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BIM APPLICATION IN THE BRAZILIAN BUILDING LABELING PROGRAM: A REVIEW

APLICAÇÃO DE BIM NO PROGRAMA BRASILEIRO DE ETIQUETAGEM DE EDIFICAÇÕES: UMA REVISÃO

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Abstract

This study presents a comprehensive literature review on integrating Building Information Modeling (BIM) within the Brazilian Building Labeling Program (PBE Edifica), focusing on challenges, workflows, and research gaps. Emphasizing the advantages of BIM in PBE Edifica, this research highlights its effectiveness in data extraction, automation, and visualization tasks. Challenges encompass the absence of standardized practices for integrating BIM with Building Energy Modeling (BEM), interoperability issues, and limited exploration of universal standards, such as Industry Foundation Classes (IFC). The identified challenges involve disparities in simulation outcomes, concerns about BIM model reliability for energy assessments, and complexities in direct and indirect BIM-BEM exports. Future research should consider in-depth investigations into BIM tool intricacies, a comprehensive understanding of data syntax and semantics, and strict adherence to modeling guidelines. This study highlights the crucial connection between design processes and energy efficiency by encouraging the exploration of BIM as a methodological approach. Moreover, there is a need to develop standardized guidelines for BIM modeling, enhanced OpenBIM tools to improve interoperability, and the exploration of ontologies and machine learning for optimized data exchange. The research recommends a broader approach to address technical aspects for successfully integrating BIM in building energy assessments within the Brazilian context.

Palavras-chave: building information modeling, BIM, Brazilian Building Labeling Program, PBE Edifica.

Resumo

Este estudo apresenta uma revisão da literatura sobre a integração da Modelagem da Informação da Construção (BIM) no âmbito do Programa Brasileiro de Etiquetagem de Edificações (PBE Edifica), destacando desafios e lacunas de pesquisa. Os benefícios do BIM na extração, automação e visualização de dados no contexto do PBE Edifica foi exposta. Os desafios incluem a falta de práticas padronizadas para a integração do BIM com o Building Energy Modeling (BEM), questões de interoperabilidade e a exploração limitada de padrões como o Industry Foundation Classes (IFC). Os desafios identificados envolvem disparidades nos resultados de simulação, preocupações com a confiabilidade do modelo BIM para avaliações energéticas e complexidades nas exportações BIM-BEM. Futuras pesquisas devem investigar as complexidades das ferramentas BIM, compreender a sintaxe e semântica dos dados, e aderir às diretrizes de modelagem. O estudo destaca a conexão entre o processo de projeto e a eficiência energética, destacando o uso do BIM como abordagem metodológica. Recomendações incluem o desenvolvimento de diretrizes padronizadas para modelagem BIM, adesão ao OpenBIM para ampliar a interoperabilidade, e a exploração de ontologias e aprendizado de máquina para otimizar a troca de dados. Sugere-se uma abordagem mais ampla para lidar com aspectos técnicos na integração bem-sucedida do BIM em avaliações energéticas de edificações no contexto brasileiro.

Keywords: *modelagem de informação da construção, BIM, Programa Brasileiro de Etiquetagem de Edificações, PBE Edifica.*

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LFM1: conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualization, writing – original draft, writing – review and editing. **LG2:** conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualization, writing – original draft, writing – review and editing. **APM3:** supervision, writing – review and editing.

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Introduction

The building sector consumes 35% of the world's energy and is responsible for emitting 38% of carbon dioxide (CO2) (Unep, 2020). Considering the UN's sustainable development agendas and objectives, immediate actions are required to reduce the environmental impacts of buildings.

Certifications and energy efficiency labels in buildings are public policies adopted in several countries to expand sustainable building stocks and mitigate the environmental impacts of the construction sector (Harter *et al*., 2020).

In Brazil, the government has created the Brazilian Building Labeling Program (PBE Edifica) and the National Energy Conservation Label (ENCE). The ENCE verifies the energy efficiency class of buildings based on a system that ranges from "A" (i.e., more efficient) to "E" (i.e., less efficient) (INMETRO, 2022). The ENCE classification is obtained through technical quality regulations (RTQs) and normative instructions from Inmetro (INIs), guidelines for evaluating and classifying the energy efficiency of buildings (Brasil, 2013; INMETRO, 2022).

The government has shown interest in making the ENCE compulsory, given the Normative Instruction No. 02/2014, which requires federal public buildings and retrofitted old buildings to obtain the ENCE class A energy efficiency rating (Brasil, 2014). By 2035, labeling may become mandatory for all new buildings in Brazil (EPE, 2020).

Energy labeling promotes information transparency, enhances society's awareness of energy efficiency, assists consumers in making decisions regarding the purchase or rental of a property, and increases sustainable building stocks (Li; Kubicki; Guerriero; Rezgui, 2019).

One way to assess energy efficiency is by Building Energy Modeling (BEM), which involves the use of energy simulation tools capable of estimating the energy consumption and energy performance of a building. BEM tools provide results that are closer to reality but require many inputs (e.g., construction systems, climate, equipment, usage patterns, among others), demanding a considerable amount of time to execute the BEM model and multidisciplinary knowledge from the user (Hensen; Lamberts, 2019).

Several studies have proposed simplified calculation models for the Brazilian Building Labeling Program to make the assessment faster and more accurate (Carlo, 2008; Melo, 2012; Versage, 2015; Mazzaferro, 2021). These proposals, although simplified, still require a significant amount of project data, which, in many cases is more complex to obtain from the projects (Gomes, 2017). Manual data acquisition is a problem in energy labeling because human interference in the process affects data quality, increases the time of the process, and widens the gap between the performance presented on the label and the actual performance of the building (Hårsman; Daghbashyan; Chaudhary, 2016).

In Brazil, several difficulties are reported in the labeling process, such as a large amount of data required for evaluation; detailing errors and omissions of project data; difficulty in obtaining specific properties of construction systems; high time demand; potential for human errors in the process; lack of media exposure for labeling; and insufficient enforcement of Normative Instruction No. 02/2014 (Gomes, 2017; Ohlweiler *et al.,* 2019; Muta, 2022).

The mentioned aspects hinder the dissemination of labeling in the country. Partially, these challenges originate during the design process. The conventional design process is based on two-dimensional (2D) documentation and is characterized by fragmented phases (Sacks; Eastman; Lee; Teicholz, 2018). Communication between design teams is limited, requiring more effort and time to transmit all the information. There are many manual steps, and information technology needs to be more utilized, leading to errors and omissions of data during the design process (Soliman Junior; Baldauf; Formoso; Tzortzopoulos, 2018).

Design flaws are propagated until the energy efficiency evaluation, one of the last stages performed (Oliveira, 2019). Energy efficiency should be considered in the early design phases, but for that to happen, the project needs to be integrated (Gerrish *et al*., 2017).

Building Information Modeling (BIM) emerges as a methodology, comprising technologies, people, and processes, capable of enhancing collaboration and flaws throughout the project (Sacks; Eastman; Lee; Teicholz, 2018). BIM tools enable the creation of digital representations of buildings, including various technical and construction-related information inherent to the building (Kim; Asl; Yan, 2015).

In Brazil, using BIM in public works has been encouraged since 2021, according to Law No. 14.133/2021 (Brasil, 2021). Considering Normative Instruction No. 02/2014 and Law No. 14.133/2021, it is evident that labeling and the use of BIM potentially converge in the realm of federal public buildings.

The use of BIM by designers in the country has grown recently, benefiting the civil construction industry. However, there is still room for improvement in energy efficiency (Boldrini, 2020). One significant challenge in building labeling in Brazil is the lack of awareness among designers about labeling requirements (Gomes, 2017; Boldrini, 2020). Moreover, the adoption of BIM in Brazil encounters obstacles, ranging from company organizational structures to challenges in establishing government norms and requirements (Arrotéia; Freitas; Melhado; 2021).

