RESIDE: REPRESENTATIVE DATABASES FOR MULTI-CRITERIA DECISION TOOL

RESIDE: BANCOS DE DADOS REPRESENTATIVOS PARA FERRAMENTA DE DECISÃO MULTICRITÉRIO

RESIDE: BASES DE DATOS REPRESENTATIVAS PARA HERRAMIENTA DE DECISIÓN MULTICRITERIO.

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ABSTRACT

RESIDE is a software that allows designers and decision-makers to simultaneously consider issues related to energy consumption for environmental conditioning and water heating, construction costs and public policies from the initial planning stages of residential developments. However, its use is conditional on the existence of a database for the context analyzed. Understanding the growing importance of addressing the innate complexity in sustainability-oriented design activities, this article presents a procedure to identify representative databases for the state of Minas Gerais, in order to enable the use of the RESIDE multi-criteria decision tool.

KEYWORDS

Multicriteria Decision Method; Thermoenergetic Performance; Housing Policy.

RESUMO

O software RESIDE permite aos projetistas e tomadores de decisão desde as fases iniciais de planejamento dos empreendimentos residenciais considerar simultaneamente questões relacionadas ao consumo de energia para condicionamento ambiental e aquecimento de água, custos de construção e políticas públicas. Contudo, sua utilização é condicionada à existência de um banco de dados para o contexto analisado. Entendendo a importância cada vez maior de abordar a complexidade presente na atividade de projeto voltado a busca pelo desenvolvimento sustentável, este artigo apresenta um procedimento para identificação e construção de bancos de dados representativos para o estado de Minas Gerais, a fim de viabilizar a utilização da ferramenta de decisão multicritério RESIDE.

PALAVRAS-CHAVE

Método de Decisão Multicritério; Desempenho Termoenergético; Política habitacional.

RESUMEN

El software RESIDE permite a los diseñadores y tomadores de decisiones, desde las etapas iniciales de planificación de los proyectos residenciales, considerar simultáneamente cuestiones relacionadas con el consumo de energía para acondicionamiento ambiental y calentamiento de agua, costos de construcción y políticas públicas. No obstante, su uso

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está condicionado a la existencia de una base de datos para el contexto analizado. Entendiendo la importancia cada vez mayor de abordar la complejidad presente en la actividad de diseño orientada a la búsqueda del desarrollo sostenible, este artículo presenta un procedimiento para la identificación y construcción de bases de datos representativas para el estado de Minas Gerais, con el fin de viabilizar el uso de la herramienta de decisión multicriterio RESIDE.

PALABRAS CLAVE

Método de Decisión Multicriterio; Desempeño Termoenergético; Política habitacional.

1. INTRODUCTION

It is increasingly observed in various spheres of society that human activities are expanding in complexity. Mitchell (2009) begins her work by defining complexity through biological (environmental), economic, and social examples. Throughout the work, although the author does not directly reference the concept of sustainable development, the in-depth exploration of complexity science and its implications in computational fields and information processing allows for inferences about how these concepts influence project activities aimed at sustainability.

The building design processes have grown more complex as they address an increasing number of criteria, which aligns with the principles of sustainable development. However, there is not always enough time or tools available to make decisions with the required accuracy. The challenge of improving the environmental performance of buildings, in a context of growing concern over reducing negative environmental impacts, has driven the search for innovative, effective, and accessible tools to assist in decision-making moments for entrepreneurs and designers. In this scenario, where designers are under pressure to enhance their responsiveness within tight deadlines, applications that incorporate multicriteria analysis methods emerge as strategic solutions, enabling the simultaneous consideration of various quantitative and qualitative factors in the processes of planning and designing buildings.

Considering this reality and the increasing energy demand for environmental conditioning in residential buildings—between 2005 and 2017, the ownership of air conditioning units in homes grew by 9% per year (EPE, 2018)—the RESIDE tool (Loura et al., 2019) was developed to assist in the multicriteria decision-making process regarding solutions for building envelopes and water heating systems (SAA) for bathing, taking into account the costs and benefits of these solutions in the early stages of residential project design. The RESIDE framework was designed with the Brazilian construction market context in mind, integrating the thermal and energy performance of residential buildings with the costs associated with envelope solutions and SAA, aiming to meet the needs of public administrators involved in housing policy and entrepreneurs. For the former, RESIDE enables the formulation of housing policies based on energy efficiency in a consistent and responsible manner. From the perspective of entrepreneurs or designers, this software can directly assist in decisions for specific projects.

