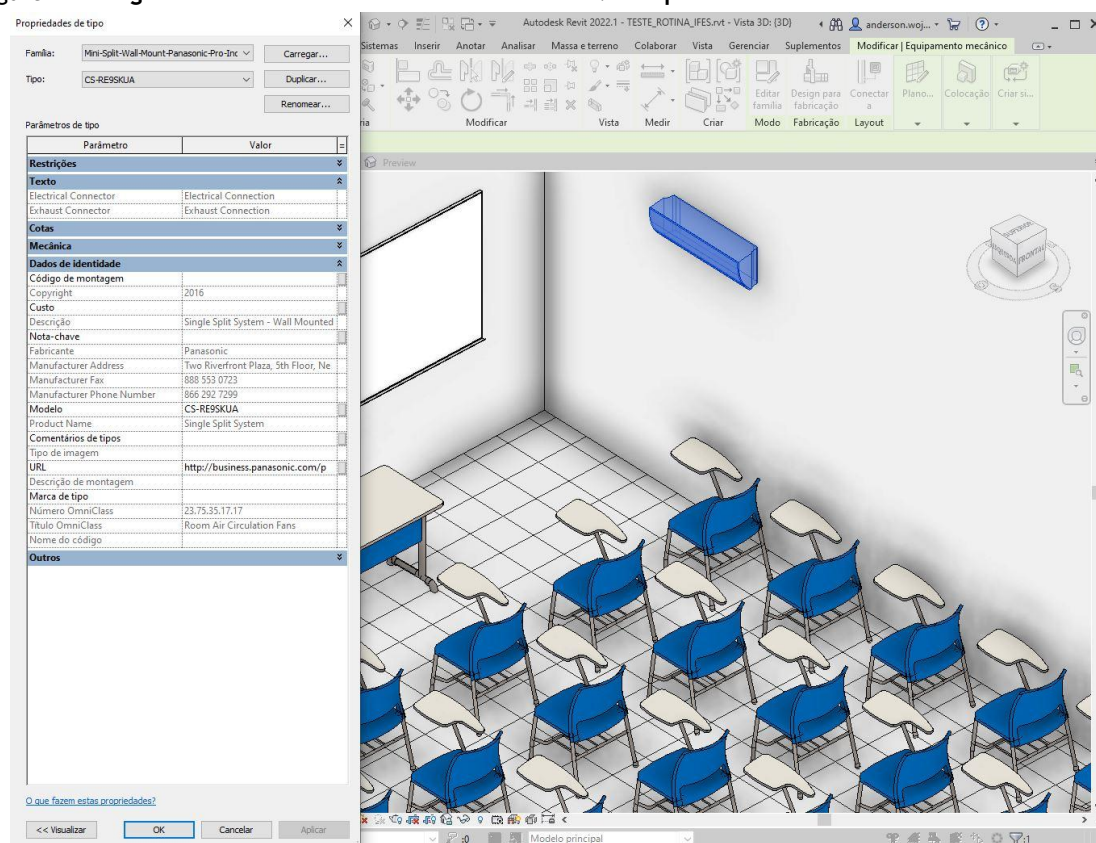
Integration of information requirements into BIM

With the definition of the information requirements necessary to support the maintenance of HEIs buildings, the possibility arises to use BIM models containing maintenance information for integrated management, which can enhance maintenance processes and support decision-making by facility managers.

In this case, the attributes were linked considering a hypothetical scenario in which an air conditioning unit received these data, serving as an information repository during the O&M phase (Figure 7)⁶.

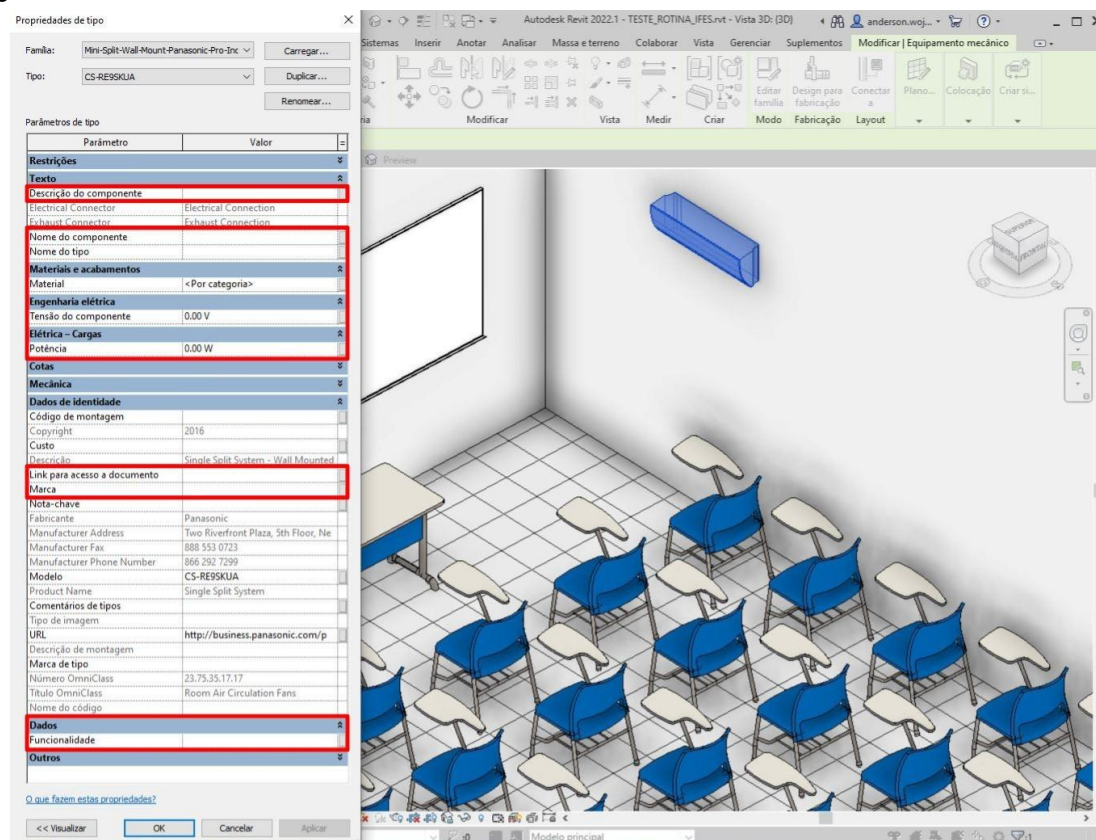
By inserting the identified attributes into the model, new parameter fields were created, becoming properties that support the maintenance management process. Thus, when selecting the object's parameter field, it is possible to view the corresponding information directly within the 3D model, providing a more complete and intuitive representation of the data (Figure 8). This creates an integrated BIM management system with the potential to be used in the O&M phase.

