energies

Article

Guidelines for the Implementation of BIM for Post-Occupancy Management of Social Housing in Brazil

Maria Conceição da Costa Silva [1], Alyx Diêgo Oliveira Silva [1], Emilia Rahnemay Kohlman Rabbani [1], Luciana H. Alencar [2], George da Mota Passos Neto [2], João Pedro Couto [3,*] and Rodolfo Valdes-Vasquez [4]

1 Civil Engineering Department, Universidade de Pernambuco, Recife 50720-001, Brazil
2 Management Engineering Department, Universidade Federal de Pernambuco, Recife 50670-901, Brazil
3 Department of Civil Engineering, University of Minho, 4800-058 Guimarães, Portugal
4 Department of Construction Management, Colorado State University, Fort Collins, CO 80523, USA
* Correspondence: jpc@civil.uminho.pt

Abstract: This study presents an analysis of the potential uses of BIM for managing the maintenance and refurbishment of existing housing assets to propose thermal comfort and energy efficiency guidelines for future social housing projects in Brazil. To do so, a case study analysis of a residential development with social–environmental certification in the city of Garanhuns, Pernambuco, Brazil was performed, and a literature review on the use of BIM for residential unit maintenance was conducted. The standard house in the residential development was found to be noncompliant with the Brazilian standard for ventilation openings (NBR 15.220). Therefore, three alternative layouts were created and analyzed to meet the requirements of the standard as well as the needs of the residents. The authors recommend that socio-environmental certifiers use BIM models so that energy performance and other simulations can be carried out. The study also proposes guidelines for BIM implementation in future government housing projects. These guidelines were grouped into five categories: BIM encouragement, energy efficiency, maintenance management, user requirement management, and continuous improvement. The significance of this study is in providing a path for the gradual implementation of BIM for maintenance and post-occupancy management in the Brazilian housing program.

Keywords: energy management for maintenance; social interest housing; sustainability and energy efficiency; BIM

check for updates

Citation: Silva, M.C.d.C.; Silva, A.D.O.; Kohlman Rabbani, E.R.; Alencar, L.H.; Passos Neto, G.d.M.; Couto, J.P.; Valdes-Vasquez, R. Guidelines for the Implementation of BIM for Post-Occupancy Management of Social Housing in Brazil. *Energies* **2022**, *15*, 6802. https://doi.org/10.3390/en15186802

Academic Editors: Benedetto Nastasi and Antonis A. Zorpas

Received: 23 July 2022
Accepted: 15 September 2022
Published: 17 September 2022

1. Introduction

Improvements of the well being and living conditions of a population are directly linked to city planning [1]. However, in developing countries, cost and funding restrictions imposes limits on governments that seek to develop housing programs, creating severe housing deficits [2]. Such cost restrictions, associated with lower quality processes and projects, lead directly to occupant discomfort and to high energy consumption, thereby decreasing the quality of life for the occupants [3]. To address this issue, researchers [4] have recommended that social housing residential designs include improvements to the overall size of units, better quality facades, preservation of the environment, natural lighting, and ventilation to decrease electricity consumption.

In Brazil, the government-provided Social Interest Housing (SIH) programs aim to subsidize housing for low-income populations who do not have access to formal dwellings [5]. Between 2009 and 2019, SIH programs delivered approximately 4.6 million housing units with an approximate investment of $60.6 billion, serving various regions and user profiles [6,7]. However, the programs still have areas that can be improved. Most dwellings were built according to a standard design, requiring the residents to make modifications. Depending on climatic conditions, thermal comfort may also have been impacted, affecting energy consumption [8]. A previous analysis of the thermal performance of a standard Brazilian social housing project, carried out through simulations, showed that designs had not taken into consideration the local climatic zone where they were constructed [3,9]. These studies concluded that the predominant typology of the Brazilian habitational program would not be able to perform well across all regions of the country [3,9].

Furthermore, over the last two decades in Brazil, many problems have arisen concerning the distribution of electrical energy, with several states experiencing blackouts that harmed thousands of people and led to an economic loss of R$ 45.2 billion in the year 2001 alone, 60% of which fell on consumers in the form of higher energy tariffs [10]. This energy crisis accelerated the development of standards aimed at improving energy efficiency. For instance, in 2005, the Brazilian standard for ventilation, NBR 15.220 [11], appeared, which addressed the thermal performance of buildings in Brazilian bioclimatic zones. Subsequently, in 2013, another standard, NBR 15.575 [12], established energy performance criteria for residential building construction projects, and the National Electrical Energy Conservation Program (PROCEL) organized a classification for the energy efficiency level of residential buildings [13].

Nevertheless, Brazilian social housing projects still have not significantly improved their energy performance [8], and there is no formal post-occupancy management for social housing in Brazil. As a result, maintenance and renovation activities are, by default, the responsibility of the residents, who do not have access to tools that provide feedback regarding use, which could help improve future dwellings built by the housing program. Improving the post-occupancy energy management of social housing is, therefore, an undertaking that can benefit both the residents and society [14], resulting in more affordable energy costs and social equity [15].

In this context, maintenance and renovation activities that improve efficiency and performance become increasingly important. Several studies point out that building information modelling (BIM) is essential for managing building maintenance and renovation, as well as for analyzing a building's performance [16]. Therefore, BIM has expanded to cover the analysis of buildings throughout their entire life cycle, providing a database containing information that can be shared and used collaboratively under various approaches [17]. In addition, BIM provides accurate construction data and can be integrated with other tools that perform energy performance, cost, and schedule analyses [18]. It can then be seen as an integrated set of technologies that contribute to the management of a building throughout its life cycle [17,19]. In this way, BIM has the potential to simplify maintenance activities [18].

Since the early 2000s, countries like Finland and the United States have encouraged the use of BIM in public procurement. In Brazil, the first standard for the use of BIM appeared in 2011, NBR 15.965 [20], and only in 2018 was the National Strategy for Dissemination of Building Information Modelling published in Brazil (BIM BR Strategy) [21]. In its first phase, the incentive for BIM adoption by the Brazilian government prioritizes economic infrastructure projects and is not yet mandatory for housing projects [22]. Data on the use of BIM in Brazil indicates that little more than 9% of public agencies and 23% of construction companies used the modelling in their design processes in 2021 [23]. This indicates that having the Brazilian housing program encourage the use of BIM would help boost the use of this technology in the country.

This study, therefore, investigates three research questions: (1) How are energy efficiency, thermal comfort, and post-occupancy management currently taken into consideration in SIH programs in Brazil? (2) What are the functions and benefits of using BIM for maintenance and renovation management? And (3) which path should the Brazilian social housing program follow to be able to manage the post-occupancy phase of its projects? As such, the main objective of the paper is to analyze the current SIH program in terms of energy efficiency and thermal comfort through a case study, and then to provide research-based guidelines for the gradual implementation of BIM for maintenance and post-occupancy management in the Brazilian housing program.

The case study was conducted at a social housing development project in Garanhuns, Pernambuco, Brazil, subsidized by a government housing program. It is the first social housing development in Brazil's northern and northeastern regions to obtain the CAIXA *Selo Casa Azul* certification [24]. According to previous studies [25,26], local observation, and documentary research, approximately 90% of the houses had undergone renovation. Furthermore, almost 70% of the residents reported the appearance of pathologies, especially cracks and infiltrations, which required repairs. The residents also needed to use equipment such as fans or air-conditioning to improve comfort, resulting in increased energy costs [26].

The paper is structured as follows: Section 2 details the methods presented for the elaboration of the study. Section 3 describes the physical characteristics, climate, energy consumption, and layout of the residential units, the materials used, the perceptions of the residents, and the environmental certification of the CAIXA *Selo Casa Azul* [24] for the case study under analysis. Section 4 describes the literature review, addressing any deficiencies in the case study analysis, with the leading articles that have presented the functions and benefits of the use of BIM for post-occupancy monitoring. Section 5 discusses the results, presents suggestions for alternative unit layouts to improve ventilation, and presents comparative tables for window opening sizes. Finally, Section 6 presents the conclusions and makes suggestions for future research.

2. Materials and Methods

This paper analyzes the current Brazilian SIH program with regard to energy efficiency and thermal comfort, and then provides guidelines for the gradual implementation of BIM for maintenance and post-occupancy management. The program is first assessed through a case study, and then a literature review was necessary to identify mandatory BIM inputs and their functions and benefits for post-occupancy. Finally, the guidelines are proposed based on the case study and the literature review.

The residential project selected as a case study received a sustainability certification and is composed of 108 housing units, built with only one design model. The case study collected data using direct observation and documentary research, complemented with data from previous studies conducted at the same residential project [25,26]. In addition, from previous analysis by [25,26], three new layouts were developed, using Autodesk Revit, to best meet users' needs and facilitate decisions on future interventions.