To make the software applicable to multiple national climate and urban-related contexts, it is necessary to develop databases that represent a given reality. This article aims to document the development stage of representative databases for the state of Minas Gerais, encompassing different economic and climatic scenarios, as well as construction typologies. The effort here is to achieve a relevant scope that allows free use of RESIDE throughout the state. Additionally, it discusses the importance of providing easily accessible digital multicriteria analysis tools in the design process to support technical decisions based on the rational use of environmental and economic resources.

2. LITERATURE REVIEW

RESIDE is a software developed based on the ELECTRE-III (ELimination and Choice Expressing Reality) method, introduced by Roy (1977). This method constructs its classification process from a set of preferences. Generally, two alternatives are compared at a time to determine whether there is (i) a strong or weak preference for one action over another, (ii) indifference between the actions, or (iii) incomparability between the actions. The evaluation of each action or alternative \(A_i \) (where \(i = 1,2, ..., n \)) across various criteria \(Cr1, Cr2, ..., Crm \) is performed using a vector with several attributes \(\{E_{i1}, E_{i2}, E_{i3}, ..., E_{im}\}\). Preference limits include "P," which indicates the difference beyond which a strict preference can be established, "Q," which marks the difference beyond which no preference can be established, and "V," the veto limit for each criterion, representing the difference beyond which the comparison between two actions should be ignored.

In summary, setting up the evaluation matrix requires (i) a list of alternatives, (ii) criteria and their respective weights, and (iii) the definition of the limits. After performing calculations and tests for over-ranking, agreement, and disagreement, the algorithm constructs two matrices—one for agreement and one for disagreement—in which all possible pairs of actions are compared. From these, a third matrix, called the credibility matrix, is generated. The classification of alternatives is established based on this credibility matrix, with alternatives ordered from the best to the worst based on their descending ranking.

Despite being developed in the 1970s, ELECTRE-III remains widely used for classifying alternatives based on multiple criteria. A brief review of recent literature from 2019 to 2024 shows that this multi-criteria decision-making

(MCDM) method continues to be relevant for decision support in areas related to energy, sustainability, and the built environment. For instance, Ebadi Tork Ayesha et al. (2019) utilized ELECTRE-II as a tool for determining the site for solid waste treatment infrastructure. Battisti (2022) employed ELECTRE-III to develop an evaluation method capable of synthesizing judgments based on recognized objective parameters within Strategic Environmental Assessment procedures. Kosova et al. (2022) used MCDM tools, including ELECTRE-III, to analyze resilience in a county in Albania. Labed et al. (2024) introduced a flexible multi-criteria decision-making system for regional planning, developed from an enhanced version of ELECTRE-III. Finally, Salvador et al. (2024) conducted a literature review demonstrating that this method has frequently been applied to supplier selection, either alone or integrated with other MCDM methods.

In RESIDE, ELECTRE-III is applied to create representative databases for different contexts based on output from thermal energy simulations, construction material and service costs, and targets available in national planning instruments such as the National Energy Plan and the National Energy Efficiency Plan. A database must be created for each residential construction typology, considering whether it is single-family or multi-family, the number of floors for multi-family units, and the construction standard (Social Housing, Normal or High standards), according to NBR 12.721 (ABNT, 2006). Users should first select the most appropriate database for the construction typology of interest based on the climate and urban contexts. The next step requires the user to establish analysis alternatives. The software provides multiple options that can be chosen in each of its parameters, such as (i) eight building orientations, (ii) two options of opening-to-floor-area ratios, (iii) presence or absence sun shading devices on windows, (iv) opening rates on opposite and adjacent facades, (v) six types of wall systems, (vi) six roofing systems, and (vii) 14 water heating systems.

For each comparative analysis, users can select up to 16 distinct alternatives within a climate context, considering the same construction typology. These alternatives are evaluated based on six criteria: (i) percentage of hours of passive thermal comfort, (ii) condition of cross-ventilation, (iii) number of degree-hours for cooling, (iv) percentage variation in costs of envelope solutions, (v) government incentives for water heating technology, and (vi) complexity of the complete SAA (Water Supply and Sanitation) infrastructure for bathing. The characteristics of the ELECTRE-III method, based on non-compensatory analysis and incomparability between solutions, are crucial for ensuring the reliability of results in RESIDE. This approach prevents the favoring of alternatives that are highly valued by one or a few criteria but less valued by others. Since the criteria used are of varying levels of importance to different stakeholders in construction planning, non-compensatory analysis helps protect the interests of those with decision-making power while preventing the neglect of other important criteria.

Nome do Projeto

Autor da Análise

01/04/2024

BH_R8

Figure 1: RESIDE alternatives interface for parameters selection.

Source: created by the authors.