Given the presented context, the following questions have been raised: "What are the difficulties and limitations observed in BIM application in PBE Edifica labeling?"; "What are the most commonly used workflows in the application of BIM/BIM-BEM in PBE Edifica labeling?"; "What are the existing research gaps between BIM and PBE Edifica labeling?".

This research reviewed BIM application in the PBE Edifica labeling. The benefits, limitations, and gaps and the BIM/BIM-BEM workflows were identified. The aim of the review was to present the existing knowledge in the literature to support the development of future research in the field.

Method

Bibliographic research was carried out to gather scientific information from studies involving the use of BIM in the Brazilian Building Labeling Program. The labeling process is carried out based on the following regulations and normative instructions:

- Technical Regulation of Quality for the Energy Efficiency Level of Commercial, Service, and Public Buildings (In Portuguese: Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas – RTQ-C);
- Technical Regulation of Quality for the Energy Efficiency Level of Residential Buildings (In Portuguese: Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Residenciais – RTQ-R);

- Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Service, and Public Buildings (In Portuguese: Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas – INI-C);
- Inmetro Normative Instruction for the Energy Efficiency Classification of Residential Buildings (In Portuguese: Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações - INI-R).

The method used in this study was an integrative literature review, which sought to synthesize and analyze the knowledge already produced on a specific topic and evaluate the relevance of the methods employed (Botelho; Cunha; Macedo, 2011).

The method comprises five steps: formulating research questions, sampling the literature, evaluating selected documents, analyzing data, and presenting findings and discussions. The research questions were presented in the Introduction section.

The literature sampling was based on organized search criteria, from a string that included BIM and terms related to the labeling process in the Scopus index: ("BIM" OR "Building Information Model*" OR "Modelagem da Informação da Construção") AND (“Brazilian Energy Labeling” OR “Etiquetagem PBE Edifica” OR "INI-C" OR "INI-R" OR "RTQ-C" OR "RTQ-R").

The search was limited to Portuguese or English publications, including journals, conferences, specialization final projects, master’s theses, and doctoral dissertations. The inclusion criterion for the documents was the use of BIM in the Brazilian labeling process. The exclusion criteria included publications that merely cited BIM or aspects of the Brazilian Building Labeling Program, or those that addressed other labeling systems or methodologies.

The search on Scopus resulted in one paper that met the inclusion criteria. The bases were expanded to include Google Scholar and the repositories of universities and federal institutes that present programs in BIM and energy efficiency in buildings. It is worth noting that, unlike Scopus, Google Scholar does not allow filtering the search by title, abstract, and keywords separately. The search can be conducted on the entire document or the title only. Since filtering by title is too restrictive, a search of the whole document was made.

The search returned 538 publications, of which 28 were approved. Due to the search filter covering all the documents, most of the resulting publications only cited BIM and aspects of the Brazilian Building Labeling Program. There was an exception regarding the search filter; Pereira (2022) – undergraduate thesis – was included in this review because it constitutes the complete work of Pereira and Andrade (2021).

The 28 approved publications were read in full and categorized according to the specific use of BIM in the Brazilian Building Labeling Program. Three primary categories were identified, which are as follows: BIM as a data extraction tool for labeling, BIM and programming for labeling, and BIM-BEM for labeling.

The category BIM-BEM for labeling was subdivided into three categories, given the variety of BIM-BEM tools and workflows:

- Direct Integration (i.e., the link between BIM and BEM tools occurs through add-ons or APIs, for example, Autodesk's Revit and Insight).

- Direct Export (i.e., from exporting a BIM model to a BEM tool, for example, exporting gbXML[1] from Revit to DesignBuilder).
- Indirect Export (i.e., the link between BIM and BEM tools depends on an intermediate file conversion tool or process, for example, converting Revit's IFC[2] to IDF using OpenStudio and importing it into EnergyPlus).

The raised publications and the bibliometric analysis were both presented in the discussion section.

Energy efficiency labeling of buildings in Brazil

The discussions on energy efficiency began in the 1980s and culminated in the creation of the Brazilian Labeling Program (PBE). However, the most significant measures for buildings emerged after the energy crisis in 2001 (Altoé *et al*., 2017). Law 10.295/2001 and Decree 4.059/2001 established the maximum energy consumption levels and minimum energy efficiency levels for machines, equipment, and buildings in Brazil (Brasil, 2001).

In 2003, the National Program for Energy Efficiency in Buildings (Procel Edifica) was established, aiming to promote the conservation and efficient use of natural resources in buildings reduce waste and environmental impacts. The merger of PBE and Procel Edifica led to the creation of the Brazilian Labeling Program for Buildings (PBE Edifica).

PBE Edifica covers energy efficiency labeling of buildings through the National Energy Conservation Label (ENCE). The classification presented in ENCE considers the performance of the building envelope, lighting, air conditioning, and water heating systems. ENCE also provides information on renewable energy generation, rational water use, and carbon dioxide emissions (INMETRO, 2022). It can be issued in the design phase and in the constructed building stage, delimited by residential, commercial, public and service buildings (Brasil, 2022). To obtain the ENCE, the project and the constructed building must be inspected by an Inspection Organization Accredited (OIA) by Inmetro. The OIA uses the Technical Regulations for Quality (RTQs) or the Inmetro Normative Instructions (INIs) to determine the ENCE classification (INMETRO, 2022).

The RTQs were the first documents to present requirements and procedures for evaluating the energy efficiency classification of buildings in Brazil. The RTQ-C, published in 2009, provides guidelines for assessing commercial, service, and public buildings; and the RTQ-R, published in 2010, provides guidelines for assessing residential buildings (INMETRO, 2013). The RTQs present two evaluation methods: prescriptive, a simplified calculation model based on the application of equations and tables; and a simulation, which employs computational simulation tools to estimate the energy consumption of the building (INMETRO, 2013).

The simulation method provides results closer to reality but requires various design, construction, climate, and building use data, as well as specialized simulation professionals, and demands a significant amount of time to be completed (Hensen; Lamberts, 2019). To simplify the evaluation, research was conducted to create a simplified calculation method based on the statistical technique of multiple linear regression, capable of assessing the thermal performance of building envelopes, which

[1] gbXML is an open data schema used for transferring information from BIM to energy analysis (Bahar; Pere; Landrieu; Nicolle, 2013).
[2] The Industry Foundation Classes (IFC) is a non-proprietary universal protocol, certified by BuildingSmart, for exchanging data between different applications, compatible with most software in the market (BuildingSmart, 2022).

gave rise to the prescriptive approach of the RTQs. The prescriptive method was developed through simplifications and assumptions regarding climate, usage patterns, occupancy, and building type (Carlo; Lamberts, 2010a, 2010b).

PBE Edifica offers complementary materials that assist in the application of the prescriptive method of RTQ-C and RTQ-R. Among these materials, WebPrescritivo stands out, an online interface that adopts the guidelines of RTQ-C to verify the hypothetical ENCE classification based on inputs provided by the user. For RTQ-R, there is a spreadsheet that calculates the energy efficiency of the housing unit based on user-entered data. The prescriptive method requires less time to be applied compared to the simulation method. Moreover, the simplifications and assumptions made while creating it led to discrepancies between the results of those methods. The results obtained through the prescriptive approach may diverge by up to 60% from the results obtained through computational simulation (Melo *et al.,* 2014).

Many studies, conducted by Procel Edifica in partnership with the Brazilian Center for Energy Efficiency in Buildings (CB3E), have been carried out in recent years to bridge the gap between the results of the prescriptive and computational simulation methods. In 2022, Ordinance No. 309/2022 was published, establishing the Normative Instructions (INIs) that present updated procedures for evaluating and classifying the energy efficiency of commercial, service, and public buildings (INI-C) and residential buildings (INI-R) (INMETRO, 2022).