The first stage of the study reproduced the actual architectural model of the standard 50m^2 single-family social dwelling using the Autodesk Revit BIM software. This software was chosen because it is widely used around the world due to its interoperability, and its multidisciplinary and immersive capabilities [27]. It also can perform energy simulations in the cloud using industry-leading, reliable, and widely established simulation engines [28]. After this, three alternative layouts were explained, based on perceptions obtained from the visits made by the researchers [25,26], to analyze and compare their compliance with the thermal and luminous performance parameters of CAIXA Selo Casa Azul certification [24], NBR 15.575 [12], and NBR 15.220 [11]. The availability of essential building modelling (BIM) data to support the management of residential maintenance and renovation was also investigated.

Following this, a literature review was carried out on the benefits and advantages of using BIM modelling for maintenance management and the refurbishment of existing buildings, along with the BIM data required to make these activities possible. Searches were conducted in databases such as Scopus, Web of Science, and Google Scholar, and articles published between 2018 and 2022 that discussed the use of BIM to support the management of building maintenance and renovation, with a focus on improving user comfort and energy efficiency using the search terms: "social housing", "post-occupancy", "maintenance", "refurbishment", "facilities", "thermal comfort", "energy efficient houses", "BIM", and "BEM".

Initially, 1653 articles were found, with 391 remaining after being limited by Title, Abstract, or Keyword terms. Duplicate articles were excluded, and subsequently, titles and abstracts were analyzed to verify how well the articles fit the following topics: (i) social housing projects, post-occupancy; (ii) BIM and social housing; (iii) BIM, thermal comfort, and energy efficiency; and, (iv) BIM, maintenance management, renovation, and retrofit of buildings. In the screening phase, 101 studies were identified that fit the general research topics. After that, these studies went through a content analysis evaluation and selection process, from which 19 articles were found that indicated the functions and benefits of BIM in the post-occupancy phase, summarized in the results section.

Finally, based on the case study and the literature review, an assessment was made regarding how the residential project could benefit from using BIM for its post-occupancy management. This assessment was used to create guidelines for future Brazilian social housing projects. The guidelines are also presented in the results section, including aspects such as encouraging the use of BIM and the mandatory input of data, to utilizing users' data to improve future projects. Figure 1 shows a summary of all of the steps performed in the study.

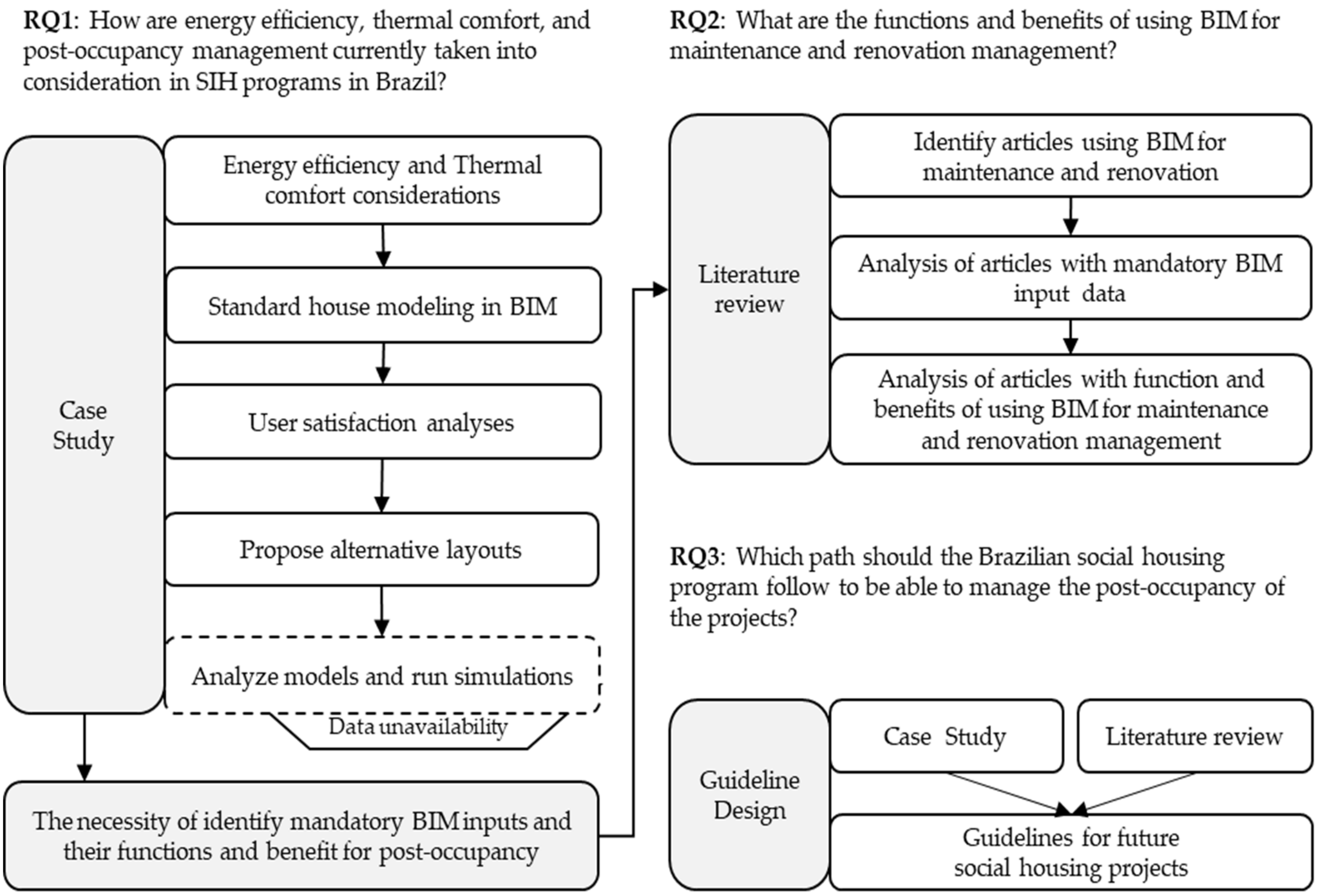

Figure 1. Study workflow diagram.

3. Case Study

This section presents information about the residential housing project that was used as a case study. Information on the location of the residential project is presented first, followed by the standard house plan and the materials and sustainability certification obtained. Finally, a profile of the residents is shown, along with an analysis of user satisfaction that can be useful for developing new layouts.

3.1. Climate Information

The case study is located in the municipality of Garanhuns, Pernambuco, Brazil. The residential project is located in the *Agreste* region, about 230 km from the state capital of

Recife, as shown in Figure 2. The city of Garanhuns sits at an altitude of 842 m, in a region of broken hills separated by deep river-cut valleys [29]. The climate is characterized as a high-altitude humid mesothermal forest, with an average annual temperature of 20 °C, having a minimum of 8 °C in August and a maximum of 30 °C in November and December. Yearly precipitation averages 908.6 mm, with a tendency to increase from west to east [29]. The elevation of the residential project ranges from 796 and 830 m.

Figure 2. Map of Pernambuco with the city of Garanhuns and the capital Recife marked (Adapted from Google Maps).

3.2. Bioclimatic Zone and Construction Guidelines from NBR 15.220

Based on data from NBR 15.220 [11], the city of Garanhuns is located in bioclimatic zone five. Construction recommendations for this zone include medium-sized windows with shading, light and reflective walls, and light, thermally insulated roofs. In addition, cross ventilation in summer, and heavy internal seals with high thermal inertia in winter are recommended as bioclimatic strategies.

3.3. Characterization of the Residential Project and the Standard House

The residential complex contains 130 residences, as confirmed during the site visits. Of these, 108 were certified single-family properties located in blocks A, C, D and E, which make up the areas under study in this paper. The block B was not included in this study because the houses in this block were not certified with the CAIXA *Selo Casa Azul* certification, and therefore had different layouts. The residential complex also has two green areas and three lots (represented in yellow) that are destined for mixed-use, as shown in Figure 3. The standard house has two bedrooms, one living room, one kitchen, one bathroom, and an outdoor service area, totaling 50 m^2 of built area. All of the houses in the complex have identical layouts. The BIM model of the standard house was developed from site visits, on-site measurements, and observations, as shown in Figure 4.

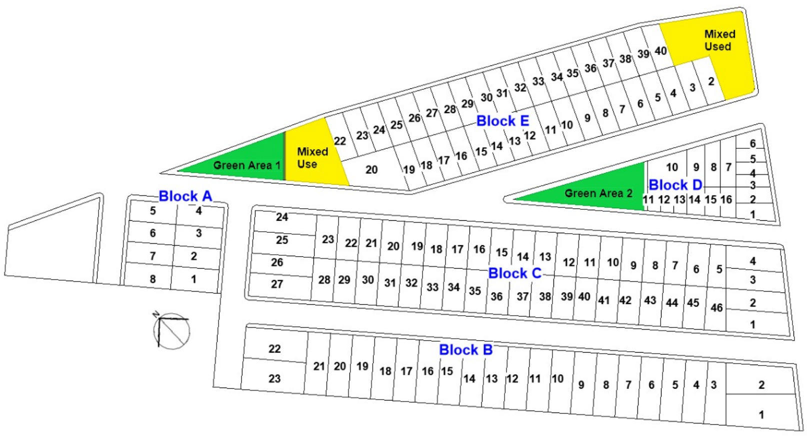

Figure 3. Site plan of the Residential housing project.