The software suggests weights for each criterion, but users can specify the weights that are most relevant to their analysis. Each database includes eight reference cases, one for each building orientation relative to geographic north, based on standard envelope solutions (walls and roofs) established by NBR 12.721 (ABNT, 2006) and the most common SAA solution in the analyzed context. For representative cities in Minas Gerais, this is typically the electric shower. This does not imply that this alternative is better or worse than others in that context. In fact, it reflects the current market practice in local construction, which is crucial in order to support the decision-making process.

The classification of alternatives is obtained by clicking "Calculate Result." RESIDE also allows users to perform a sensitivity analysis of the ranking. According to Tervonen et al. (2005), defining weights is one of the most critical parameters for multicriteria analysis using ELECTRE-III. Therefore, RESIDE emphasizes the importance of users being able to validate the ranking by varying criterion weights. Sensitivity analysis is not the only validation method. During database development, uncertainty analyses are conducted throughout the process of defining values of each criterion. Additionally, the ELECTRE-III method itself verifies the credibility of the generated matrices. Thus, the sensitivity analysis performed after ranking aims to evaluate the stability and consistency of the presented ranking.

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Teste

Autor da Análise
01/04/2024
BH_R3

Condição de ventilação natural cruzada	Percentual de horas de conforto higrotérmico passivo	Número de graus-horas para resfriamento	Variação percentual do custo das soluções de envoltória	Incentivo governamental (aquecimento de água)	Grau de complexidade (aquecimento de água)		
1	2	1	3	3	2		
10	61,8	9760	1303,6	10	10	Ação 01	X
10	61,9	9721.1	1026	20	20	Ação 02	R
10	67,4	6980.4	807,5	10	10	Ação 03	X
10	66,4	7392.4	721,05	10	20	Ação 04	X
20	62,8	9948.1	612	10	20	Ação 05	X
10	66,7	7965.2	1303,6	10	10	Ação 06	X
10	62	9677.3	1026	20	20	Ação 07	R
10	66,3	7853.6	950	10	10	Ação 08	X
-	-	-	-	-	-	Ação 09	L
-	-	-	-	-	-	Ação 010	L
-	-	-	-	-	-	Ação 11	L
-	-	-	-	-	-	Ação 12	L

Figure 2: Interface for criteria weight and list of alternatives on RESIDE.

Source: created by the authors.

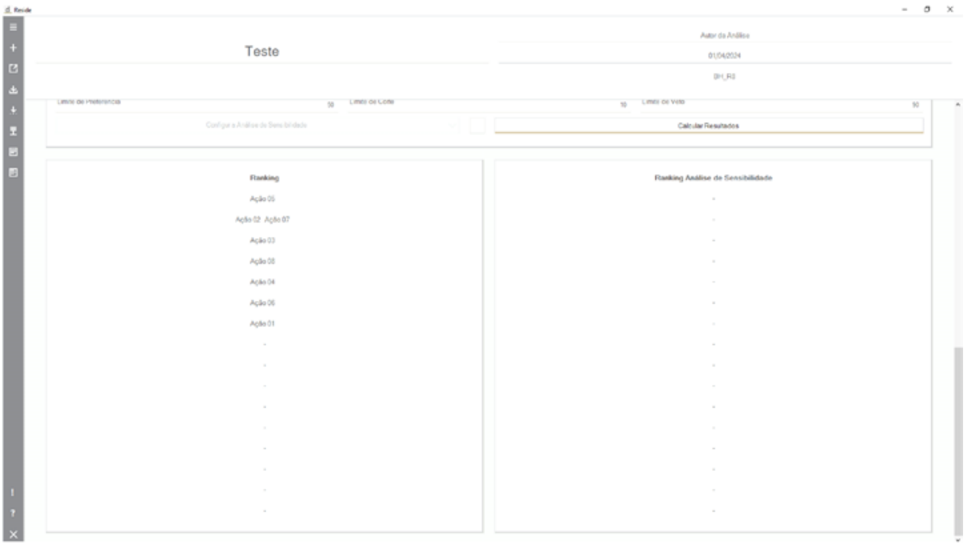

Figure 3: Classification and sensibility analysis interface on RESIDE.
Source: created by the authors.

3. METHODOLOGICAL PROCEDURES FOR REPRESENTATIVE DATABASE DEFINITION

Minas Gerais stands out in Brazil for at least two reasons: its climate diversity and its high number of municipalities. According to IBGE (2017), the state is divided into 13 intermediate geographic regions to organize its territory, considering political, socioeconomic, and cultural aspects for planning, management, and implementation of public policies.