The INIs include both the simulation and simplified methods, replacing the prescriptive approach of the RTQs. The simplified form in the INIs is based on simplified calculation metamodels to predict the thermal load of the analyzed buildings (INMETRO, 2022). The statistical method adopted in the development of the metamodels was Artificial Neural Networks (ANN), which resulted in discrepancies of less than 1% compared to the computational simulation method (Melo *et al*., 2016).

Despite the advancements in energy efficiency assessment, some studies have shown difficulties in applying the methods of RTQs and INIs (Gomes, 2017; Leite; Hackenberg, 2020; Muta, 2022). The data acquisition process is laborious and time-consuming, and the fragmented stages of the conventional design process exacerbate the situation (e.g., 2D documentation, and communication gaps). In this context, the BIM methodology can represent a paradigm shift in project development, benefiting the energy efficiency discipline.

Building Information Modeling

Building Information Modeling (BIM) can have different definitions. This work relies on the concept defined by Sacks, Eastman, Lee and Teicholz (2018), in which BIM is characterized as the integration of modeling technology, processes, and people to produce, communicate, and analyze virtual construction models. BIM models can combine design with construction, manufacturing, assembly, management, maintenance, energy performance monitoring, retrofit, and the building's lifecycle information. Information is inputted into the models, optimizing time through automated modeling processes, as observed in research dating back over 20 years (Bazjanac, 2001). Costs related to building facilities and operations are also reduced when decisions are collectively made in the early stages of the project (Gao; Koch; Wu, 2019).

Despite the capacity to enhance the construction of buildings with reduced costs, BIM projects require paradigm shifts for companies, encompassing changes in processes, technologies, and individuals. The paradigm shift is a process that presents some obstacles. In both developed and developing countries, the main barriers to BIM implementation are similar and relate to the unavailability of standards and guidelines, lack of BIM training, shortage of qualified personnel, high implementation costs, and lack of BIM research and implementation, interoperability issues, organizational concerns, and, in some cases, a lack of national standards (Liu; Xie; Tivendal; Liu, 2015; Criminale; Langar, 2017; Manzoor *et al.,* 2021; Othman *et al*., 2021; Arrotéia, Freitas, Melhado, 2021). These barriers are associated with the company and its organization and are related to the design process. However, this scenario has been undergoing recent changes due to the actions of government agencies, as well as the industry, which have resorted to standardization and standard rules for the use of BIM.

Several decrees were enacted in Brazil within the scope of the BIM BR Strategy (Brasil, 2018), whose purpose is to promote an environment suitable for BIM investment and its dissemination in the country. One of these decrees is Federal Decree No. 10.306, which ensures BIM's direct or indirect use in federal public works and civil engineering services. The Brazilian Association of Technical Standards - ABNT - also defined a set of technical standards related to BIM, including requirements for modeling objects, guidelines for libraries, system classification, and information management in construction.

In Brazilian academia, groups of professors and students from various educational institutions carried out actions for digital transformation based on a Curricular BIM Implementation Plan (PIBc). Through a public call, the Built Environment Technology Association (ANTAC) multiplied the number of BIM cells created in the country. The ANTAC BIM Cells Network presented partial results that demonstrate a significant potential for understanding BIM Maturity in education and the latent capacity for incorporating BIM into the undergraduate courses in Architecture and Urbanism, and Civil Engineering (Ruschel; Ferreira, 2022).

Despite the progress, there still needs to be more knowledge about the use of BIM in collaborative processes by designers and other users in the early stages of construction projects (Miettinen; Paavola, 2014). According to Barison and Santos (2016), the BIM workflow in Brazil has emerged differently from the North American model, where the architect manages the entire workflow. In Brazil, developers or clients usually appoint a project coordinator who may also act as a BIM manager, or there may be a specific person for this role. The BIM manager is typically a consultant who assists in implementing BIM within companies. Design offices also have a model manager who coordinates their discipline, modeling guidelines, and tools.

In the Brazilian context, the ideal process for developing BIM models using federated models (i.e., models from each discipline linked to a single integrated/federated central model) begins by organizing project survey data. In this initial stage, the architect, the project owner, and the BIM manager gather to organize the data, project schedules, initial cost information, and project requirements to determine the team of designers and tools to be used. The architect then develops the conceptual model and conducts the feasibility study. Then, the stakeholders decide on the project's structure and specificities (Barison; Santos, 2016). According to this organization, this stage appears to be an opportune moment for including energy simulations of the project, which can help choose the best solutions with the possible reduction of energy consumption. After this stage, the preliminary design phase would follow, involving analyzing processes and formalizing a product.

Some methodologies have attempted to describe the design processes and include energy simulations or environmental sustainability requirements. Stipo (2015) gathered data from several design offices in different parts of the world, aiming to standardize aspects or subprocesses of their sustainable design methods. Despite the small sample size, similarities were identified among them, suggesting a possible generalization. The author proposed a flexible design model for designers to achieve project sustainability. Unlike Barison and Santos (2016), the author refers to creating a conceptual design model for initial energy simulations. Additionally, it is indicated that the design will be refined with detailed energy simulations, and subsequently, construction documentation will be generated, accompanied by a BIM coordination process.

Including Building Information Modeling in processes requiring energy simulation, such as the Brazilian Building Labeling Program, can bring significant benefits. These benefits include the accuracy and consistency of results, identification of project opportunities, reliability resulting from data integration, cost and waste reduction, and facilitating the maintenance and operation of buildings.

BIM in Brazilian Building Labeling Program

This section presents the selected research in the integrative review, organized according to the type of BIM application in the Brazilian Building Labeling Program. Study that considered BIM tools for optimizing building energy performance and subsequent labeling was also considered.

The computational simulation process for the Brazilian Labeling Program requires the construction of a BEM model for thermal load prediction. BIM models already contain most of the information needed for BEM models, such as location data, geometry, materials, thermal properties, electrical systems, and HVAC (Pinheiro *et al.,* 2018). The obtained information can be used in various ways, for example, for thermal-energy analysis, data systematization, visualizations, and interoperability with other software (Dubljevi´c; Tepavcevi´c; Markoski.; Anđelkovi, 2023).

It is essential to ensure that models are shared in a standard structure for reading and writing, using the same file formats and protocols. The concept of interoperability refers to the ability of different computational systems to exchange data, streamlining the workflow and eliminating the need to manually copy information generated by other programs (Sacks; Eastman; Lee; Teicholz, 2018).

BIM as a tool for data extraction

BIM is frequently regarded as a tool for extracting the necessary data in the Brazilian Labeling Program. Researchers adopting this approach conduct exploratory studies to analyze the potential of BIM in data extraction and apply workflows, as well as templates, in case studies to evaluate the proposed procedures (Oliveira *et al.,* 2011; Wollz Netto, 2015; Ohlweiler *et al.,* 2019; Serra; Filho, 2019; Muta *et al.,* 2022).

Oliveira *et al.* (2011) propose a BIM workflow for evaluating the building envelope using the prescriptive method of RTQ-C. The authors used Revit, applied the BIM workflow in a case study, and compared it with the traditional CAD workflow. It was found that the BIM workflow reduced the time to evaluate the building envelope by 21 times. Wollz Netto (2015) and Serra and Filho (2019) conducted similar works. However, Wollz Netto (2015) considered the guidelines of the prescriptive method of RTQ-R, and Serra and Filho (2019) incorporated the WebPrescritivo into the workflow.

Ohlweiler *et al.* (2019) explored the potential of Revit in extracting the necessary data for evaluating the building envelope using the prescriptive method. Data required for the building envelope assessment were extracted from a case study. The quality of the extracted data was analyzed in a sample study involving 29 Architecture and Urbanism students. The building envelope classification, calculated using the data from the Revit program, coincided with the results from the CAD program.