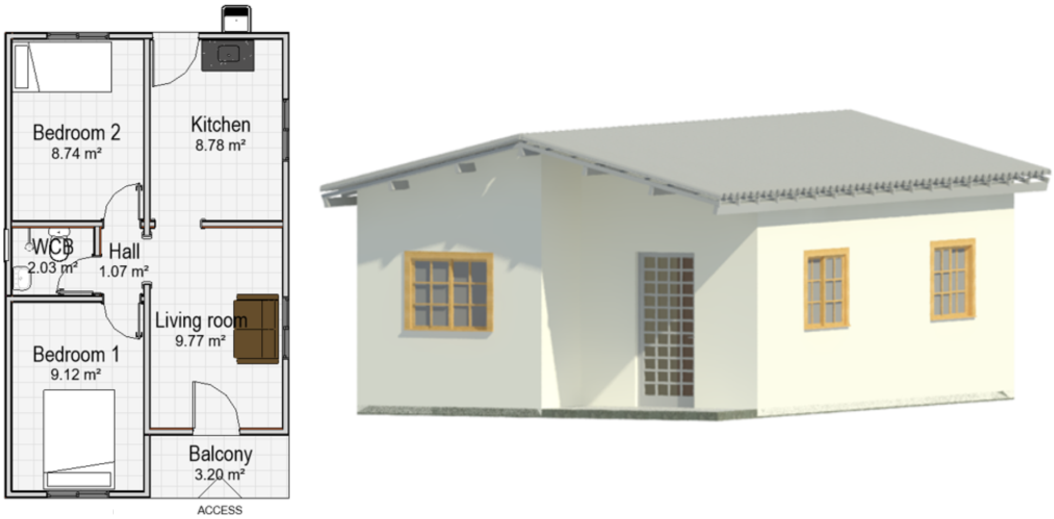

Figure 4. Floor plan and 3D view of the standard house.

The materials used to construct the residences and their available thermal transmittance values are presented in Table 1. For this study, the thermal and lighting performance parameters were evaluated according to the thermal performance standard for buildings, NBR 15.220 [11]. However, as shown in Table 1, much information about thermal transmittance was not made available, making it challenging to perform energy simulations.

Table 1. Materials used.

Typology	Materials	Thermal Transmittance (W/m^{2}K)
Foundation	Surface slab, with reinforced concrete, approximately 30 cm trenches.	Not available
Walls	Ceramic blocks 9 × 14 × 24 cm, mortar (internal and external 2.5 cm), and PVA latex paint.	2.59 [24]
External windows	Iron with colorless glass panes, painted white.	Not available
Internal Doors	Wood	Not available
Floors	Cement with white ceramic floor tiles and white grouting.	Not available
Ceramic lining	Lining in the bathroom at a height of 1.5 m and below the kitchen sink.	Not available
Roof system	Plaster ceiling (3 cm), air void layer (>5 cm), timbering with purlins, rafters, and wooden laths, thermal blanket insulation, and colonial ceramic tiles (1 cm).	1.91 [24]

3.4. CAIXA Selo Casa Azul Certification

In 2009, the Caixa Econômica Federal (CAIXA), a Brazilian financial institution responsible for a significant portion of the financing of social housing policies in the country, established the CAIXA *Selo Casa Azul* certification [24]. This certification analyzes 53 criteria, both mandatory and elective, divided into six categories (urban quality, design and comfort, energy efficiency, conservation of natural resources, water management, and social practices) covering environmental, economic, and social aspects. The evaluation method consists of a checklist, with the possibility of obtaining a gold, silver, or bronze classification according to the total number of criteria met [24].

Altogether, the residential building from the case study met 19 mandatory and 12 elective criteria, corresponding to a gold rating, which is the highest certification rating. However, with regard to thermal comfort and energy efficiency, the residence was limited to the mandatory criteria, with only one elective criterion related to ventilation and natural lighting of bathrooms, as shown in Table 2 [21].

Table 2. Compliance of the residential with the CAIXA *Selo Casa Azul* certification.

Category	Criteria	Compliance
Design and comfort	**Mandatory Criteria—Comfort**	✔
	Thermal Performance—Sealings	✔
	Thermal Performance—Sun and Wind Orientation	✔
	Elective Criteria—Comfort	✖
	Natural Lighting of Common Areas	✖
	Natural Ventilation and Lighting of Bathrooms	✔
Energy efficiency	**Mandatory Criteria**	✔
	Low Energy Bulbs—Private Areas	✔
	Saving Devices—Common Areas	✔
	Individual Measurement—Gas	✔
	Elective Criteria	✖
	Solar Heating System	✖
	Gas Heating System	✖
	Efficient Lifts	✖
	Efficient Household Appliances	✖
	Alternative Energy Sources	✖

Note: The check mark (✔) indicate the criterium was met.

The design and comfort category includes a mandatory thermal performance criterion, which considers insulation and orientation to the sun and wind. In compliance with the thermal performance criterion, the construction company reported using thermal insulation blankets on the roofs. Concerning orientation to the sun and wind, approximately 78% of the dwellings have rooms that benefit from ventilation. In 95% of the houses, the position of the bedrooms is protected from the setting sun, favoring thermal comfort [25]. In the energy efficiency category, the criteria include the mandatory use of low-consumption light bulbs, energy-saving devices, and individual gas meters.

The evaluation by checklist and sum of isolated criteria adopted by the CAIXA *Selo Casa Azul* weakens the analysis of the residential performance and environmental impacts by not analyzing the building in a holistic manner [25]. As observed in the following sections, some users were dissatisfied. That dissatisfaction may have been due to the thermal performance criteria of the certification and of NBR 15.575, which are limited when compared to the recommendations from NBR 15.220, especially considering concerns regarding the thermal transmittance and thermal capacity of external walls, the thermal transmittance of roofs, and the limited natural ventilation requirements. Therefore, an analysis of the case study was performed according to NBR 15.220 and NBR 15.575, which have more rigid criteria.

3.5. Residents' Profile

Regarding the number of residents, studies performed on site [25,26] showed that 8.8% live alone, 35.3% live with one other person, 20.6% live with two other people, 23.5% live with three other people, and 11.8% live with four or more other people. Only 10.3% of the residents rented their property, while 89.7% are making monthly payments to CAIXA [25,26].

Concerning their income level, 1.7% survive with an income less than or equal to one minimum salary (R$ 1100.00/month), about U$197.00. As shown in Figure 5, another 41.4% have an income between one and three times the minimum salary, 39.7% between three and five times the minimum salary, 13.8% between five and seven times the minimum salary, and 3.4% earn more than seven times minimum salary [26].

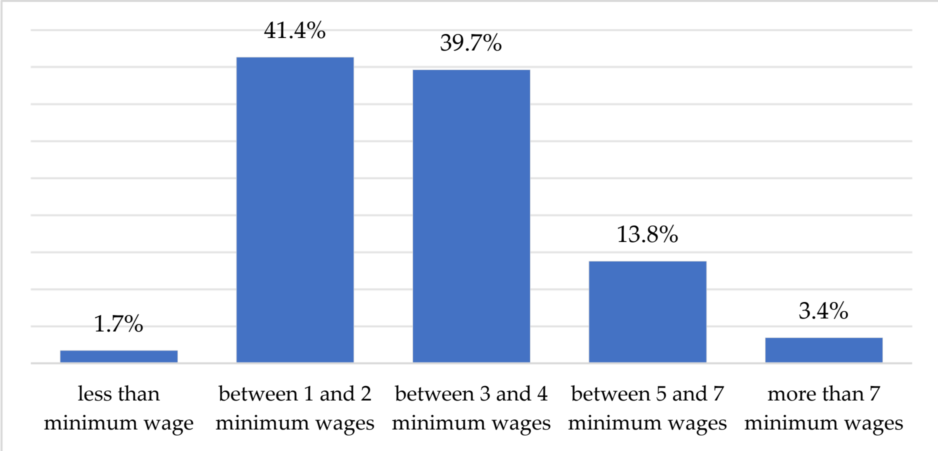

Figure 5. Family income in the Residential complex [22].

In terms of energy consumption, only 6.25% of the residents reported energy consumption of less than 50 kW per month, 6.25% consumed between 50 and 75 kW, 21.88% consumed between 100 and 150 kW, 15.63% consumed between 150 and 175 kW, 15.63% consumed between 175 and 200 kW, and 21.88% consumed more than 200 kW [26], as shown in Figure 6. Residents who consume more than 200 kWh/month approach 220 kWh/month, the maximum limit for inclusion in the government program that subsidizes the energy tariff for low-income consumers [30]. Considering the socioeconomic profile, the energy expenditure has an important impact on the families' income, which could benefit from design optimizations to improve energy efficiency. It is important to note that the higher energy consumption is due to the use of electric showers, because the average temperatures in the city are around 21 °C throughout the year.

