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Energy Efficiency: Use of BIM in Energy Analysis for Multi-family Residences

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Abstract—**The design of large frames is a strategy used to increase the capture of natural light in buildings. However, this solution entails a higher expense related to the use of climate controls. Therefore, this work employs the Building Information Modeling (BIM) methodology, using the Revit software, and its Green Building Studio and Insight plug-ins, to define a roadmap to test various window frames on the facade and their effects on energy consumption. It was concluded that the size of the frames directly impacts energy efficiency, especially in hot climate regions, highlighting the relevance of this kind of study to obtain more sustainable buildings.**

Keywords—**building information modeling, energy efficiency, sustainable buildings, frames**

I. INTRODUCTION

The construction industry always had a major impact on waste generation and resource consumption, both during the construction phase and during use and operation [1]. In 2019, Brazilian households were responsible for 10.3% of the country's use of energy, with 46.0% of this consumption in the form of electricity, representing an increase of 3.5% in its use compared to 2018. In a country with a tropical climate, the demand for air conditioning has significantly contributed to this growth [2].

Given the country's economic situation, many people find themselves in low-end homes and without access to air conditioning technologies. Typically, sustainable measures are also not taken into account, resulting in poorer quality of life and higher building use costs for residents. However, it is possible to reduce the consumption of new constructions by up to 80%, present better comfort for the occupants, and still have greater durability, requiring an increase of only 5%–15% in the construction cost [3].

In this context, facade frames play an important role in terms of lighting and air conditioning. The larger the spans, the greater the levels of natural lighting, reducing the need for artificial lighting and greater ventilation, contributing to occupants' visual comfort. At the same time, the greater the exchange of heat with the external environment. In hot places like Brazil, the heating of the internal environment increases thermal discomfort and the need to use fans and air conditioning [4].

Therefore, the objective of this research is to develop a replicable workflow that allows the analysis of a standard building model, in which punctual changes are made according to the desired information. In this study, the window areas were changed in order to observe their influence on energy consumption. The work also aims to highlight the importance and practicality of carrying out simulation studies, since they can present a great gain not only in terms of sustainability but also financially.

II. MATERIALS AND METHODS

The study was conducted based on a three-dimensional model and its respective location. Then a solar study was carried out using conceptual masses that will define the best position and orientation for the project within the terrain. This procedure also allows for an analysis of the insolation to be carried out, so that it is possible to observe how the facades are exposed to the sun during the day and their differences throughout the year, as well as the relationship between this exposure and the shadows, helping in the distribution of frames on the facades.

The next step is to enter information about the building's use, such as the usage pattern, the expected number of people, the planned active lighting, and HVAC system options to be evaluated. Thus, the analysis phase of different models can then begin. These models are defined through parameter changes within the program, such as the typology of materials and families, frame

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sizes, and building orientation. As the BIM methodology uses parametric projects, these models automatically have lists of materials used, which facilitates the calculation of the implementation cost. At the same time, the analysis programs provide the annual consumption of electricity, fuel, and water, making it possible to calculate the cost of operating the building, along with maintenance information.

To help create the model, it is possible to define reference parameters, such as maximum energy consumption values, or the accepted total air conditioning expenditure, and from these values eliminate models that do not meet minimum criteria. Finally, the valid models are compared and then the decision-maker evaluates which are the best options. The steps are described in Fig. 1.