Given the characteristics of RESIDE, it is evident that providing users with a variety of databases to represent different climate and urban contexts is crucial to enhance the accuracy of the analysis and support decision-making in the early stages of project development. However, considering the climate and constructive diversity, as well as the large number of municipalities, it would be unrealistic to expect the development of specific databases for each territory as a basic requirement for using the software.

In the initial effort to make RESIDE available, it was necessary to build databases that represented different regions of the state. Based on the intermediate regions (IBGE, 2017), cities with available TMY (Typical Meteorological Year) files were identified in each area. These cities were then classified according to their climate context, using the classifications established by Nimer (1979) and Köppen (Instituto de Pesquisas e Estudos Florestais, 2024).

According to Nimer (1979), Minas Gerais features eight different climates: hot, super humid climates with an average air temperature greater than 18ºC throughout the year; hot humid climates with 1 to 3 dry months; hot semi-humid climates with 4 to 5 dry months; hot semi-arid climates with 6 to 8 dry months; sub-hot climates with an average temperature between 15ºC and 18ºC in at least one month, humid with 1 to 3 dry months; sub-hot semi-humid climates with 4 to 5 dry months; mild mesothermal climates with an average temperature between 10ºC and 15ºC, humid with 1 to 3 dry months; and mild mesothermal semi-humid climates with 4 to 5 dry months.

Köppen (Instituto de Pesquisas e Estudos Florestais, 2024) classifies the state's climate into several categories: savanna climate with a drier season in summer (As), savanna climate with a drier season in winter (Aw), subtropical humid climate with summer concentrating 70% of precipitation (Cwa), temperate oceanic climate (Cfb), and subtropical highland climate (Cwb).

Based on the climate classification and the availability of TMY files, 13 representative cities were selected—one from each intermediate region—to illustrate the climate diversity described by both Nimer and Köppen. The next step involved studying the urban morphology of each of these 13 cities to identify the construction typologies and patterns cited in NBR 12.721 (ABNT, 2006) and most frequently observed in the area. Using Google Earth and Google Street View, a classification was made considering various typologies according to ABNT (2006). These included single-floor, low standard single-family buildings; single-floor, normal standard single-family buildings; four-story, multi-family low standard affordable buildings; four-story, multi-family normal standard affordable buildings; eight-story, multi-family low standard buildings; eight-story, multi-family normal standard buildings; and 16-story multi-family normal standard buildings.

In the effort to achieve representative databases for the state—understanding that every selection excludes some typologies present in these urban contexts—up to four of the most relevant constructive typologies were defined for each city.

4. REPRESENTATIVE DATABASE FOR MINAS GERAIS

Table 1 presents the 13 cities selected as representative contexts for the state from socioeconomic, cultural, and political perspectives—following the intermediate regions (IBGE, 2017)—and climate classifications adopted.

The software suggests weights for each criterion, but users can specify the weights that are most relevant to their analysis. Each database includes eight reference cases, one for each building orientation relative to geographic north, based on standard envelope solutions (walls and roofs) established by NBR 12.721 (ABNT, 2006) and the most common SAA solution in the analyzed context. For representative cities in Minas Gerais, this is typically the electric shower. This does not imply that this alternative is better or worse than others in that context; rather, it reflects the current market practice in local construction, which is crucial for supporting the decision-making process.

After analyzing the urban morphology of the chosen cities, it was possible to identify up to four predominant typologies in each, as shown in Table 2. This table also provides data such as population, according to IBGE Cities (2024), and the two key economic sectors, according to FJP (2024).

The analysis indicates the need to create 51 databases, a satisfactory and feasible number to produce given the amount of municipalities in the state—852 cities—and their climate and urban morphological diversity.

City	Nimer Classification	Köppen Classification
Belo Horizonte	Sub-warm Semi-humid with 4 to 5 dry months	Cwb
Montes Claros	Warm Semi-arid with 6 to 8 dry months	As
Teófilo Otoni	Warm Humid with 4 to 5 dry months	Aw
Formiga	Sub-Warm Semi-Humid with 4 to 5 dry months	Cwb
Governador Valadares	Warm Semi-humid with 4 to 5 dry months	Aw
Viçosa	Sub-warm Humid with 1 to 3 dry months	Cwa
São João del Rey	Mild mesothermal Semi-humid with 4 to 5 dry months	Cwb
Uberaba	Warm Semi-humid with 4 to 5 dry months	Cwa
Patos de Minas	Sub-warm Semi-humid with 4 to 5 dry months	Cwa
Timóteo	Warm Semi-humid with 4 to 5 dry months	Aw
Capinópolis	Warm Super-humid with 1 to 3 dry months	Aw
Pouso Alegre	Mild mesothermal humid with 1 to 3 dry months	Cfb
Varginha	Mild mesothermal Semi-humid with 4 to 5 dry months	Cwb

Table 1: Selected cities and climate classification.