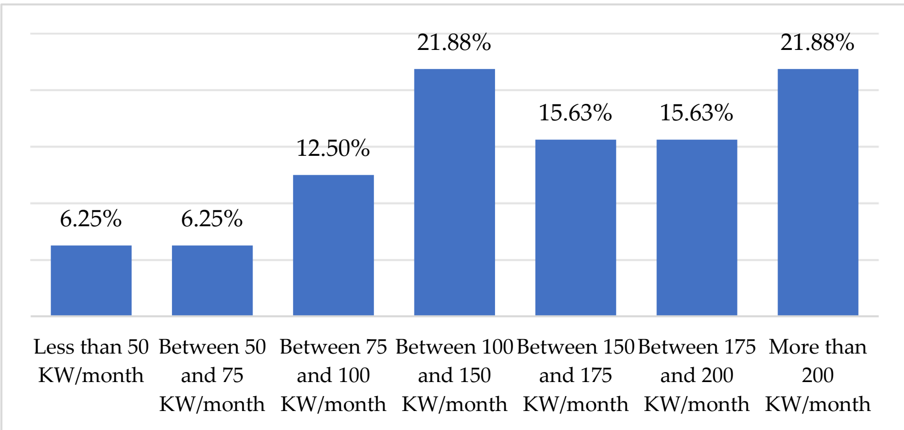

Figure 6. Average energy consumption (kW) in the Residential complex [22].

3.6. Post-Occupancy Analysis

During the field visits, a high rate of intervention in the dwellings was identified, contributing to the architectural deconfiguration of the original design [22]. Therefore, the user satisfaction analysis serves as a basis for identifying the need for future interventions in the building, such as moving the location of doors and windows or renovations that change the layout. To avoid future interventions that generate waste and can affect the integrity of the dwelling when carried out without adequate technical monitoring, the design of the project must take the user's needs into consideration.

According to Ref. [25], residents expressed the highest dissatisfaction with the bathroom and kitchen sizes, 41% and 45%, respectively. This information was stratified based on the number of people living in the houses, as shown in Tables 3 and 4. These user evaluations are extremely important to provide feedback to the program and contribute to future projects more aligned with the users' profiles.

Table 3. Residents' dissatisfaction with bathroom size, by number of residents.

Residents/House	n	Dissatisfied Resident	%	% Total
1 to 2 people	22	4	18%	41%
3 people	14	8	57%	
4 to 5 people	22	12	55%	

Table 4. Residents' dissatisfaction with kitchen size, by number of residents.

Residents/House	n	Dissatisfied Resident	%	% Total
1 to 2 people	22	8	36%	45%
3 people	14	6	43%	
4 to 5 people	22	12	55%	

4. BIM for Building Maintenance and Refurbishment Management

BIM can be seen as an integrated set of technologies that contributes to managing the design phase, monitoring the construction, and making decisions during the operation and maintenance phases, by making it possible to use and update design information throughout the building life cycle [17,19]. For example, BIM modelling can contain information about building systems, such as walls and structures, hydraulic and electrical installations, doors, windows, and finishing materials, including dimensions, specifications, manufacturers, and material suppliers [31].

Therefore, BIM has the potential to make maintenance activities easier due to its ability to provide accurate construction data and integrate with other tools that perform energy performance, cost, and schedule analyses [18,32–34]. Furthermore, BIM, used as an energy simulation model, makes it possible to investigate residents' comfort to find the most efficient solutions [28]. Modelling is an efficient method of presenting various renovation solutions, allowing for decision-making based on the financial and environmental impacts of the alternatives [35].

Beyond that, facility maintenance is essential for improving the energy performance of buildings, similar to safety and sustainability. Previous studies have indicated that building modelling assists in monitoring and planning interventions for retrofit, renovation, and maintenance. When combined with Building Energy Modelling (BEM), the information storage functionalities of BIM perform energy performance analysis using simulations [36,37]. The importance of BIM in improving these simulations has been highlighted in the literature, indicating that the sharing of information between BIM and BEM can enhance the sustainability of construction projects and help guide the renovation of existing buildings [38]. The advantages and limitations of building modelling in the maintenance stage are also widely discussed in the literature [18]. Some studies show that BIM produces better results when implemented during the design phase. However, the operation and maintenance phases can benefit from modelling to support the planning and selection of more appropriate and sustainable interventions [39,40].

Several BIM software programs are available, such as Revit, ArchiCAD, DesignBuilder, eQuest, Microstation, OpenStudio, Hevacomp, Ecotect, and Green Building Studio, among which Revit Autodesk and ArchiCAD Graphisoft are the most widely used due to their interoperability, and to their multidisciplinary and immersive capabilities [27,41]. However, several challenges limit their comprehensive application in the construction industry, such as their high cost, complex workflow, and non-user-friendly interfaces. Furthermore, a lack of databases limits their use in many countries, with the use of foreign databases leading to results that fail to correspond to reality [27].

Maintenance and renovation activities require a set of input data that makes it possible to evaluate the best alternatives [42–47]. Even considering that information gaps between the model and the building exist, modelling can be useful because BIM in the design phase creates records of the elements and information that are essential for the operation phase [31,38,48]. BIM modelling for the management of user requirements in social housing projects, as proposed in [6], generates additional opportunities, making it possible to monitor energy efficiency and performance indicators. It also makes it possible to analyze the economic viability of retrofitting alternatives through simulations that provide a good idea of the potential energy consumption savings and costs of each option [35,49,50].

BIM has been proposed to compare alternatives for housing retrofits, focusing on improving energy performance and user comfort [38]. The BIM approach to managing the stock of existing housing indicates that the technology can be a viable option for maintenance and performance analysis [51]. Coupled with sensors and other tools, modelling can facilitate post-occupancy monitoring by capturing building usage data [52,53].

The literature also helps to identify BIM's main functions and benefits for building maintenance and renovation, as shown in Table 5. BIM brings several advantages to a construction performance analysis by providing and collecting data [31,42,49,54], enabling simulations to choose the best scenario, and consequently, to help stakeholders make more conscious decisions [28,49,55,56], manage assets [37,50–52,54] and manage user requirements [7]. These findings support possible paths for implementing BIM in social housing projects in Brazil, focusing on post-occupancy management.

Table 5. Functions and benefits of using BIM for building maintenance and refurbishment.

Functions	Benefits	Publications
Provision of life cycle data	Providing data for energy management, maintenance, and refurbishment of buildings	[31,42,49,51,52,54,57,58]
Operation simulation	Simulation and energy modelling for assessing thermal and energy performance of buildings and materials	[3,27,36,49,50,56,58]
	Operation simulation for analysis of more sustainable building alternatives and retrofit	
Decision making	Economic feasibility analysis of maintenance alternatives, renovation, and retrofits	[27,28,35,49,50,54–56]
	Development and monitoring criteria and indicators for decision making, energy efficiency, and performance	
Asset management	Asset aging management	[37,50–52,54,56,59]
	Performance analysis of building materials and systems	
Requirement Management	Managing user requirements for improvement of future projects	[3,7,54,56]
Design Optimization	Introduction of improvements and new typologies based on lifecycle performance	

According to the benefits presented in Table 5, the BIM model can provide, transfer, and aggregate data for maintenance, renovation, and retrofitting tasks. These data, combined with simulation tools, are essential for decision-making, especially regarding the performance and energy efficiency of the building. Still, there are challenges to be overcome, especially with regard to the connection between systems and data interoperability [17]. In addition, the literature draws attention to the need to consider the BIM maturity level of the stakeholders in order to ensure the success of collaborative work among teams. Finally, previous studies suggest that guidelines should be defined to implement BIM modelling for building maintenance management [18].

5. Results

In this section, BIM will be used to meet the demands of users and perform evaluations of the models developed. The limitations to its extensive use, due to the non-availability of data, will also be discussed, considering that the implementation of BIM in the post-occupancy phase requires a set of data feeds from the planning, design, and execution phases. Following this, the proposed guidelines to overcome this non-availability and improve the SIH program will be presented.

5.1. Use of BIM for Refurbishment and Maintenance of SIH Projects

Three new layout models that better fit the needs of the residents were proposed. These three layouts and the original were checked for thermal performance, compared to the recommendations of NBR 15.220 and the CAIXA Selo Azul. Following this analysis, the available data and information from the case study essential for the adoption of BIM for maintenance and renovation of these housing assets were evaluated.

5.1.1. Proposed Layouts

The housing units in the case study were delivered in 2014, and the users did not have access to their designs or to any manuals with guidelines for maintenance and renovation. Regarding user satisfaction, 40% of users considered the materials good and easy to maintain, 47% with the built area, but only 29% were satisfied with the layout [25,26]. As such, the frequency of changes in the original project is indicative of the overall user dissatisfaction. The main renovations performed were the construction of walls and layout changes, as well as maintenance to treat cracks and infiltrations in the roof.