Muta *et al.* (2022) conducted an exploratory study as did Ohlweiler et al. (2019) but considered the evaluation of the building envelope using the simplified method of INI-C. All the data were obtained and applied in the metamodel to classify the building envelope. The energy assessment using Revit was possible, however, the authors state that data extraction is not the critical point between BIM and Brazilian Building Labeling Program. The main aspect lies in the minimum requirements and guidelines adopted in the construction of the BIM model, which impact the energy evaluation process.

Even with limited use for data extraction, the use of BIM is advantageous for energy efficiency. 3D models facilitate the visualization of geometric details, construction information can be automatically extracted and applied in spreadsheets, web interfaces, or metamodels, and design disciplines can be integrated into a central BIM model, streamlining the decision-making process that impacts the building's energy efficiency (Zemero, 2016; Lopes, 2019; Rosa, 2019; Santos; Salgado, 2019; Muta *et al.*, 2022).

Zemero (2016) used Revit to develop a BIM model, integrating architectural, electrical, hydro-sanitary, and HVAC projects. The project considered sustainability principles, and the energy assessment was conducted using the prescriptive method of RTQ-C with the application of WebPrescritivo. Lopes (2019) and Rosa (2019) showed similar research to Zemero (2016) but focused on existing federal public buildings.

Santos and Salgado (2019) used ArchiCAD to automatically verify natural ventilation requirements specified in RTQ-R. The approach was based on verification rules created from tables with model information. The authors state that automating requirements enables selecting the best design solutions.

Muta et *al.* (2022) presented modeling requirements and guidelines for developing BIM models, focused on evaluating the building envelope using the simplified method of INI-C. The procedures were devised in an exploratory study and applied in a case study. The required data for the building envelope assessment were obtained from a table generated by a Revit template. The data were exported from Revit and entered into the metamodel to create the building envelope classification.

Use of scripting/programming

Some of the works in this research addressed the integration of BIM with energy efficiency evaluation using programming to partially or fully automate the assessment and labeling process.

Boldrini (2020) presents a proposal for a web interface layout based on user experience design to assist in evaluating the simplified method of INI-R. Based on a survey of the work experience in architectural offices, a user-friendly interface proposal capable of integrating files in open formats (i.e., IFC and gbXML) and evaluating energy efficiency was presented. The author does not suggest programming languages for building the tool and needs to consider the challenges of incorporating two distinct standards as IFC and gbXML.

Teixeira (2018) developed a web interface capable of evaluating the building envelope using the prescriptive method of RTQ-C. The interface was designed in the Hypertext Preprocessor (PHP) language and managed by SQL Server Express, which functions by importing data from Revit. The interface was integrated with a database that allows access to the quantitative tables generated in Revit. For the classification to occur, it is necessary to manually select the available options for lighting and air conditioning systems on the interface. The work was also published in a national journal (Teixeira, Pellanda; Reis; Micelli Júnior, 2018).

Oliveira (2022) developed a script using the visual programming language (VPL) with Dynamo software, integrated with Revit, to address the evaluation of the simplified method of INI-R. The workflow depends on a template that generates nomenclatures for building components and provides a standard project sheet, organizing the results and levels of energy efficiency on a color scale. The tool consists of several scripts that must be executed sequentially to reduce processing time.

Oliveira (2019) also used VPL with the Dynamo program to evaluate the prescriptive method of RTQ-R. The tool optimizes processing by combining Python scripts with Dynamo. The necessary data for the tool's operation are obtained through a template developed in Revit. The device was tested and validated in an extension course, in which architecture students, professors, and professionals participated. The results were compared with those calculated in the performance calculation spreadsheet available on the PBE Edifica website. There were minor differences between the results. The products were published in a national journal by Oliveira, Bittencourt and Dória (2020), and three conferences by Oliveira, Bittencourt and Dória (2019a); Oliveira, Bittencourt, and Dória (2019b); and Oliveira, Bittencourt, and Dória (2022).

Bracht (2020) developed a semi-automatic integration method between BIM and the metamodel of INI-R. Integration occurs through a tool developed by the author in Python, capable of extracting data from the BIM model in gbXML format and inserting it into the metamodel. Revit, ArchiCAD, and Building Designer were used in the tests of the proposed method. There were interoperability issues while converting the BIM model to the gbXML format (i.e., geometry failures and loss of semantic data), requiring manual corrections for the script to function correctly. The product proposed by Bracht (2020) was published in an international journal by Bracht, Melo and Lamberts (2021).

Direct integration

The publications in this section demonstrate the research that used BIM and BEM tools through direct integration.

Pretti (2018) analyzed the integration of Revit with Green Building Studio (GBS) and Insight, comparing the results of energy analyses from both tools with the results calculated using the prescriptive method of RTQ-C. There were no concerns regarding BIM-BEM interoperability, meaning the BEM simulations were completed without any issues. However, the simulation results could have been more consistent with the building's reality. This led to the conclusion that GBS and Insight offer limited possibilities for users to edit simulation parameters and rely on many standardized data, leading to inconsistencies in the results.

Lopes (2019) presented a study similar to that conducted by Pretti (2018), focusing on designing sustainable buildings in BIM. Through a case study, Lopes (2019) optimized the energy efficiency of a public building using Revit, GBS, and Insight. The building envelope's energy efficiency was evaluated based on the prescriptive method's guidelines of RTQ-C. Lopes affirms that GBS and Insight are simple energy analysis tools intended for early design stages and are not recommended for labeling due to the limited number of available simulation configurations.

Queiróz *et al.* (2019) analyzed the compatibility of Insight Lighting Analysis, integrated into Revit, in assessing natural lighting considering the guidelines of RTQ-R. It was concluded that Insight Lighting Analysis is incompatible with the criteria required by

RTQ-R because the tool's configurations and outputs are geared towards meeting LEED certification criteria.

Pimentel, Barbosa and Souza (2020) conducted a literature review on using BIM and BEM in labeling. The authors concluded that Insight and GBS are unsuitable for the Brazilian Building Labeling Program because they do not evaluate comfort through natural ventilation, which is necessary for some cases of RTQ-C and RTQ-R. There are also limitations regarding the configurations of parameters used for energy simulation, especially in air conditioning systems.

Gomes (2021) used Revit with GBS to estimate the cooling thermal load - a criterion for evaluating the building envelope using the simulation method of RTQ-R - for a set of single-family buildings. The author concluded that integrating BIM with proprietary format simulation is promising and needs to be explored but clarified that there are limitations. The simulation parameters available for editing are scarce, especially in characterizing the air conditioning system, which affects the results of the building envelope evaluation.

Pereira and Andrade (2021) conducted a preliminary study to verify if Revit and ArchiCAD, along with their respective energy analysis tools (i.e., Revit's GBS and ArchiCAD's EcoDesigner Star), meet the requirements for applying the INI-C simulation method. The authors discuss the differences in each tool and conclude that ArchiCAD and EcoDesigner Star from Graphisoft meet more requirements, but both have limitations regarding INI-C demands.

Pereira (2022) used ArchiCAD integrated with EcoDesigner Star to assess the energy efficiency of a federal public building. The tool was chosen based on a preliminary study (Pereira; Andrade, 2021). The author concluded that the simulation results were inconsistent with the building's reality but did not rule out the potential of BIM integration with BEM tools, primarily due to the range of outputs and functions available in the tools.

Direct export

The interoperability between BIM models and labeling assessment through direct export was identified in the works of Zemero (2016), Pretti (2018), Pimentel, Barbosa, and Souza (2020), and Pimentel, Barbosa, and Reis (2021).

Zemero (2016) surveyed Brazil's leading BEM software (i.e., Domus, EnergyPlus, OpenStudio, and DesignBuilder) and evaluated their integrated use between BIM design and PBE Edifica labeling for commercial buildings. The gbXML format was exported from Revit and imported into the BEM tools. DesignBuilder was the only tool capable of performing the simulation. The other software encountered errors in reading the gbXML files. Pimentel, Barbosa, and Souza (2020) also considered DesignBuilder the most suitable tool for energy simulation using RTQ-C.