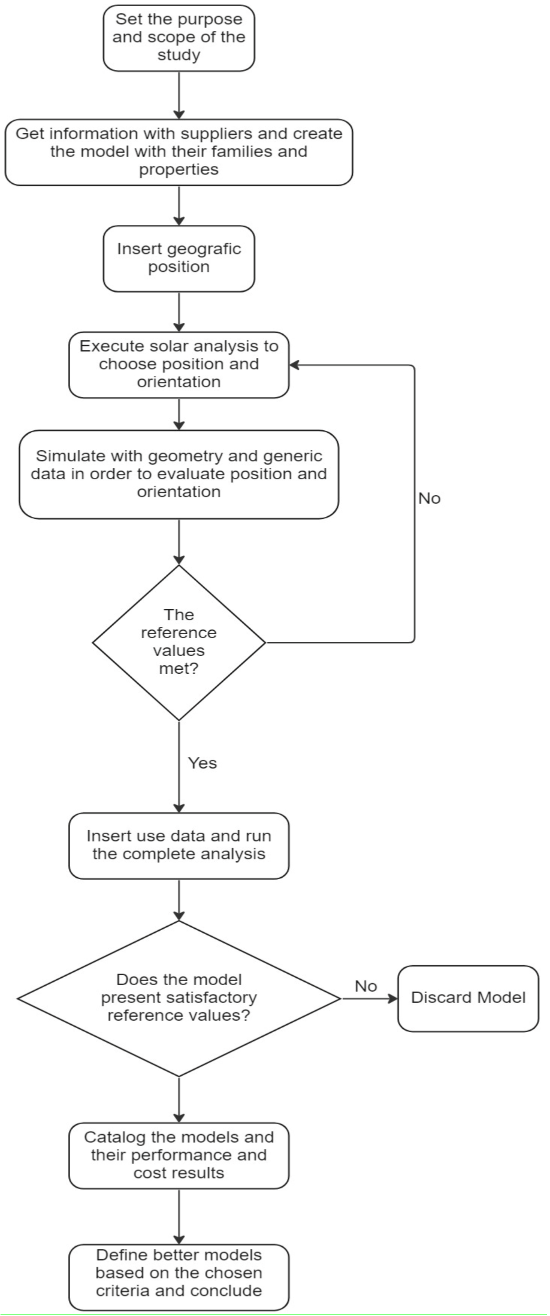

Figure 1. Energy efficiency analysis flowchart.

III. THE PROJECT

The selected project was a multifamily residence with eight floors, one of them being the ground floor, and one more roof floor and technical área. Each floor consists of four units, totaling thirty-two apartments, in addition to an access hall on each floor, with an elevator and stairs, totaling 1,785m² of built area. Each unit has two bedrooms, a bathroom, a kitchen with a laundry área, and a living room. Among the different models, only the arrangement of the frames on the facades will be changed. The model was created using Autodesk Revit 2021 software.

Different families were created for each of the constructive elements: concrete slabs, masonry, ceiling, floor, and frames. The masonry modeling is specified in Tables I and II.

TABLE I. INTERNAL MASONRY COMPOSITION

Material	Thickness (cm)
PVA painting / Ceramic Plate	1.00
Mortar	2.00
Ceramic masonry	9.00
Mortar	2.00
PVA painting / Ceramic Plate	1.00

TABLE II. EXTERNAL MASONRY COMPOSITION

Material	Thickness (cm)
PVA painting / Ceramic Plate	1.00
Mortar	2.00
Ceramic masonry	14.00
Mortar	2.00
PVA painting / Ceramic Plate	1.00

It is important to note that the finish can vary between PVA paint for indoor areas and ceramic for wet areas. The stair wall is finished in PVA paint and the elevator has no interior finish. The slab was modeled in reinforced concrete, the apartment's floor with ceramic tile, the hall floor in slate stone, and the ceiling in plaster. The materials were selected from equivalents from the program itself, taking advantage of their thermal properties. The thickness of each layer was chosen based on the standard used in practice for buildings.

The doors, hall windows, and bathroom hinges are from families already made available by Revit, but the living room, kitchen, and bedroom windows were modeled to meet the desired dimensions for the study.

Based on the standard project, eight families of frames were created with different dimensions, as shown in Table III, always maintaining the aluminum frame and 4 mm thick smooth glass.

TABLE III. DIMENSIONS OF THE MODELED FRAMES

Model	Height (mm)	Width (mm)
1	1.029	1.400
2	1.200	1.200
3	1.400	1.029
4	1.400	1.400
5	1.225	1.600
6	1.600	1.225
7	1.200	1.400
8	1.500	1.200

In addition to information about the constructive components, it is also necessary to provide the program with the usage characteristics and the environment. In Revit, the project needs to be geographically located so that the nearest weather station can be associated with the project. To calculate the cooling loads, which will be used in the subsequent analysis of the model energy efficiency, the maximum dry bulb temperature for each month of the year is used. This corresponds to the temperature that is exceeded, on average, during 1% of the time in that month for the locality. This information, as well as the weather stations, belong to the ASHRAE database. The nearest station was then selected, highlighted in orange, as shown in Fig. 2.

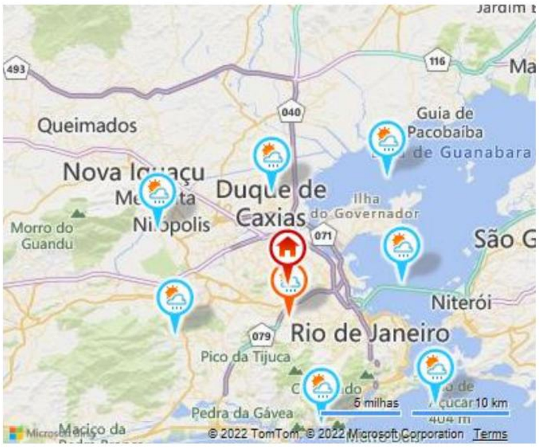

Figure 2. Project geographic location.