As the original designs and specifications were unavailable, the architectural model in BIM Revit of the standard units was prepared from a field survey, which limited the capture of data from the housing unit initially delivered by the program, considering the modifications made by users during eight years of occupation. Based on observations and complaints during the post-occupancy phase reported by [25,26], civil engineers and architects with more than 20 years of experience proposed three new models to better meet the residents' needs. In layout M1, the principal changes were the window arrangements in both bedrooms, the cladding of the service area, a larger bathroom, a small decrease in the size of bedroom 2, and a granite countertop integrating the kitchen and living room of the house.

In layout M2, there were changes to the location of bedroom 1, which was placed next to bedroom 2. The kitchen was moved to the front, with a main access door on the left side and a secondary access door on the right side. An awning was placed over the service area, and a ceramic floor was added, complementing the space. The social bathroom was rearranged to make it more comfortable for the residents, with a sliding door and a larger area for bathing. In layout M3, more abrupt changes were made, utilizing an open concept that connects the living room and kitchen. The service area is on the right side, and the main entrance is in the front of the house. In addition, the window placement is concentrated on the sides, and the bathroom has more space. Floor plans for layouts M1, M2, and M3 are shown in Figure 7, and the 3D views are shown in Figure 8.

Providing layouts that consider the users' demands and allow for different possibilities for different family realities should lead to lower demand for future renovations. Therefore, the Brazilian SIH program should consider incorporating alternative layouts that reflect the reality of the local users, adding value to future dwellings and contributing to lower rates of future interventions, consequently making the program more sustainable.

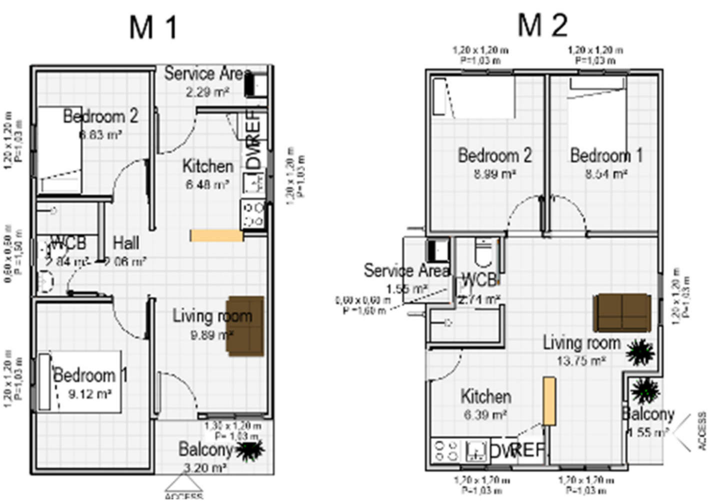

Figure 7. Floor plans.

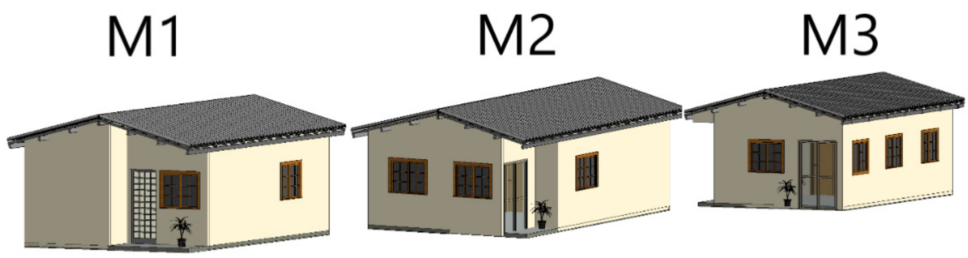

Figure 8. 3D views of the layouts.

5.1.2. NBR 15.220 Compliance with Thermal Performance—Openings

The study then uses the models created to compare the recommendations from the NBR 15.220 standard and the CAIXA *Selo Casa Azul* certification regarding the Thermal Performance criterion—insulation. Based on the zones established by NBR 15.220 [11], in which the city of Garanhuns is classified as bioclimatic zone 5, the following standards were used as references. For this bioclimatic zone, the ventilation openings must have an area of between 15% and 25% of the room floor area.

For the analysis, only rooms in which residents spend extended amounts of time were considered: living rooms, kitchens, and bedrooms. For example, 1.20 m^2 is the window area for the kitchen, corresponding to 13.67% of the 8.78 m^2 kitchen floor area. Therefore, as shown in Table 6, the windows of the standard house in the Brahma Residential complex have window openings smaller than the acceptable percentage range for the room areas.

Although the external wall and roof systems met the thermal transmittance limits defined by NBR 15.220, the ventilation openings were below the recommended size for the bioclimatic zone. This indicates that the material specifications and layouts need to be adequate for the region where the dwelling is located, contributing to thermal performance. Furthermore, the results are compatible with the findings of previous studies that analyzed the thermal performance of the standard design used by the country's housing program in various Brazilian climatic regions, from the perspective of NBR 15.220 [3].

The standards [6] also recommend lightweight external walls with $U \leq 3$ W/m^2.K and a lightweight roof with $U \leq 2$ W/m^2.K, and these standards are met here, as shown in Table 1. Thermal insulation was used to meet the limit indicated for the roof [25]. However, as shown above, the original model does not meet the recommendations of NBR 15.220 [11], where the minimum window area for bioclimatic zone 5 must be between 15% and 25% of the floor area, openings shading and cross-ventilation. To meet this standard, an increase in the height of the windows to 1.20 m would be required, as was done in proposed layouts M1, M2, and M3. Therefore, the proposed layouts are in accordance with NBR 15.220, and take residents' behavior into consideration, leading to lower demand for future renovations and increased user comfort.

Table 6. Effective ventilation openings for rooms where residents spend extended amounts of time.

	Room	Area (m^2)	Window Width (m)	Window Height (m)	Window Area (m^2)	Percentage
Standard House	Kitchen	8.78	1.20	1.00	1.20	13.67%
	Living Room	9.77	1.20	1.00	1.20	12.28%
	Bedroom 1	9.12	1.20	1.00	1.20	13.16%
	Bedroom 2	8.74	1.20	1.00	1.20	13.73%
M1	Kitchen	6.48	1.20	1.20	1.44	22.22%
	Living Room	9.89	1.30	1.20	1.56	15.77%
	Bedroom 1	9.12	1.20	1.20	1.44	15.79%
	Bedroom 2	6.83	1.20	1.20	1.44	21.08%
M2	Kitchen	6.39	1.20	1.20	1.44	22.54%
	Living Room	13.76	1.20	1.20	2.88	20.93%
	Bedroom 1	8.54	1.20	1.20	1.44	16.86%
	Bedroom 2	8.99	1.20	1.20	1.44	16.02%
M3	Living/Kitchen	19.39	1.20	1.20	4.32	22.28%
	Bedroom 1	8.54	1.20	1.20	1.44	16.86%
	Bedroom 2	8.99	1.20	1.20	1.44	16.02%

The above observations show that the standard layout used by the residential complex did not consider the residents' demands, nor did it consider the requirements of the bioclimatic zone in which Garanhuns is located, resulting in an increase in the residents' monthly energy consumption, as presented in Figure 6. The original layout directly increases the demand for future renovations, which could have been avoided had the original design considered these aspects, rather than simply using a standard layout for all contexts. The survey of residents indicated that about 84% had to build fences, and 45% performed either removal or addition of internal walls [26].

5.1.3. BIM Input Data for Refurbishment and Maintenance of SIH Projects

To evaluate the availability of the data required to use BIM for managing the renovation and maintenance activities in the case study, the researchers reviewed the data for modelling the original dwelling, the local construction standards, and the energy efficiency parameters indicated in the Brazilian standards [34]. Table 7 shows the data required for efficient maintenance management in BIM [42] and displays the available data from the case studies for the analyzed residential complex [25,26]. However, because no BIM model was provided by the design and construction teams, detailed information about residential construction was lacking. This lack of data made it challenging to produce a model that allowed performance simulations to be made, thereby keeping BIM from reaching its full potential for maintenance management.

The use of occupancy data is not mandatory for Brazilian SIH. Therefore, this data was not available for the residential complex. However, presence and time sensors were installed in the common areas as required by the *Selo Casa Azul*, satisfying the energy-saving device criteria [24]. As for the SAP rating data, there is an equivalent system in Brazil for evaluating the energy performance of buildings, known as PROCEL RTQ-R [13,60]. Unfortunately, this rating is also not mandatory.

Table 7. BIM input data.