Similarly to Zemero (2016), Pretti (2018) tested various solutions for BIM-BEM tool integration while evaluating a commercial building. The author's proposal involved exporting gbXML and IFC files, which were then imported into OpenStudio and IES-VE. Additionally, gbXML was imported into GBS and DesignBuilder. The tests revealed that IES-VE did not import IFC and did not simulate the imported gbXML. OpenStudio could not import any of the formats. The author compared the results of successful simulations and found differences in area values and energy consumption (i.e., lighting, equipment, and air conditioning). Information loss or recognition issues occurred in the BIM-BEM interoperability process. The DesignBuilder tool showed the most data loss during importing gbXML files, failing to recognize the HVAC system specified in Revit and doubling the building's area, which impacted the simulation results.

Pimentel, Barbosa, and Reis (2021) analyzed a building through simulation by exporting a gbXML file from the Revit program to the DesignBuilder program. The BEM model presented geometry flaws and data loss, resulting in rework. The simulation results in DesignBuilder were compared with simulations performed exclusively in the BEM domain (i.e., the building was developed and simulated directly in DesignBuilder and OpenStudio/EnergyPlus, without importing the gbXML file from Revit). The variations between the total consumption results in the three simulations were less than 1%.

Indirect export

The works of Pretti (2018) and Pimentel, Barbosa, and Souza (2020) identified the interoperability between BIM models and labeling assessment through computational simulation and indirect export.

Pimentel, Barbosa, and Souza (2020) presented a file conversion workflow from gbXML to Input Data File (IDF), which is the format used by EnergyPlus. The authors used a text editor to convert gbXML to 8-bit Unicode Transformation Format (UTF-8), and then Autodesk Ecotect Analysis was used to convert UTF-8 to IDF. The authors had to validate and correct errors in the converted model using SketchUp and Legacy OpenStudio plugin. It was concluded that this flow is not viable for the authors' context, mainly due to the software cost, training, and time required.

Pretti (2018) presented different solutions for indirect integration. GBS and Insight were used to convert gbXML from Revit to IDF and InPage Document (INP). IDF was used for simulation in EnergyPlus and OpenStudio, while INP was used for simulation in eQUEST. OpenStudio did not import the IDF, and eQUEST imported the INP but did not load the geometry data from the model. The BIM-BEM flow was incipient and had constant failures in the model's geometry and data loss. Only the EnergyPlus generated from gbXML conversion through GBS provided coherent results, but the IDF file required manual adjustments. All area values presented by the BEM tools diverged from each other and the original BIM model.

Discussions

This section discusses the research papers that addressed the use of BIM to support the labeling process. The survey considered works published in journals, theses and dissertations, specialization final papers, conference papers, and an undergraduate thesis. The quantity of documents, the authors, the research database, and the type of publication are presented in Table 1.

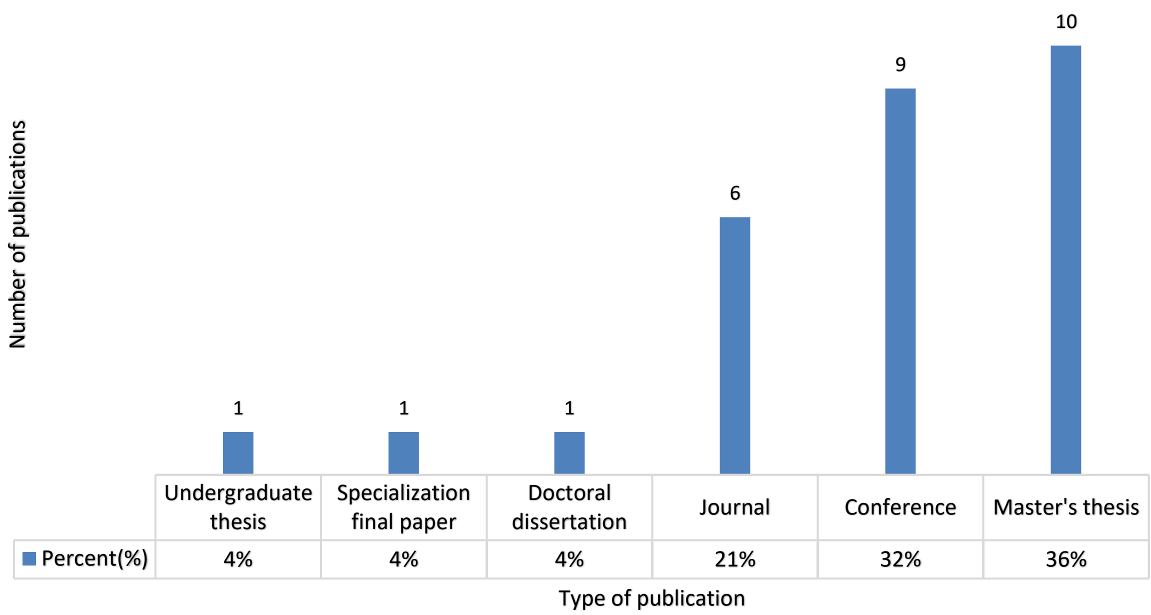
Most of the publications were master's theses (10), followed by conference papers (9). There is one doctoral dissertation, one specialization paper, and six works in journals (Figure 1). It was noted that there was a significant number of publications from the same authors, referring to the same doctoral dissertation. The low number of publications found in the research area (28) indicates a gap for further research.

Table 1 – Works that contain BIM applied to the Brazilian Building Labeling Program

Type of document	Reference	Classification
Conference	(Oliveira *et al.*, 2011)	data extraction
Specialization final paper	(Wollz Netto, 2015)	data extraction
Master's thesis	(Zemero, 2016)	data extraction; direct export
Master's thesis	(Pretti, 2018)	direct integration; direct export; indirect export
Master's thesis	(Teixeira, 2018)	scripting/programming
Journal	(Teixeira; Pellanda; Reis; Miceli Júnior, 2018)	scripting/programming
Conference	(Santos; Salgado, 2019)	data extraction
Conference	(Queiróz *et al.*, 2019)	direct integration
Conference	(Oliveira; Bittencourt; Dória, 2019a)	scripting/programming
Conference	(Oliveira; Bittencourt; Dória, 2019b)	scripting/programming
Conference	(Ohlweiler *et al.*, 2019)	data extraction
Master's thesis	(Lopes, 2019)	data extraction; direct integration
Master's thesis	(Rosa, 2019)	data extraction
Journal	(Serra; Filho, 2019)	data extraction
Doctoral dissertation	(Oliveira, 2019)	scripting/programming
Master's thesis	(Boldrini, 2020)	scripting/programming
Master's thesis	(Bracht, 2020)	scripting/programming
Journal	(Pimentel; Barbosa; Souza, 2020)	direct integration; direct export; indirect export
Journal	(Oliveira; Bittencourt; Dória, 2020)	scripting/programming
Conference	(Pereira; Andrade, 2021)	direct integration
Master's thesis	(Gomes, 2021)	direct integration
Journal	(Bracht; Melo; Lamberts, 2021)	scripting/programming
Journal	(Pimentel; Barbosa; Reis, 2021)	direct export
Conference	(Oliveira; Bittencourt; Dória, 2022)	scripting/programming
Conference	(Muta *et al.*, 2022)	data extraction
Master's thesis	(Oliveira, 2022)	scripting/programming
Master's thesis	(Muta, 2022)	data extraction
Undergraduate thesis	(Pereira, 2022)	direct integration

Source: the authors.