The building had its true north rotated in relation to the project's north by 45 º counterclockwise, to match the main facade with the direction of the street, as shown in Fig. 3. For the analyses, the direction used is true north, with the north of the project used only to simplify the project. As it is a densely urbanized area, hypotheses that would change the orientation of the construction were not considered.

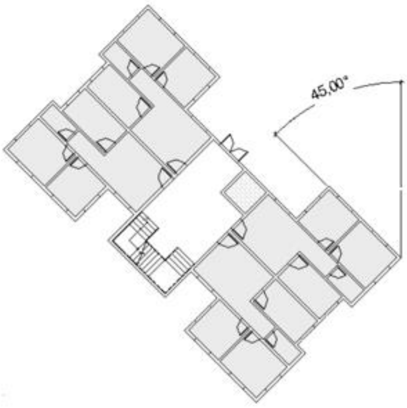

Figure 3. Project true North orientation.

For the analysis to be carried out, it is necessary to define the type of construction, which must reflect the planned use of the building. This specification becomes the standard for the entire project, and its information is defined based on data from ASHRAE 90.1–2019 [5], ASHRAE 90.2–2018 [6], and ASHRAE 62.1 [7]. Table IV contains the data used for the project.

TABLE IV. DATA FOR MULTI-FAMILY BUILDINGS

Parameters	Corresponding Value
Occupation type	Residential
Inhabitantes / 1m ^{2}	2.70
Sensitive heat gain per person (W/person)	73.30
Latent heat gain per person (W/person)	58.60
Lighting load density (W/m ^{2})	6.50
Equipment load density (W/m ^{2})	5.40
Infiltration flow (ACH)	0.40
Outside air flow per person (L/s)	-
Outside air flow by area (L/s)	1.30

It is also necessary to choose the air conditioning system. In this study, the split residential model was chosen. Finally, the material properties were adjusted so that the details of the elements that make up the model were used, instead of using generic assumptions.

Another important step is the subdivision of the model into spaces, which must be created throughout the building. The environments that will be inhabited must have their spaces categorized as such, while the environments where there will be no people, must have their spaces categorized as unoccupied. This definition of spaces influences energy analysis and is also linked to the type of building.

It is important to create many different spaces so that the analyzes are more accurate, because when joining several environments in a single space, the software only calculates the net heat loss or gain, without really separating where this loss or gain comes from, which can affect calculations of cooling and heating loads.

IV. SOLAR ANALYSIS

The summer and winter solstice days were chosen because they are critical days. The selected times were 7 am, 12 pm, and 5 pm, to follow the interaction between the model and the sun at the beginning, middle, and end of the day. Based on these studies, it was noticed that the west facade is very exposed to the sun at critical moments (Fig. 4), so it was decided that the only frames present would be bathrooms and kitchens, to allow an airy environment.

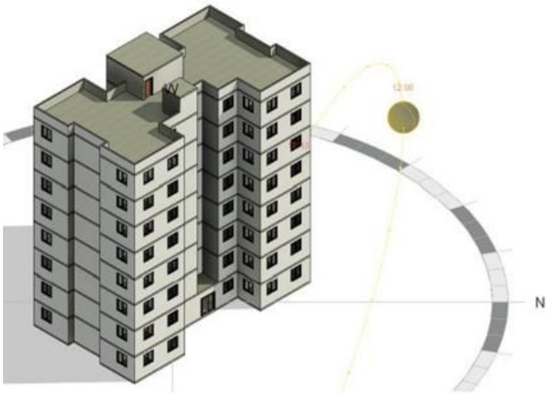

Figure 4. Solar analysis in Autodesk Revit®.

V. THE MODELS

To perform energy analysis in Revit, you first need to create a building energy analytical model, in which all the functional and modeling systems that define an enclosed space are abstracted into a model consisting of spaces and surfaces. Nine different models were created, the only difference being the facade frames. The objective of the study was to create facades with a PAF close to that indicated in previous studies, with frames that had the same area, but different dimensions, thus maintaining this percentage. The Insight plugin automatically calculates the PAF of each facade and presents alternatives of this percentage for each facade, and how each of them affects the energy consumption of the model. The results are presented as shown in Fig. 5.