Figure 7 - Assignment of maintenance attributes to a BIM component



⁶The linking was implemented using the proprietary software Autodesk Revit, one of the main BIM authoring tools.

Figure 8 - Visualization of maintenance information in the BIM model



An integrated maintenance management system for higher education institutions (HEIs), utilizing information and BIM models, facilitates efficient management and strategic application of historical maintenance data to support stakeholder decision-making. This approach introduces an advanced paradigm in maintenance information management within Federal HEIs, establishing a robust framework for the sustainable preservation of public buildings.

Conclusion

This research study aimed to propose a process model for managing information requirements for maintenance using BIM in buildings of Federal HEIs, with the purpose of supporting the maintenance activities of these facilities. Design Science Research was the methodological approach adopted and this process model is the main outcome of this investigation.

Initially, the need for building maintenance information, the degree of importance of this data in the context of Brazilian Federal HEIs, and the flow of such information throughout the building life cycle were identified. These findings were obtained through the application of questionnaires to specialists and professionals involved in maintenance management.

The organization of the main attributes resulted in the development of a set of information requirements aimed at improving the use of BIM in the maintenance process of buildings linked to HEIs. This includes identifying the optimal timing for capturing these data, considering that each attribute within this group is associated with the specific phase of the building life cycle in which it should be captured and incorporated into the BIM model.

The information requirements established for the maintenance of HEIs were reviewed, as well as the methods for inserting and integrating this information into a digital BIM representation, resulting in the development of a Process Model for Information Requirements Management for Maintenance.

The proposed Process Model represents potential actions to ensure better maintenance management of buildings belonging to Federal HEIs in Brazil and to expand the application of BIM in this context, especially considering these organizations have limited BIM adoption in their management processes.

Additionally, other public organizations may also benefit from the Process Model, as Brazil still has low BIM adoption in its governmental processes, enabling its practical application to solve real problems across various public administration entities. If adapted, the Process Model could also be used by private organizations for the same purpose, although this is beyond the scope of this study.

One benefit worth highlighting is that identifying and formalizing the information needed by maintenance teams ensures more efficient operation of HEI facilities, which tends to reduce costs and extend the lifespan of buildings, directly contributing to the preservation and enhancement of public assets.

Another benefit relates to understanding the flow of information that should support maintenance activities in HEIs, which enables pinpointing the exact moment when this data should be captured and the designation of those responsible for the process even before the preparation of the basic and executive designs and the start of construction.

To meet legal requirements and optimize the management of engineering works and services in HEIs, minimum maintenance requirements may be required at the bidding stage for public projects and works, addressing the relationship between BIM and public procurement processes.

However, the proposed process may face implementation challenges within public organizations, given the need for sophisticated equipment and the acquisition of BIM software – factors that can be further complicated by the constant technological evolution, which these institutions do not always manage to keep up with.

The lack of specialized professionals in Federal HEIs may represent another obstacle, as it requires maintenance management team members to have training and qualifications compatible with the systems and tools to be used, as well as specific knowledge to operate them.

Regarding the limitations of this research, the validation of the proposed model was conducted based on questionnaires and expert analysis, but future studies could include practical tests in real maintenance projects at HEIs to evaluate the application of the Process Model in complex scenarios.

One avenue with potential for exploration concerns the development of a tool for filling in information in BIM models, based on the Industry Foundation Classes (IFC) standard, in the context of a federated maintenance management model. The objective is to propose a conceptual model that offers an integrated view of the relationship between information and the components or spaces associated with maintenance.

The research holds potential for significant developments and advances in the application of BIM for building maintenance management. It is expected that this study will help drive the dissemination of BIM in Brazil and serve as an alternative to shed light on the third and final phase of Decree No. 10.306, which mandates the use of BIM by entities of the federal public administration for managing and maintaining projects and works developed or executed with BIM starting in 2028.

Based on the results obtained in this research, the following recommendations are presented for future studies:

- (a) apply the proposed method, or parts of it, in an action research context, using the Process Model presented in this study;
- (b) investigate the implementation of maintenance information requirements and information flow in public works projects, to verify compliance with maintenance management processes;
- (c) expand the process of hierarchy and prioritization of maintenance requirements to other sectors, whether public or private;
- (d) integrate the Process Model for Information Requirements Management for Maintenance of Federal HEIs into the bidding processes for projects, construction works, and engineering and architecture services, so that it serves as a reference for a new contracting method; and
- (e) broaden the scope to explore the integration of the model with emerging technologies and deepen studies on interoperability, especially concerning IFC-related issues.

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