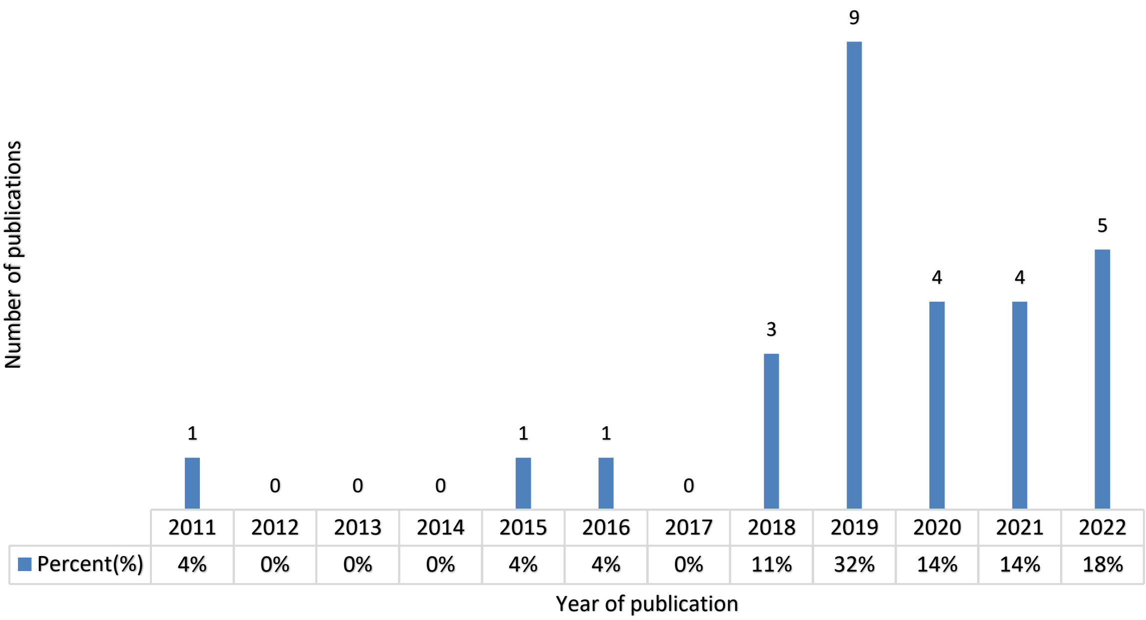
Figure 1 – Database survey



Source: the authors.

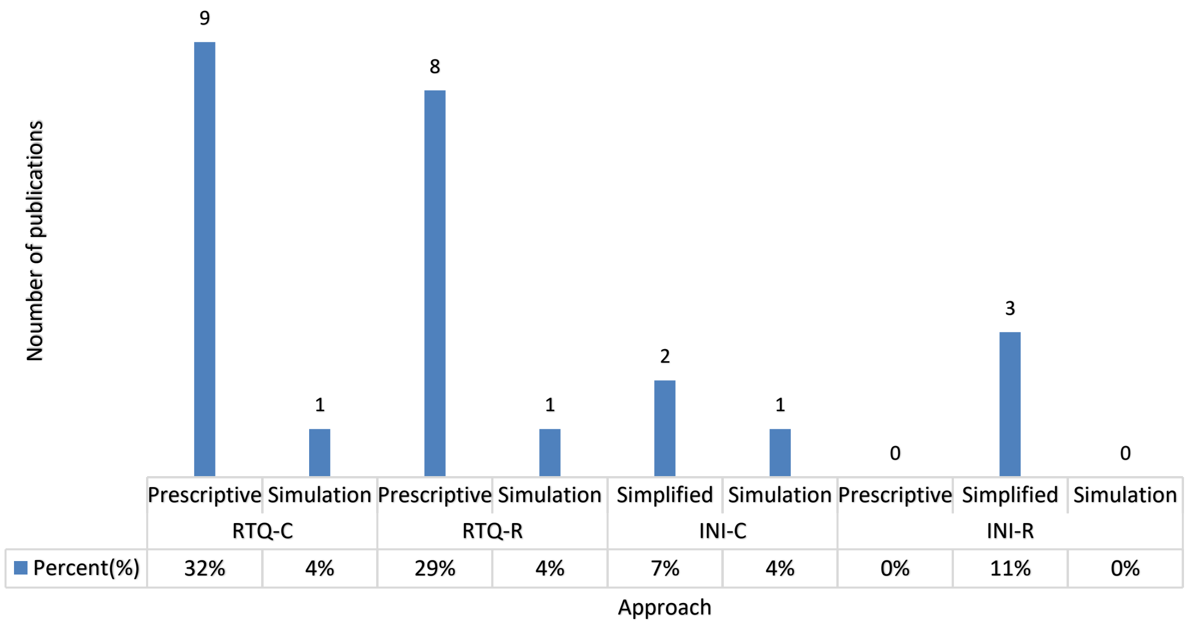
According to the survey (Figure 2), 46% of the research papers were published in 2020, 2021, and 2022, and only 21% applied the INIs, with 50% focused on INI-R and the other 50% on INI-C (Figure 3), demonstrating difficulties due to the recent update of the new Brazilian Building Labeling Program's procedures. The survey also revealed that only three publications (11%) applied the simulation method (Figure 3). However, only one of the studies compared the BIM-BEM simulation with the simulation performed exclusively in the BEM tool to validate the results.

Figure 2 – Database according to the year



Source: the authors.

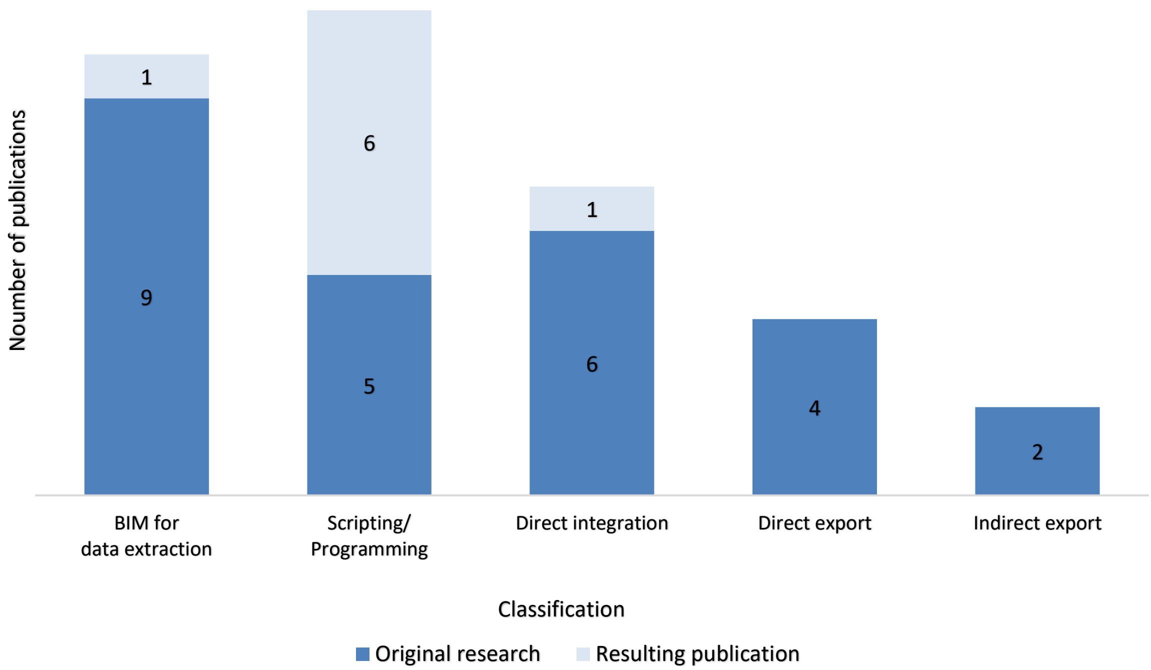
Figure 3 – Number of works using the labeling process according to the approach



Source: the authors.