Source: created by the authors.

5. DATABASE BUILDING PROCEDURE

The construction of the databases involves six steps, using a diverse set of information and tools, as follows:

- Modeling of construction typologies for thermal and energy simulations;
- Thermal and energy simulations;
- Processing of simulation data;
- Cost spreadsheet and comparative analysis;
- Parameters of public policies;
- Construction of the database file.

5.1 Constructive typology modeling for thermal and energy simulation

The work begins with modeling in SketchUp using the Euclid plugin for construction typologies based on the plans and sections present in NBR 12.721 (ABNT, 2006). After modeling the geometry, the process moves to the EnergyPlus, where adjustments are made for natural ventilation parameters, building occupation schedules, shading calculation methods, heat transfer, as well as specifying the location and external conditions of the elements (such as the differentiation between internal and external walls), among other essential parameters to ensure the accuracy of the energy simulations. The importance of groups related to material combinations (Construction and BuildingSurface), which determine the thermal properties of construction elements, and window protection (WindowShadingControl), which directly influences solar heat gain and consequently indoor thermal comfort, is emphasized. These settings generate different simulation files, allowing for a detailed analysis of the energy performance across different scenarios.

Additionally, the groups Building (North Axis), Parametric:SetValueForRun, and Parametric:FileNameSufix are crucial for performing simulations with varying solar orientations. These groups enable the automatic simulations for eight distinct solar orientations (N, NE, E, SE, S, SW, W, NW), providing a comprehensive view of how orientation impacts the thermal performance of a building. All settings in the software are made considering the orientations specified in the Inmetro Normative Instruction Procedure (INI-R) (INMETRO, 2022).

For each city, 144 files must be produced, resulting in 1152 simulations. Each output file contains information about thermal comfort status and degree-hours for long-term stay environments (bedrooms and living room) for each of the 8760 hours of the typical meteorological year. Given the volume of information, it is necessary for the researcher to plan the modeling work in advance by standardizing the nomenclature of the modeled surfaces and creating orientation maps for the modeling. This standardization not only ensures agile traceability for the researcher but also allows for the use of Python codes to reproduce the files.

City	Typologies and Construction Patterns	Population	Key Economic Fields
Belo Horizonte	PPB; R8B; R8N; R16N	2.315.560	Construction; Transportation and Storage
Montes Claros	R1N; PPB; PPN; R8N	414.240	Transportation and Storage; Communication and Information Services
Teófilo Otoni	R1B; R1N; PPB; R8N	137.418	Food Manufacturing; Construction
Formiga	R1B; R1N; PPB; PPN	68.248	Food Manufacturing; Transportation and Storage
Governador Valadares	R1B; R1N; PPB; PPN	257.171	Food Manufacturing; Construction
Viçosa	R1B; R1N; PPB; R8N	76.430	Food Manufacturing; Construction
São João del Rey	R1B; R1N; PPB; PPN	90.225	Transportation and Storage; Extractive Industries
Uberaba	R1B; R1N; PPB; R8N	337.836	Food Manufacturing; Energy

City	Typologies and Construction Patterns	Population	Key Economic Fields
Patos de Minas	R1B; R1N; PPB; R8N	159.235	Food Manufacturing; Agriculture
Timóteo	R1B; R1N; PPB; R8N	81.579	Steel Industry; Construction
Capinópolis	R1B; R1N; PPB	14.655	Energy; Transportation and Storage
Pouso Alegre	R1B; R1N; PPB; R8N	152.271	Food Manufacturing; Transportation and Storage
Varginha	R1B; R1N; PPB; R8N	136.467	Food Manufacturing; Transportation and Storage

Table 2: Typologies and Construction Patterns, Population and Key Economic Fields.
Source: created by the authors.

5.2 Thermal energy simulation

To speed up the process, the simulation is divided into batches according to the size of the openings and the presence or absence of sun shading: Large Window with Protection (JGCP), Large Window without Protection (JGSP), Medium Window with Protection (JMCP), and Medium Window without Protection (JMSP). Using the EnergyPlus Launch, group of Input Files are created for each folder, which consist of IDF (Input Data File) files and EPW (EnergyPlus Weather File) weather files that are specific to the studied city. In addition to organizing the simulation documents and their output, this folder separation prevents data overload, which could cause delays or errors during simulation, especially in cases of unexpected failures. By segmenting the files into smaller groups, it becomes easier to identify and correct potential issues without compromising the entire set of simulations, increasing the reliability and efficiency of the process.