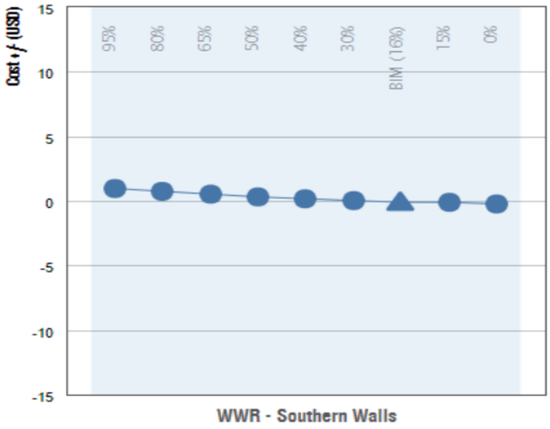

Figure 5. PAF of the South facade in Autodesk Insight®.

The Green Building Studio plugin provides users with energy consumption in KWh and indicates the usage distribution of this consumption in three categories: lighting, air conditioning, and miscellaneous uses. Fig. 7 indicates how the Green Building Studio application informs this distribution.

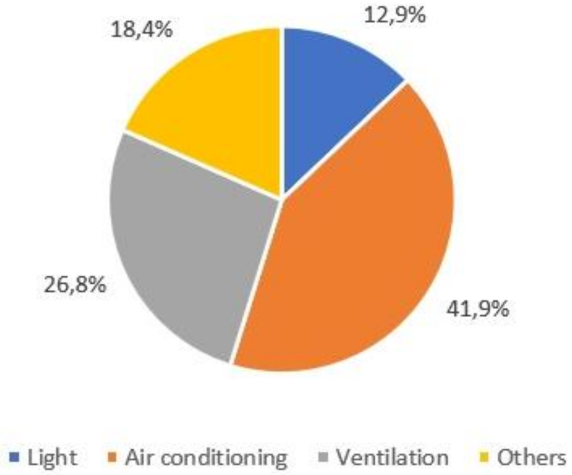

Figure 6. Distribution of the model annual electricity usage.

Model 1–In this model, the East and West facades have the same frames. Bathroom frames are 406 × 610 mm, kitchen frames are 1200 × 1500 mm, and bedroom frames are 1400 × 1400 mm. Thus, both facades have PAF equal to 19%. The South and North facades have all frames measuring 1400 × 1400 mm, but the North facade also has the hall floor frame, which measures 915 × 1830 mm. Thus, the South façade has a PAF of 19% and the North façade has a PAF of 23%.

Model 2-Using solar studies results, it was decided to remove the window frames from the rooms on the West facade, taking advantage of the fact that the same rooms also have another window on the North and South facades, with natural lighting. This facade, however, retains the bathroom and kitchen frames, as they are important areas for ventilation. In this way, the West façade has a PAF of 13%. It should be noted that in all other models the West facade will repeat the characteristics of Model 2. The North, South, and East facades have not been altered.

Model 3-The window frames of the rooms on the East facade are 1029 × 1400 mm, with a PAF of 17%. The North and South facades have 1225 × 1600 mm frames. The North facade has a PAF of 22% and the South of 18%.

Model 4-For the North and South facades, frames measuring 1600 × 1225 mm were used. The North facade has a PAF of 23% and the South of 19%. The East facade remained unchanged, a detail that will be repeated until model 8.

Model 5-For the North and South facades, 1200×1200 mm frames were used. The North facade has a PAF of 18% and the South of 14%.

Model 6-For the North facade, frames measuring 1029 × 1400 mm were used, with a PAF of 18%. For the south facade, 1200×1200 mm frames were used, with a PAF of 14%.

Model 7-For the North facade, frames measuring 1400×1400 mm were used, with a PAF of 23%. For the South facade, 1200×1200 mm frames were used, with a PAF of 14%.

Model 8-For the North facade, 1200×1200 mm frames were used, with a PAF of 18%. For the south façade, frames measuring 1400×1029 mm were used, with a PAF of 14%.

Model 9-For the East facade, 1400×1400 mm frames were used, with a PAF of 18%. For the North facade, 1200×1200 mm frames were used, with a PAF of 18%. For the South facade, 1400×1400 mm frames were used, with a PAF of 19%.

VI. RESULTS AND DISCUSSION

The energy consumption and cost values were obtained for each model, which were separated between lighting and air conditioning. The cost estimate was performed using residential energy consumption data for each month of 2020, in the Southeast region, from the national Energy Research Company. From these values, a percentage of annual consumption was estimated for each month, represented in Table V.