Regarding the classifications proposed by this research, the most significant number of publications belongs to the category of works that used scripting or programming to partially or fully automate the evaluation and labeling process. However, initially, five research papers resulted in other publications from the same researchers. Figure 4 shows the number of research papers per classification, distributed in bars. The dark colors within each typology indicate the number of original research papers, and the light colors represent the resulting publications from the original research.

Figure 4 - Number of works using the labeling process according to the classification



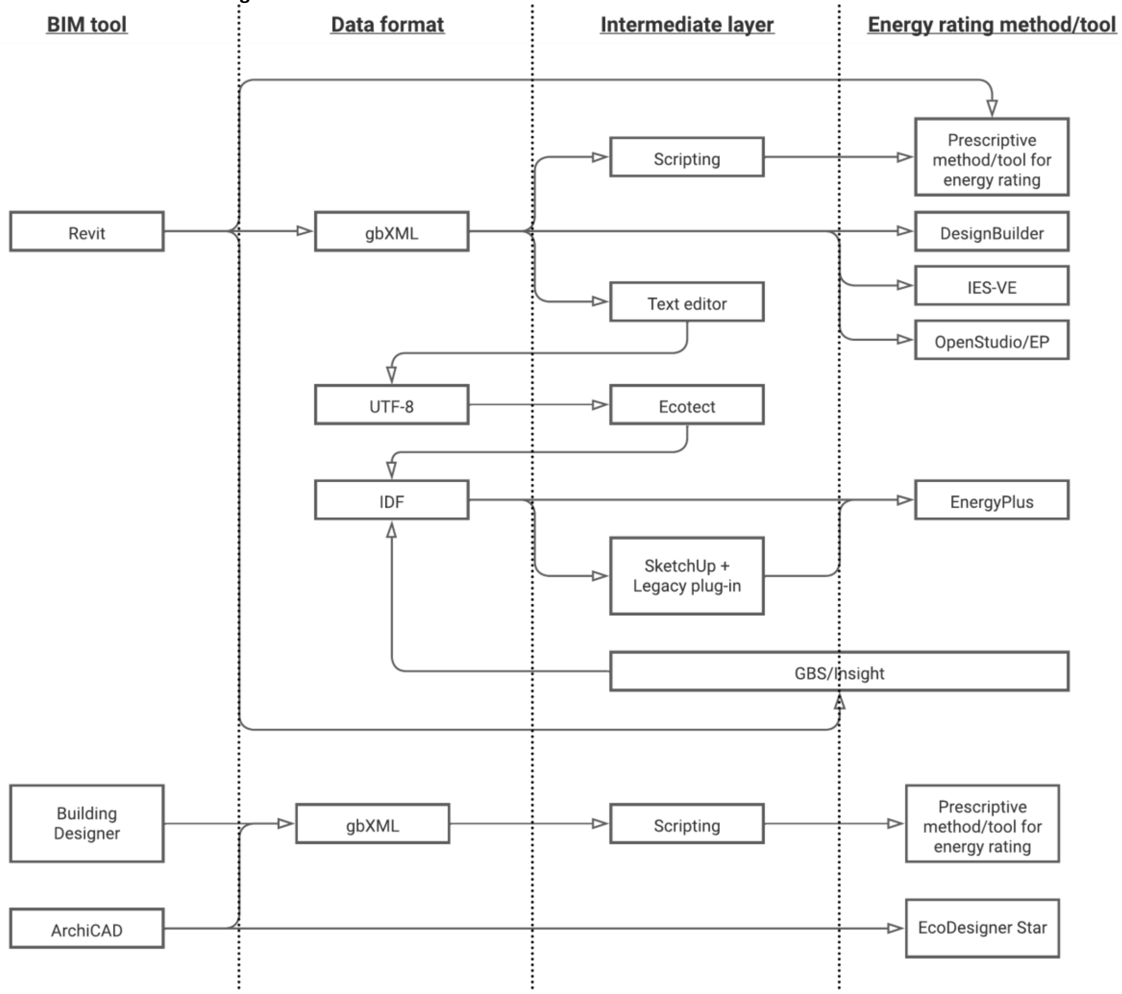
Source: the authors.

The workflow patterns identified in the literature are presented in Figure 5. The structure of the flowchart is divided into four columns. First, the "BIM tool" shows which proprietary BIM tool was used. Second, "Data format" demonstrates the type of file format used in the workflow. Some research did not convert the BIM file into another data format (e.g., exporting the native Revit file to gbXML). Third, the "Intermediate layer" shows the tools/processes used between the BIM domain and the energy efficiency assessment (e.g., developing a script for automatically extracting data from the BIM model). Fourth, the "Energy rating method/tool" presents the set of methods/tools used for energy efficiency assessment (e.g., adopting a prescriptive calculation tool that performs energy efficiency classification based on data from the BIM model).

The box labeled "Prescriptive method/tool for energy rating" refers to the tools and methods used for evaluations by the prescriptive and simplified methods of RTQs and INIs (i.e., calculation spreadsheets, web interfaces, and metamodels). The box labeled "GBS/Insight" occupies two columns of the flowchart because there are two distinct uses: as a tool for energy analysis or as an intermediate application for converting the BIM model into an IDF file.

The prevalent use of BIM for data extraction streamlines the labeling process and brings benefits, including process automation and enhanced visualization. A crucial step is complying with minimum requirements and guidelines for constructing the BIM model. The effectiveness of data extraction relies on accurate adherence to these guidelines, emphasizing the importance of proper modeling practices for reliable and meaningful building assessment. Notably, only a single surveyed study analyzed the need for standardization and establishing minimum requirements and guidelines within BIM modeling for the labeling process.

Figure 5 – BIM - PBE Edifica labeling workflow identified in the literature review



Source: the authors.

Scripting and programming for BIM integration with the Brazilian Building Labeling Process indicate a move towards automated approaches. Researchers used various methods, such as web interfaces and diverse programming languages, revealing flexibility and interoperability challenges due to the lack of standardized practices. Validation methods vary across studies, showing a commitment to ensuring tool practicality. Despite promising advancements, the field faces standardization, interoperability, and ongoing tool refinement challenges. This wide range of approaches reflects the evolving interdisciplinary nature of the field, providing opportunities for future developments. As BIM integration with energy assessment progresses, the field remains dynamic, requiring efforts to address challenges and establish common frameworks for continued advancement.

Publications using BIM for data extraction and scripting/programming aligned with the prescriptive and simplified methods of the Brazilian Building Labeling Program have achieved success in obtaining energy label classifications. However, the absence of identified processes for model auditing in the assessed models raises concerns about the accuracy of the evaluation results.

BIM-BEM integration is underexplored, whereby most publications rely solely on proprietary software for data acquisition. The predominant choice for architectural modeling is Autodesk Revit, evident in 24 out of 28 research papers. Graphisoft Archicad is used in only four, while AECOsim Building Designer is used in two studies. The choice of software does not have defined criteria of superiority. Notably, Bracht, Melo and Lamberts (2021) demonstrate greater reliability in Archicad compared to other options. The preference for Revit is driven by its market dominance, coupled with the availability of materials and training, highlighting its influence in shaping choices within the field.

The studies reveal recurring themes and challenges associated with the direct integration of BIM-BEM. In general, seamless interoperability, leads to promising outcomes when employing direct integration of BIM-BEM. However, certain studies highlight disparities between simulation results and actual building performance, attributing these differences to restricted user control over input data for energy simulation. This approach is perceived as more suitable for early design stages rather than for in-depth energy assessments. Nevertheless, some researchers used BEM tools that do not adhere to the requirements of the simulation method, such as applying the direct integration flow with Revit-GBS or ArchiCAD-EcoDesigner Star for envelope classification. Despite these limitations, there is acknowledgment of the potential of direct integration, and ongoing efforts are required to refine BEM tools and enhance their flexibility.