5.3 Data processing of thermal and energy simulation

The simulation output is presented in “comma separated values” (.csv) files compatible with Excel, LibreOffice Calc, and Google Sheets. The output variables include the average air temperature and operative temperature for every hour of the typical year in all long-term stay environments. Using an equation to evaluate thermal comfort based on the neutral temperature calculated for the city, it is possible to determine whether the long-term stay environments are in a state of thermal comfort or not. In order to build the research databases, Humphreys' equation (1978 apud PEREIRA and ASSIS, 2010) was selected due to the climate conditions of Minas Gerais. The equation to be used must be defined for each new database constructed, based on the acclimatization characteristics of the local population. Thermal comfort was considered when the average air temperatures were up to 1ºC above the neutral temperature calculated for the month. The percentage of hours of passive hygrothermal comfort for each environment in a housing unit corresponds to the ratio between the total number of comfort hours throughout the year and the total hours of the year. The average value for each housing unit is calculated using a weighted average based on the area of the environment. Similarly, to calculate the building mean percentage, an average value of the results from each unit was defined, as all of them had the same area. No minimum limit for hygrothermal comfort was set using adaptive comfort indexes because, given the climate conditions of Minas Gerais, it is possible to overcome hygrothermal discomfort caused by cold with slightly heavier-than-usual clothing. The Report on Equipment Ownership and Usage Habits (ELETROBRÁS, 2019) supports this assertion, as it does not list any equipment exclusively for heating buildings.

The result of this process is an average percentage value for each construction alternative in the database, with a directly proportional evaluation, meaning higher values are more satisfactory than lower ones.

The second data processing procedure aims to obtain the cooling degree-hours based on the operative air temperature. The calculation of annual cooling degree-hours followed the INI-R methodology as presented in INMETRO (2022), with the values being weighted by the area of each environment to calculate the value for each housing unit. The average value for the building is then calculated from the averages of the housing units.

The result is expressed in the unit of measurement "degree-hours/year," which is a criterion with an inversely proportional evaluation, meaning higher values indicate a worse condition.

There is a processing spreadsheet for each typology and city. To speed up the data processing, automation using Python codes was chosen, programmed in the Visual Studio Code environment. The automation was implemented using the Pandas library, widely used for data manipulation and analysis, along with the Openpyxl and xlwings commands, which allow manipulation of Excel spreadsheets (.xlsx format). This means that if the data output is in .csv format, it must first be converted to .xlsx. This conversion is performed by a code developed specifically for this research, ensuring that the data is in the correct format for subsequent processing.

Proper organization of the files is essential to ensure the correct functioning of the codes. The research method requires that all source files, obtained from the EnergyPlus simulations, follow a specific naming convention: "'city'_'typology'_'material-combination'_'opening'-'direction'". A practical example for the city of Unaí would be: "unai_R1N_P6C6_JGCP-W". This standardized naming convention simplifies the identification of files during the automated process and ensures that data is logically organized.

Three codes were developed: the first to convert all files from the chosen folders from .csv to .xlsx format, and the second to duplicate and rename the treatment spreadsheet for a specific city to accommodate all 288 possible combinations of material and solar orientation.

A third code is responsible for copying data from the source spreadsheets generated in EnergyPlus and inserting them into the corresponding treatment spreadsheet. This code was designed to interpret the file name and accurately relate the variables between the spreadsheets. For instance, it ensures that data from the file "formiga_R1N_P1C1_JGCP-SE" is correctly inserted into the JGCP tab of the spreadsheet "planilha_de_tratamento_R1N_formiga_SE_P1C1." This process eliminates the risk of human error during data transfer and ensures that the simulations are based on accurately allocated information.

5.4 Costs spreadsheet and comparative analysis

Initially, cost composition tables for budgeting are developed for all constructive solutions of vertical enclosures and roofing, as shown in table 3. Considering the six masonry options and the six roofing options, a total of 36 combinations were evaluated.

The next step is to check the costs in the National System of Construction Cost and Indexes Survey (SINAPI) for December 2013, 2018, and 2023. Following that, the cost of the 36 compositions was calculated. The cost of the reference alternative (External Wall 1, Internal Wall 1, and Roof 2), which is specified by NBR 12.721 (ABNT, 2006) for the typology, was considered in its totality in each year.

Subsequently, the percentage variations in the costs of the other envelope compositions were calculated by the ratio between the cost of each composition and the cost of the reference alternative (for both masonry walls and roofing) for each year analyzed. A comparative temporal analysis of the percentage variation of the values between alternatives was conducted to investigate those whose costs fluctuated significantly over time. It was possible to identify that some solutions experienced an expansion in market share and a relative reduction in cost. The value adopted was the relative cost in December 2023, as shown in Table 4.