TABLE V. MONTHLY DISTRIBUTION OF ENERGY USE

Month	Percentage (%)
January	8.80
February	8.42
March	8.42
April	8.11
May	7.75
June	7.72
July	7.85
August	8.10
September	5.408.22
October	8.92
November	8.57
December	9.11

Based on these values, an energy tariff flag was established for each month based on a historical series from January 2014 to July 2021. The values updated on June 29, 2021, were used, according to Table VI.

TABLE VI. VALUE OF TARIFF FLAGS

Tariff flag	Addition per kWh (R$)	Applied months
Green	----	January to April and December
Yellow	0.01874	May and November
Red	0.09492	June to October

The value without tariff was calculated using electric power company low voltage values, in force since March 15, 2021. Table VII presents the distribution of energy consumption and expenditure for each model.

TABLE VII. POWER CONSUMPTION BY MODEL

Model	Total Spend (kWh)	Total Cost (R$)	Lighting Spend (kWh)	Lighting Cost (R$)	HVAC Spend (kWh)	HVAC Cost (kWh)
1	392,645	298,662	48,687	37,034	274,458	208,765
2	384,021	292,103	48,770	37,097	265,742	202,135
3	380,362	289,319	48,686	37,032	262,069	199,341
4	382,819	291,188	48,618	36,980	264,527	201,211
5	373,039	283749	48,868	37,171	254,785	193,801
6	372,993	288,423	48,862	37,783	254,754	196,993
7	379,184	283,745	48,914	36,603	260,879	195,216
8	373,033	283,745	48,867	37,170	254,781	193,798
9	377,882	287,433	48,746	37,079	259,605	197,466

From the models, it is possible to observe that, in general, the higher the PAF, the higher the consumption of air conditioning and the lower the consumption of lighting. However, in climates such as Rio de Janeiro, which are hot and with a high incidence of solar radiation, the impact of air conditioning on energy consumption is much greater than the impact of lighting. It is also possible to notice that frames with the same area, but different dimensions, translate into different consumption of air conditioning and lighting. Models with frames with a width greater than height present lower consumption than windows with a height greater than width. However, for the frame models used in this study with less than $2.00m^2$, the observed effects are insignificant. For larger frame areas, greater energy impacts would be observed.

VII. CONCLUSIONS

One of the objectives of this paper was to demonstrate how BIM tools can be used to assist decision-making in construction projects. The software can analyze the smallest differences between models and indicate the cost of air conditioning and lighting in a practical way. Non-geometric information only needed to be entered once, eliminating the need to waste time repeating the process for all analyses. The main difficulty was the standardization of the software for the American and European markets. Thus, the list of materials, the conditions of use of the buildings, and the calculation of the cost of use of the building provided by the program do not have the necessary characteristics to adapt to the Brazilian market, requiring many adaptations.

In addition, the case study of this theoretical model served to show the use of these energy analysis programs, producing a replicable and adaptable roadmap that allows evaluation of the best energy options for the project. For future work, it is necessary to delve deeper into the psychological effects of the presence of openings in relation to the sensation of thermal comfort, and how much this affects the occupants' indulgence in discomfort, something that is not measured or taken into account by the analysis of energy programs.

Finally, it is interesting to carry out studies following NBR 15220 [8], which aims to adapt single-family housing of social interest to the climate in which these dwellings are, defining constructive guidelines for each bioclimatic zone.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Thiago C. C. Solberg, Karoline V. Figueiredo, and Assed N. Haddad; Methodology, Thiago C. C. Solberg, Karoline V. Figueiredo, and Assed N. Haddad; Validation, Thiago C. C. Solberg, Kéyshilla N. S. Rodrigues and Olavo P. C. Bastos; Formal analysis, Bruno Barzellay F. da Costa, Gisele S. Barbosa, and Claudia Garrido; Investigation, Thiago C. C. Solberg and Karoline V. Figueiredo; Resources, Thiago C. C. Solberg and Assed N. Haddad; Data Curation: Thiago C. C. Solberg, Kéyshilla N. S. Rodrigues, and Olavo P.C. Bastos; Writing—original draft preparation, Thiago C. C. Solberg and Karoline V. Figueiredo; Writing—review and editing, Kéyshilla N. S. Rodrigues, Olavo P. C. Bastos, Bruno Barzellay F. da Costa, Gisele S. Barbosa, and Claudia Garrido; Visualization, Bruno Barzellay F. da Costa; Supervision, Assed N. Haddad; Project administration, Assed N. Haddad. All authors had approved the final version of the manuscript.

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