Phase	Work Stage	BIM Input Data	Availability
Assessment	Strategic Definition	Housing type and year built (as-built data)	✔
		Dimensions: (a) Floor area (floor plans) (b) Story height(c) Building materials (wall, roof, floor, window, and door)	✔
		Detailed construction information: (a) Construction types for all elements (b) Material types for external windows and doors (c) U-values for all housing elements (d) Additional extension or in-situ construction	✖
		Occupancy data and SAP rating data	✖
	Preparation and brief	Customer preferences: (a) Refurbishment priorities of the house element (b) Decision-making factors for selecting refurbishment options (c) Refurbishment materials	✖
		3D House information model	
Design	Concept Design	Building regulations	✔
	Developed design	Energy standards	✔
	Technical Specifications	Material Attributes (thickness and types)	✖
		Risk of damage to the insulation system	✖

As noted in the previous section, the residents' preferences were not considered during the design phase. Therefore, a high rate of user dissatisfaction was observed [26]. Furthermore, guidance on the risk of damaging the existing insulation system is not a mandatory item. However, the management of insulation damage during renovation and maintenance follows the habitability requirements of ABNT 15.575 [12], regarding water tightness and thermal performance.

As shown in Table 7, several BIM management input data were unavailable, making extensive use of BIM for maintenance management unachievable. In addition, to carry out a performance simulation, several specific data, such as the thermal conductivity of all materials, need to be available, which was not the case. Unfortunately, the above architectural models could not be integrated into energy performance simulation software based on the information available. Therefore, this study could not develop energy models of the building and its thermal, energy, or material performance.

The architectural model of the case study's standard design was produced using the Autodesk Revit software. Following this, available data regarding the thermal behavior of materials and building systems, geographic data, and the bioclimatic zone were introduced, in order to perform an energy simulation using the Revit INSITH 360 plugin [61,62]. However, with the available data, it was not possible to obtain the energy model of the dwelling, impairing the evaluation of the thermal performance through simulation.

When an energy model for the residential complex can be obtained, a validation of the model should still be performed. This validation determines the degree to which the model accurately represents the real world. There is more than one framework for such validation. However, the validation needs to include three steps: (i) analytical validation; (ii) comparative testing; and (iii) empirical validation [63].

5.2. Guidelines for Future Social Housing Projects

The government social housing program in Brazil has no mechanisms for monitoring the life cycle of existing houses. Moreover, residents are responsible for the maintenance and renovation of their own dwellings. Supported by a case study, this paper analyzed the use of BIM for post-occupancy management of social housing, and identified the need to capture a set of data from the design phase, with updates and complementary data gathered during construction. A number of information gaps were found during the case study analysis, indicating that residents have been modifying their homes without support from guidelines or user manuals. Although the residences are certified for sustainability, several potential improvements could be achieved through BIM modelling, resulting in more economical and sustainable maintenance and renovation solutions.

With information about the designs, material specifications, and building systems used in construction, BIM modelling can add value to the operation phase, making it possible to perform life-cycle analysis and decision-making during maintenance and renovation [34,36]. In addition, occupancy data needs to be monitored during the operation phase with the installation of appropriate equipment. Smart sensors can provide data on energy consumption and the thermal comfort of residents, and can also provide information to the housing program that will guide the design optimization process [50,52].

The use of materials accounts for a significant portion of the energy incorporated in the housing life cycle [64]. The *Selo Procel Edificações* classifies buildings on a scale of efficiency ranging from "A" for highest efficiency to "E" for lowest efficiency. The label is awarded at two points in time: at the design stage and following construction. In the design stage, the project must comply with the limits recommended by NBR 15.220 and NBR 15.575. Following construction, the building is evaluated through on-site inspection, where the building envelope, the water heating systems, and the common areas' systems are assessed, such as lighting and elevators in the case of multifamily buildings [60].

The results highlight the need for the government to incorporate modelling from the design stage through construction, with the capture and updating of essential data collection for the post-occupancy phase [42]. The schedule for the implementation of this technology can be gradual, in line with the investment conditions of the Brazilian social housing program. The adoption of BIM projects, properly fed with essential data, by the Brazilian social housing program can facilitate post-occupancy management and has the potential to support maintenance, renovation, and performance evaluation activities for housing assets already in use [51].

The gaps discovered in the case study, correlated with the functions and benefits of using BIM for maintenance and renovation management, guided the development of the guidelines for implementing BIM for the post-occupancy management of social housing in Brazil, presented in Table 8. The guidelines are grouped into five categories: BIM encouragement, energy efficiency, maintenance management, user requirement management, and continuous improvement

Table 8. Guidelines for implementing BIM for post-occupancy management in future SIH projects.

Case Study (SIH)	Guidelines		Publications
Use of traditional project methods, which bring information gaps.	**1**	**BIM Encouragement**	[26,34,35,37–41]
	1.1	The model should contain all information necessary for operation and maintenance activities and simulations.	
	1.2	The model should contain not only architectural features, but also electrical and hydro-sanitary installations.	
	1.3	Plan for possible alterations that will be made by residents, such as extensions and layout changes.	
	1.4	Include information regarding materials, construction systems, and budget.	
	1.5	Stimulate the use of renewable energy sources, such as solar panels and biodigesters.	

Table 8. *Cont.*

Case Study (SIH)	Guidelines		Publications
Not compliant with NBR 15.220 standard and lacks information to perform simulations and optimize the design.	**2**	**Energy Efficiency**	[3,6,27,35,36,49]
	2.1	The design must include thermal comfort simulations: opening, ventilation, WWR ratio and materials, according to NBR 15.220 [6].	
	2.2	The design must perform energy simulations.	
	2.3	Implement energy efficiency rating in accordance with Selo Procel Edificação.	
	2.4	The design should stablish the integration of the BIM model with BEM parameters.	
Residents are not adequately oriented about maintenance and renovations.	**3**	**Maintenance Management**	[29,36–38,41]
	3.1	Provide an electronic user manual with information from the model.	
	3.2	Implement occupancy sensors in a sample of houses, so that the program has feedback regarding actual use, comfort, and thermal performance, providing feedback for future developments.	
	3.3	Monitor the performance of materials and the occurrence of building pathologies.	
Interventions are performed without feedback to the program.	**4**	**User Requirement Management**	[14,41,43]
	4.1	Monitor data on changes made by residents.	
	4.2	Provide feedback for future developments.	
	4.3	Create a user experience database.	
Experiences from past projects are not used for the benefit of future projects.	**5**	**Continuous Improvement**	[41,43]
	5.1	Gather and utilize resident experience data.	
	5.2	Design optimization of future projects to require fewer interventions from residents.	

In order to boost the adoption of BIM in public works projects, the government of Brazil has established a schedule for using BIM in public works and services by 2024 [22]. At the same time, in 2020, the federal government announced that the housing program plans to serve 1.6 million low-income families by 2024 [65]. However, the areas defined as priorities for implementing BIM in public projects do not include the housing program.

The guidelines proposed in this study expose the critical importance of BIM implementation for the program, considering the potential benefits indicated in the literature. Currently, the program monitors the housing units' planning and design phases, financing, and execution. Therefore, encouraging the use of BIM in the design stage is proposed as a strategic guideline from which the program can inaugurate the post-occupancy monitoring and the management of the housing assets delivered, extending the program's assessment to the entire life cycle of the housing units, for the benefit of the end users.

Considering the supply of housing units, implementing post-occupancy monitoring of social housing in Brazil would contribute to reducing energy demand in the sector and to improving the sustainability requirements of the program's units constructed. As a practical contribution, this study encourages the adoption of BIM in the design phase as a starting point for implementing post-occupancy monitoring. In addition, it describes the theoretical knowledge involved in housing asset management, focusing on energy efficiency and thermal comfort.

6. Conclusions

This paper presents the benefits of BIM for building maintenance and renovation, seeking to create guidelines for adopting BIM modelling for post-occupancy monitoring of social housing in Brazil. The results indicate that there is still much to be done for the government program to implement modelling for existing housing developments. In addition, many practical, financial, and operational difficulties will need to be overcome. Most importantly, there are potential benefits for residents, builders, and the overall Brazilian social housing program [14]. The layout models presented in this paper were the result of residents' opinions [25,26], and the analysis makes it possible to carry out future simulations using different solar orientations to define which layout would fit best.

In addition, the study proposed literature-based guidelines for implementing BIM for maintenance and refurbishment, focusing on improvements in thermal comfort and energy efficiency in SIH. To this end, it describes the theoretical knowledge of housing asset management, focusing on energy efficiency and thermal comfort. These guidelines serve as a gradual implementation path from project development in BIM to forming a user experience database. Additionally, the guidelines indicate that the use of modelling by the government program would help support both residents and construction companies, and could provide feedback to the program, extending the program's assessment to the entire life cycle of the housing units.

Implementing the guidelines would make it possible to improve processes, promote data-driven selection of materials and suppliers, improve the design, and offer technical guidance to residents regarding the maintenance and renovation of their homes. Furthermore, in the medium term, the post-occupancy phase information stored in BIM can provide a set of user requirements to guide the housing program in designing more sustainable projects.

The guidelines were based on a case study from a certified residential development project and on a literature review. However, energy simulations were not performed due to the non-availability of data, which is a limitation of the study, as well as an opportunity for future studies that intend to explore energy simulations for SIH. In addition, due to the lack of available data in the case study, the absence of a simulation is a stronger indication of the need for implementation so that future developments facilitate access to such data. Therefore, the lack of a performed simulation does not invalidate the results, rather, it reinforces the necessity for implementing BIM in future developments of the SIH program.