5.5 Water heating system complexity and public policies incentive

At this stage of the housing development, it is understood that performing a detailed technical analysis of water heating systems (SAA) to estimate their cost is not appropriate. Instead, three qualitative groupings were established, based on the construction complexity and cost of the SAA: low complexity, medium complexity, and high complexity. Table 5 details the grouping of each system in terms of its construction complexity and the value assigned to it. In this case, the values are inversely proportional.

In the same table 5, the three qualitative groupings are also presented for addressing the incentives for using the SAA provided by public policies. The definition of these groups was based on Brazilian plans MME (2011), (EPE, 2020) and the INI-R (INMETRO, 2022), with values assigned in a directly proportional manner—higher values indicating greater incentives.

Construction Solution	Descriptive
External Wall 1 (EW1)	Snow white paint + Industrialized external mortar(2.5cm) + ceramic block (14 cm) + sprayed gypsum (0.5cm) + Snow white paint - Ceramic Block - "Wall CE extint"
External Wall 2 (EW2)	Snow white paint + industrialized external mortar (2.5cm) + autoclaved aerated concrete block (15 cm) + sprayed gypsum (0.5cm) + snow white paint - autoclaved aerated concrete block - "wall si"
External Wall 3 (EW3)	Snow white paint + Industrialized external mortar(2.5cm) + Structural concrete block (14 cm) + sprayed gypsum (0.5cm) + Snow white paint - Structural Concrete Block - "BC wall"
External Wall 4 (EW4)	Monolayer Industrialized external mortar in snow white color(2.5cm) + Cast-in-place concrete wall (10 cm) + sprayed gypsum (0.5cm) + Snow white paint - Cast-in-Place Concrete Wall - "Wall_ext cm in loco"
External Wall 5 (EW5)	Snow white paint + Coating + Cement board(1cm) + Air chamber (14 cm) + Cement board(-1cm) + sprayed gypsum (0.5cm) + Snow white paint - LSF - "LSF-ext without insulation"
External Wall 6 (EW6)	Snow white paint + Coating + Cement board(1cm) + ROCK WOOL (9 cm) + Air chamber (5 cm) + Cement board(1cm) + sprayed gypsum (0.5cm) + Snow white paint - LSF with insulation - "LSF-ext with insulation"
Internal Wall 1 (IW1)	Snow white paint + sprayed gypsum (0.5cm) + ceramic block (9 cm) + sprayed gypsum (0.5cm) + Snow white paint - Ceramic Block - "Wall CE intint"
Internal Wall 2 (IW2)	Snow white paint + sprayed gypsum (0.5cm) + autoclaved aerated concrete block (10 cm) + sprayed gypsum (0.5cm) + snow white paint - autoclaved aerated concrete block - "wall si"
Internal Wall 3 (IW3)	Snow white paint + sprayed gypsum (0.5cm) + Structural concrete block (14 cm) + sprayed gypsum (0.5cm) + Snow white paint - Structural Concrete Block - "BC wall"
Internal Wall 4 (IW4)	Snow white paint + sprayed gypsum (0.5cm) + Cast-in-place concrete wall (10 cm) + sprayed gypsum (0.5cm) + Snow white paint - Cast-in-Place Concrete Wall - "Wall_int cm in loco"
Internal Wall 5 (IW5)	Snow white paint + sprayed gypsum (0.5cm) + Cement board(-1cm) + Air chamber (14 cm) + Cement board(1cm) + sprayed gypsum (0.5cm) + Snow white paint - LSF - "LSF-int without insulation"
Internal Wall 6 (IW6)	Snow white paint + Sprayed gypsum (0.5cm) + Cement board(1cm) + Air chamber (14 cm) + Cement board(1cm) + Sprayed gypsum (0.5CM) + Snow white paint - LSF with insulation - "LSF-int with insulation"
Roof 1 (R1)	Flat concrete slab (15 cm) + asphalt membrane + mechanical protection mortar (2cm)
Roof 2 (R2)	Flat concrete slab (15 cm) + air chamber (>50 cm) + fiber cement tile
Roof 3 (R3)	Flat concrete slab (15 cm) + air chamber (>50 cm) + aluminum membrane + fiber cement tile
Roof 4 (R4)	Flat concrete slab (15 cm) + air chamber (>50 cm) + ceramic tile
Roof 5 (R5)	Flat concrete slab (15 cm) + air chamber (>50 cm) + thermoacoustic trapezoidal metal sheet (4.5 cm)
Roof 6 (R6)	Flat concrete slab (15 cm) + asphalt membrane + mechanical protection mortar (2cm) + industrialized green roof system (ecoroof)

Table 3: Construction systems for vertical sealing and roofs.