The exploration of BIM-BEM direct export focuses mainly on transferring gbXML from Revit to tools, such as DesignBuilder, for energy simulations. However, challenges arise, as researchers face errors and recognition issues during gbXML import into BEM tools. Limitations in tools, such as DesignBuilder, especially in recognizing HVAC details and the risk of data loss, raise concerns about reliability. Despite DesignBuilder's consistent favorability, a comparative study revealed slight variations in total consumption results. Other studies pointed to significant challenges, including file import failures and data loss, casting doubt on the reliability of using exported BIM models for energy assessments. Reports of geometry flaws and data loss underscore the need for procedural improvements. While some studies report consistent results, differences in values raise doubts about exported BIM models' reliability. The contradictions reinforce the narrative of the need to standardize BIM modeling procedures. The modeling becomes flexible due to the scarcity of standards, requirements, guidelines, or specific norms for the workflow in the research area. The findings highlight the need for refinement in the export process to enhance reliability and accuracy.

Studies exploring BIM-BEM indirect export methods, for example, converting gbXML into IDF and INP formats, reveal workflow complexities and practicality concerns. Including additional software adds layers of complexity, raising doubts about the viability of such workflows due to software costs, training, and time implications, especially when not supported by standards or OpenBIM tools. Challenges even more severe than direct export emerge, including constant failures in model geometry, data loss, and divergent area values among BEM models and the original BIM model, questioning the accuracy and reliability of results. The identified issues, encompassing software dependencies and data integrity, emphasize the necessity for careful consideration and refinement before widespread adoption of indirect export approaches in practical applications. Open data formats, such as the IFC standard and gbXML, need to be fully exploited, creating a research gap.

Regarding the data exchange format, only two papers mention the universal standard IFC. In a study carried out by Pretti (2018), IES-VE software was used, but did not import the IFC format or simulate the imported gbXML. Further research is essential for a comprehensive analysis. No papers were found that leverage IFC as the standard for data exchange between BIM and BEM, despite its universal status. The overall scenario indicates the need for a deeper understanding of OpenBIM standards and tools, given the complex nature of the structure and the need for meticulously defined workflows. There are no reports on the use of ontologies, machine learning, or experimentation with more recent proprietary tools (e.g., Autodesk Systems Analysis), nor the use of BuildingSmart tools that enable the IFC standard (e.g., MVD, IfcDoc, IDS), or even BIM model auditing (i.e., geometric and information verification).

Most of the surveyed papers presented superficial analyses, particularly in evaluating BEM tools. Common issues include unexplored reasons for discrepancies in results and limitations in BEM tools, such as constrained editing options for simulation parameters and challenges in achieving smooth interoperability. While some studies hint at promising aspects of BIM-BEM integration, they often overlook significant drawbacks, such as data errors and the need for manual adjustments. These findings highlight the imperative for more comprehensive analyses to address data reliability issues and enhance the understanding of challenges in BIM-BEM integration for achieving accurate results.

In general, the studies do not address technical limitations beyond the use of tools. There needs to be more clarity between the design process and energy efficiency. Most publications that use BIM for data acquisition assume that the model will be built with the necessary information for labeling in a specific template, which is an idealistic scenario.

The Brazilian Building Labeling Program depends on the quality of information and its integration into the design process. Conventional processes that do not integrate energy efficiency become more expensive due to the time required to process data from one professional to another, leading to rework. The high cost generated by inconsistent processes results in a lack of adherence to the market's energy labeling.

Some gaps are identified, stemming from the recent introduction of BIM methodology in the market and the need for its incorporation into the curriculum of Architecture and Urbanism and Civil Engineering undergraduate programs. Other gaps may be reflected by the need for investments in technology, education, policies, and procedures to guide the professionals.

Implementing BIM requires specialized technical skills, including proficiency in BIM software, data interoperability, and awareness of evolving BIM standards. However, initial implementation costs, which encompass software, training, and transitioning from traditional workflows, may pose barriers for smaller organizations or projects. The reliability of data derived from BIM models is contingent on input data quality and adherence to established standards. Inconsistent or inaccurate data could compromise building assessments, including the PBE Edifica.

Additionally, the reviewed studies did not consider legal and contractual issues, such as ownership of BIM models and intellectual property concerns. Overcoming resistance to change from stakeholders within the construction industry and fostering a culture of BIM adoption are significant challenges. Managing sensitive data within BIM models raises concerns about data security and privacy, emphasizing the need for robust protocols to protect confidential information.

A more nuanced exploration of the identified challenges is imperative for successfully integrating BIM with the PBE Edifica. This involves addressing technical limitations comprehensively, emphasizing the crucial link between the design process and energy efficiency, and developing solutions for the identified gaps.

Conclusions

This work reviewed the literature on the application of BIM in the PBE Edifica's labeling to offer a comprehensive overview, highlighting significant contributions that inform future research. The difficulties and limitations of applying the theme and the workflows used in the application of BIM in labeling were presented.

Most of the studies used the BIM model for manual data export to comply with the prescriptive method. Some solutions were proposed for automating this workflow using scripts/programming. The evaluations are entirely dependent on the reliability of the models, which need to be adequately audited in most cases. While scripting and programming offer flexibility, the absence of standardized practices poses challenges, highlighting the need for common frameworks.

Direct integration of BIM and BEM holds promise but faces challenges related to user control over input data and disparities between simulation results and actual building performance. Examining BIM-BEM export methods, whether direct or indirect, reveals complexities and reliability concerns, emphasizing the need for procedural improvements, standardization, and enhanced export processes.

The BIM model used for the computational simulation assessments shows higher reliability due to the possibility of checking the detailed energy consumption. Moreover, it requires greater expertise in energy efficiency to identify inconsistencies in the results. The direct integration of BIM-BEM revealed the use of tools incapable of performing energy analysis for Brazilian labeling. The immediate export process mainly involves exporting the gbXML from BIM to BEM software. The indirect export process includes an intermediate step between the gbXML and the energy simulation. Both direct and indirect integrations are more costly processes as they involve more software in the process. There is a research gap for other applications that need to be addressed in the works, which use direct integration or OpenBIM workflows and programming to optimize flows in the simulation method.

The publications are focused on applying tools in case studies. There is a shortage of studies that investigate the underlying issues of labeling and how BIM/BIM-BEM will address these problems. Additionally, most of the papers do not examine the limitations of the tools and proposed solutions for interoperability issues, in many cases, not filling the gap between the design process, energy efficiency, and BIM-BEM interoperability.

The scenario indicates that projects are not developed from the perspective of energy performance and integrated processes. The late labeling process creates a gap between the data needed for energy assessment and the data and information presented in the project documentation.

The difficulties and limitations are also due to a need for more knowledge about simulation energy, simulation tools, and techniques. There is a need for a well-mapped process for BIM-BEM and the BIM model's use beyond three-dimensional modeling.

A more detailed exploration and comprehensive understanding of technical limitations, challenges, and potential solutions are imperative for successfully integrating BIM with the PBE Edifica. This involves refining tools and processes and addressing educational, legal, and cultural aspects to ensure a holistic adoption of BIM in building energy assessments.

Future studies should address the use of some direct integration tools not addressed by this research and programming used to automate processes by energy simulation, including IFC flows and OpenBIM tools uses. The absence of exploration into ontologies and machine learning presents potential areas for future research.

Most research utilizes BIM primarily as a digital model or tool, often proposing processes to prepare the model for energy simulation. What is notably lacking is a comprehensive understanding of BIM as a methodological approach. Future studies should conduct more in-depth investigations into the intricacies of the employed tools, fully grasp the syntax and semantics of the data, address information requirements, adhere to modeling guidelines, and meticulously document procedures. This would leverage the structuring of a comprehensive framework to seamlessly integrate BIM into the domain of energy labeling.

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