Moreover, in future research, similar analyses of other SIH projects may point to other demands that could be added to the guidelines. In addition, an energy efficiency study of the different scenarios presented (M1, M2, and M3) could provide insights into the feasibility of user demands. Furthermore, an empirical study that investigates the effective energy consumption and costs is suggested to help validate the guidelines and to point out any necessary adjustments. Finally, a practical study with the implementation and validation of the guidelines could be a great source of discussion to gain the support of the Brazilian government.

Author Contributions: Conceptualization, E.R.K.R., L.H.A. and J.P.C.; Data curation, M.C.d.C.S. and E.R.K.R.; Formal analysis, M.C.d.C.S. and J.P.C.; Funding acquisition, E.R.K.R. and J.P.C.; Investigation, M.C.d.C.S., A.D.O.S. and J.P.C.; Methodology, M.C.d.C.S., E.R.K.R. and L.H.A.; Project administration, L.H.A., G.d.M.P.N. and J.P.C.; Software, A.D.O.S.; Supervision, E.R.K.R., L.H.A., J.P.C. and R.V.-V.; Validation, E.R.K.R., L.H.A., J.P.C. and R.V.-V.; Visualization, A.D.O.S. and G.d.M.P.N.; Writing—original draft, M.C.d.C.S. and A.D.O.S.; Writing—review & editing, M.C.d.C.S., A.D.O.S., E.R.K.R., L.H.A., G.d.M.P.N., J.P.C. and R.V.-V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior grant number 001, by Conselho Nacional de Desenvolvimento Científico e Tecnológico grant number 317511/2021-1, by Fundação de Amparo à Ciência e Tecnologia de Pernambuco (FACEPE) grant number IBPG-1526-3.08/20, and by Escola Politécnica da Universidade de Pernambuco (POLI/UPE) grant number 0040608793.000171/2022-68 (CI n° 109/2022). And The APC was funded by Programa de Fortalecimento Acadêmico (PFA) of University of Pernambuco (UPE) through the Programa de Extensão PG18-DESS@POLI, Edital 01/2021.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Siqueira-Gay, J.; Sánchez, L.E. Mainstreaming Environmental Issues into Housing Plans: The Approach of Strategic Environmental Assessment. *Environ. Impact Assess. Rev.* **2019**, *77*, 145–153. [CrossRef]
2. Lambrechts, W.; Mitchell, A.; Lemon, M.; Mazhar, M.U.; Ooms, W.; van Heerde, R. The Transition of Dutch Social Housing Corporations to Sustainable Business Models for New Buildings and Retrofits. *Energies* **2021**, *14*, 631. [CrossRef]
3. Rodrigues Moreno, A.C.; de Morais, I.S.; de Souza, R.V.G. Thermal Performance of Social Housing—A Study Based on Brazilian Regulations. *Energy Procedia* **2017**, *111*, 111–120, ISNN 1876-610. [CrossRef]
4. Djafri, R.; Mohamed Osman, M.; Suzilawati Rabe, N.; Shuid, S. Investigating Quality of Life by Residents of Social Housing in Eastern Algeria: A Structural Equation Modelling. *J. Eng. Des. Technol.* **2020**, *18*, 1907–1926. [CrossRef]
5. BRASIL. *Lei Federal 11.124, de 16 de junho de 2005*; Sistema Nacional de Habitação de Interesse Social—SNHIS; Presidência da República: Brasília, Brazil, 2005. Available online: http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2005/lei/l11124.htm (accessed on 10 January 2021).
6. Da Silva, C.A.; Gonçalves, R.S. Os 10 Anos do Atual Programa de Moradia Social No Brasil: Uma Trajetória de (Des) Caminhos. *Rev. Ens.* **2019**, *14*, 61–79. [CrossRef]
7. Baldauf, J.P.; Formoso, C.T.; Tzortzopoulos, P.; Miron, L.I.G.; Soliman-Junior, J. Using Building Information Modelling to Manage Client Requirements in Social Housing Projects. *Sustainability* **2020**, *12*, 2804. [CrossRef]
8. Campos, R.B.A.; Guilhoto, J.J.M. The Socioeconomic Impact of Low-Income Housing Programs: An Interregional Input–Output Model for the State of São Paulo and the Rest of Brazil. *Habitat Int.* **2017**, *65*, 59–69. [CrossRef]
9. Fastofski, D.C.; González, M.A.S.; Kern, A.P. Sustainability Analysis of Housing Developments through the Brazilian Environmental Rating System Selo Casa Azul. *Habitat Int.* **2017**, *67*, 44–53. [CrossRef]
10. Guitarrara, P. Apagão de 2001. Brasil Escola. Available online: https://brasilescola.uol.com.br/historiab/apagao.htm (accessed on 9 July 2022).
11. ABNT—Associação Brasileira de Normas Técnicas. *NBR 15.220: Desempenho Térmico de Edificações*; ABNT: Rio de Janeiro, Brazil, 2003.
12. ABNT—Associação Brasileira de Normas Técnicas. *NBR 15.575: Edificações Habitacionais—Desempenho*; ABNT: Rio de Janeiro, Brazil, 2013.
13. INMETRO—Instituto Nacional de Metrologia, Qualidade e Tecnologia. *Anexo da Portaria Inmetro N° 18/2012 Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Residenciais—PROCEL RTQ-R*; INMETRO: Rio de Janeiro, Brazil, 2012.
14. Monteiro, C.S.; Causone, F.; Cunha, S.; Pina, A.; Erba, S. Addressing the Challenges of Public Housing Retrofits. *Energy Procedia* **2017**, *134*, 442–451. [CrossRef]
15. Duvier, C.; Anand, P.B.; Oltean-Dumbrava, C. Data Quality and Governance in a UK Social Housing Initiative: Implications for Smart Sustainable Cities. *Sustain. Cities Soc.* **2018**, *39*, 358–365. [CrossRef]
16. Gonzalez-Caceres, A.; Bobadilla, A.; Karlshøj, J. Implementing post-occupancy evaluation in social housing complemented with BIM: A case study in Chile. *Build. Environ.* **2019**, *158*, 260–280. [CrossRef]
17. Naghshbandi, S.N. BIM for facility management: Challenges and research gaps. *Civ. Eng. J.* **2017**, *2*, 679–684. [CrossRef]
18. Mohanta, A.; Das, S. BIM as facilities management tool a brief review. In Proceedings of the 7th International Conference on Sustainable Built Environment, Earl's Regency Hotel, Kandy, Sri Lanka, 16–18 December 2017.
19. Li, X.; Wu, P.; Shen, G.Q.; Wang, X.; Teng, Y. Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. *Autom. Constr.* **2017**, *84*, 195–206. [CrossRef]
20. ABNT—Associação Brasileira de Normas Técnicas. *NBR 15.965: Sistema de Classificação da Informação da Construção*; ABNT: Rio de Janeiro, Brazil, 2011.
21. BRASIL. *Decreto n° 9.377, de 17 de Maio de 2018*; Section 1; Institui a Estratégia Nacional de Disseminação do Building Information Modelling, Diário Oficial da União: Brasília, Brazil, 2018; p. 3. Available online: https://www2.camara.leg.br/legin/fed/decret/2018/decreto-9377-17-maio-2018-786731-publicacaooriginal-155623-pe.html (accessed on 10 January 2021).
22. BRASIL. *Lei n° 10.306, de 2 de Abril de 2020*; Estratégia Nacional de Disseminação do Building Information Modeling—Estratégia BIM BR; Presidência da República: Brasília, Brazil, 2020; Available online: https://presrepublica.jusbrasil.com.br/legislacao/828077751/decreto-10306-20#art-1 (accessed on 10 January 2021).
23. Iamamoto, L.; Schveitzer, F. Mapeamento de Maturidade BIM Brasil. Relatório Técnico. 2020. Available online: https://www.sienge.com.br/relatoriomapeamento-de-maturidade-bim/ (accessed on 15 August 2021).
24. Caixa Econômica Federal. Selo Casa Azul: Boas Práticas Para Habitação Mais Sustentável. Brasília. 2010. Available online: https://labeee.ufsc.br/projetos/manual-selo-casa-azul-caixa (accessed on 1 July 2021).
25. Lima, L.M. *A Prática do Desenvolvimento Sustentável por Meio das Certificações Ambientais*; Universidade Federal de Pernambuco: Recife, Brazil, 2018.
26. Silva, A. *Avaliação de Pós-Ocupação de Habitações de Interesse Social: Estudo de Caso do Residencial Brahma em Garanhuns-PE*; Universidade de Pernambuco: Recife, Brazil, 2022.
27. Dauletbek, A.; Zhou, P. BIM-based LCA as a comprehensive method for the refurbishment of existing dwellings considering environmental compatibility, energy efficiency, and profitability: A case study in China. *J. Build. Eng.* **2022**, *46*, 103852. [CrossRef]

28. Montiel-Santiago, F.J.; Hermoso-Orzáez, M.J.; Terrados-Cepeda, J. Sustainability and Energy Efficiency: BIM 6D. Study of the BIM Methodology Applied to Hospital Buildings. Value of Interior Lighting and Daylight in Energy Simulation. *Sustainability* **2020**, *12*, 5731. [CrossRef]
29. Chaves, A.M.S. *Indicadores de Qualidade Ambiental de Áreas Verdes Públicas Da Cidade de Garanhuns-PE*; Universidade Federal de Sergipe: Aracaju, Brazil, 2017.
30. BRASIL. *Lei n° 12.212, de 20 de Janeiro de 2010*; Planalto Federal: Brasília, Brazil, 2010. Available online: http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2010/Lei/L12212.htm (accessed on 1 July 2021).
31. Brinda, T.N.; Prasanna, E. Developments of facility management using building information modeling. *Int. J. Innov. Res. Sci. Eng. Technol.* **2014**, *3*, 11379–11386.
32. Danish, M.S.S.; Senjyu, T.; Ibrahimi, A.M.; Ahmadi, M.; Howlader, A.M. A managed framework for energy-efficient building. *J. Build. Eng.* **2019**, *21*, 120–128. [CrossRef]
33. Hu, Z.-Z.; Tian, P.-L.; Li, S.-W.; Zhang, J.-P. BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase. *Adv. Eng. Softw.* **2018**, *115*, 1–16. [CrossRef]
34. Sadeghi, M.; Elliott, J.W.; Porro, N.; Strong, K. Developing building information models (BIM) for building handover, operation and maintenance. *J. Facil. Manag.* **2019**, *17*, 301–316. [CrossRef]
35. Tzortzopoulos, P.; Ma, L.; Soliman Junior, J.; Koskela, L. Evaluating Social Housing Retrofit Options to Support Clients' Decision Making—SIMPLER BIM Protocol. *Sustainability* **2019**, *11*, 2507. [CrossRef]
36. Gerrish, T.; Ruikar, K.; Cook, M.; Johnson, M.; Phillip, M. Using BIM capabilities to improve existing building energy modelling practices. *Eng. Constr. Archit. Manag.* **2017**, *24*, 190–208. [CrossRef]
37. Bastos Porsani, G.; Del Valle de Lersundi, K.; Sánchez-Ostiz Gutiérrez, A.; Fernández Bandera, C. Interoperability between Building Information Modelling (BIM) and Building Energy Model (BEM). *Appl. Sci.* **2021**, *11*, 2167. [CrossRef]
38. Acampa, G.; Diana, L.; Marino, G.; Marmo, R. Assessing the Transformability of Public Housing through BIM. *Sustainability* **2021**, *13*, 5431. [CrossRef]
39. Sheth, A.; Price, A.; Glass, J. BIM and refurbishment of existing healthcare facilities. In Proceedings of the 26th Annual ARCOM Conference, Leeds, UK, 6–8 September 2010; Egbu, C., Ed.; ARCOM: England, UK, 2010.
40. Carpino, C.; Bruno, R.; Arcuri, N. Social housing refurbishment for the improvement of city sustainability: Identification of targeted interventions based on a disaggregated cost-optimal approach. *Sustain. Cities Soc.* **2020**, *60*, 102223. [CrossRef]
41. Sanhudo, L.; Ramos, N.M.; Martins, J.P.; Almeida, R.M.; Barreira, E.; Simões, M.L.; Cardoso, V. Building information modeling for energy retrofitting—A review. *Renew. Sustain. Energy Rev.* **2018**, *89*, 249–260. [CrossRef]
42. Kim, K.P.; Park, K.S. Housing information modelling for BIM-embedded housing refurbishment. *J. Facil. Manag.* **2018**, *16*, 299–314. [CrossRef]
43. Hosseini, M.R.; Roelvink, R.; Papadonikolaki, E.; Edwards, D.J.; Parn, E. Integrating BIM into facility management: Typology matrix of information handover requirements. *Int. J. Build. Pathol. Adapt.* **2018**, *36*, 2–14. [CrossRef]
44. Peng, Y.; Lin, J.-R.; Zhang, J.-P.; Hu, Z.-Z. A hybrid data mining approach on BIM-based building operation and maintenance. *Build. Environ.* **2017**, *126*, 483–495. [CrossRef]
45. Ahn, D.; Cha, H. Integration of Building Maintenance Data in Application of Building Information Modeling (BIM). *J. Build. Constr. Plan. Res.* **2014**, *2*, 166–172. [CrossRef]
46. Patacas, J.; Dawood, N.; Kassem, M. BIM for facilities management: A framework and a common data environment using open standards. *Autom. Constr.* **2020**, *120*, 103366. [CrossRef]
47. Heaton, J.; Parlikad, A.K.; Schooling, J. Design and development of BIM models to support operations and maintenance. *Comput. Ind.* **2019**, *111*, 172–186. [CrossRef]
48. Ilter, D.; Ergen, E. BIM for building refurbishment and maintenance: Current status and research directions. *Struct. Surv.* **2015**, *33*, 228–256. [CrossRef]
49. Kensek, K. BIM Guidelines Inform Facilities Management Databases: A Case Study over Time. *Buildings* **2015**, *5*, 899–916. [CrossRef]
50. Gong, X.; Michel, P.; Cantin, R. Multiple-criteria decision analysis of BIM influences in building energy management. *Build. Simul.* **2019**, *12*, 641–652. [CrossRef]
51. Alwan, Z. BIM performance framework for the maintenance and refurbishment of housing stock. *Struct. Surv.* **2016**, *34*, 242–255. [CrossRef]
52. Alileche, L.; Shahrour, I. Use of BIM for Social Housing Management. In Proceedings of the 17th International Conference on Computing in Civil and Building Engineering, Tampere, Finland, 5–7 June 2018.
53. Rogage, K.; Clear, A.; Alwan, Z.; Lawrence, T.; Kelly, G. Assessing building performance in residential buildings using BIM and sensor data. *Int. J. Build. Pathol. Adapt.* **2020**, *38*, 176–191. [CrossRef]
54. Park, K.; Kim, K.P. Essential BIM input data study for housing refurbishment: Homeowners' preferences in the UK. *Buildings* **2014**, *4*, 467–487. [CrossRef]
55. Kim, J.-U.; Hadadi, O.A.; Kim, H.; Kim, J. Development of A BIM-Based Maintenance Decision-Making Framework for the Optimization between Energy Efficiency and Investment Costs. *Sustainability* **2018**, *10*, 2480. [CrossRef]
56. Triana, M.A.; Lamberts, R.; Sassi, P. Sustainable energy performance in Brazilian social housing: A proposal for a Sustainability Index in the energy life cycle considering climate change. *Energy Build.* **2021**, *242*, 110845. [CrossRef]

57. Araszkiewicz, K. Digital Technologies in Facility Management—The state of Practice and Research Challenges. *Procedia Eng.* **2017**, *196*, 1034–1042. [CrossRef]
58. Singh, P.; Sadhu, A. Multicomponent Energy Assessment of Buildings using Building Information Modeling. *Sustain. Cities Soc.* **2019**, *49*, 101603. [CrossRef]
59. Pishdad-Bozorgi, P.; Gao, X.; Eastman, C.; Self, A.P. Planning and developing facility management-enabled building information model (FM-enabled BIM). *Autom. Constr.* **2018**, *87*, 22–38. [CrossRef]
60. PROCEL. Programa Nacional de Conservação de Energia Elétrica. Selo Procel. 2018. Available online: http://www.procelinfo.com.br/main.asp?TeamID=%7B88A19AD9-04C643FC-BA2E-99B27EF54632%7D (accessed on 1 August 2021).
61. AUTODESK®. 2020. Available online: http://usa.autodesk.com/adsk/servlet/pc/index?site (accessed on 15 August 2022).
62. Maile, T.; O'Donnell, J.; Bazjanac, V.; Rose, C. BIM-Geometry modelling guidelines for building energy performance simulation. In Proceedings of the BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, 26–28 August 2013; International Building Performance Simulation Association (IBPSA): Chambéry, France, 2013.
63. Anders Ohlsson, K.E.; Olofsson, T. Benchmarking the practice of validation and uncertainty analysis of building energy models. *Renew. Sustain. Energy Rev.* **2021**, *142*, 110842. [CrossRef]
64. Silva, P.J.; Sposto, R.M. A life cycle energy analysis of social housing in Brazil: Case study for the program "My House My Life". *Energy Build.* **2013**, *57*, 95–102. [CrossRef]
65. BRASIL. Ministério do Desenvolvimento Regional: Programa Casa Verde e Amarela. 2020. Available online: https://www.gov.br/mdr/pt-br/assuntos/habitacao/casa-verde-e-amarelaandanempirical (accessed on 1 July 2021).