Source: created by the authors.

Composition	Cost	Composition	Cost
EW1+IW1+R1	94.84%	EW4+IW4R1	261.72%
EW1+IW1+R2	100.00%	EW4+PI4+R2	266.88%
EW1+IW1+R3	101.14%	EW4+PI4+R3	268.01%
EW1+IW1+R4	85.48%	EW4+PI4+R4	252.35%
EW1+IW1+R5	98.82%	EW4+PI4+R5	265.70%
EW1+IW1+R6	113.51%	EW4+PI4+R6	280.39%
EW2+IW2+R1	118.14%	EW5+IW5+R1	40.69%
EW2+IW2+R2	123.30%	EW5+IW5+R2	45.85%
EW2+IW2+R3	124.44%	EW5+IW5+R3	46.99%
EW2+IW2+R4	108.78%	EW5+IW5+R4	31.33%
EW2+IW2+R5	122.12%	EW5+IW5+R5	44.67%
EW2+IW2+R6	136.81%	EW5+IW5+R6	59.36%
EW3+IW3+R1	92.32%	EW6+IW6+R1	41.40%
EW3+IW3+R2	97.48%	EW6+IW6+R2	46.56%
EW3+IW3+R3	98.61%	EW6+IW6+R3	47.70%
EW3+IW3+R4	82.95%	EW6+IW6+R4	32.03%
EW3+IW3+R5	96.30%	EW6+IW6+R5	45.38%

Table 4: Compositions and relative cost.
Source: created by the authors.

6. BUILDING THE DATABASE FILE

The database file type received and processed by RESIDE is either .SQL or an SQLite file. It contains 12 columns divided into two sets: parameters destined to define the analysis alternatives and the evaluation criteria. The former includes: (i) the construction solution type for vertical enclosures; (ii) the construction solution type for the roof; (iii) the openings size; (iv) presence of sun shading in the openings; (v) condition of cross ventilation; (vi) solar orientation of the building main axis relative to the sun and (vii) type of water supply system. These are the parameters the user can select to set up their alternatives for analysis. The evaluation criteria are: (i) percentage of comfort hours; (ii) cooling degree hours; (iii) cost of the solutions; (iv) construction complexity of the water heating system; (v) incentives from public policies for the water supply system. These are the data that RESIDE uses to rank the analyzed alternatives.

To accelerate this process and enhance reliability and robustness, a code was developed to construct the database for each city. This code is more complex than those used for handling thermal-energy simulation data. It reads specific cells in the data treatment spreadsheets and inserts the corresponding data for the two variables from the thermal-energy simulation. After this step, the remaining variables required for the database are manually filled in. Simultaneously, a manual verification is conducted to ensure there are no blank fields from the automatic filling. If any blanks are found, an analysis is performed to identify and resolve the issue.

Type	Construction Complexity	Value	Public Political Incentive	Value
Single-Family Solar Accumulation	High	1000	High	1000
Single-Family Natural Gas Instantaneous	Low	1	Medium	100
Single-Family LPG Instantaneous	Low	1	Low	1
Point-of-Use Electric Instantaneous	Low	1	Low	1
Single-Family Electric Instantaneous	Medium	100	Low	1
Point-of-Use Shower Instantaneous	Low	1	Low	1
Single-Family Natural Gas Accumulation	Medium	100	Medium	100
Single-Family LPG Accumulation	Medium	100	Medium	100
Single-Family Electric Accumulation	Medium	100	Medium	100
Multi-Family Solar Accumulation	High	1000	High	1000
Multi-Family Heat Pump Accumulation	High	1000	High	1000
Multi-Family Natural Gas Accumulation	Medium	100	Medium	100
Multi-Family LPG Accumulation	Medium	100	Medium	100
Multi-Family Electric Accumulation	Medium	100	Medium	100

Table 5: Qualitative grouping for construction complexity and public political incentive of SAA (Water Heating System).

Source: created by the authors.

The integration of the database with the RESIDE software is done by converting the .csv file into a .sql format using a free, conventional converter available online. After the conversion, the upload process in RESIDE is intuitive and straightforward, requiring only that the username the project and save the tests performed. This final step ensures that the processed data can be readily utilized within the RESIDE environment, supporting the decision-making process.

7. DISCUSSION

Although there is no official survey on the subject, we can make an educated guess: if suddenly everyone in Brazil intending to build a house sought architectural design accompanied by thermal and energy performance simulations, would they find the number of computational simulation specialists required? Considering the distribution of architects across Brazil and the ratio of architecture professionals to the total population, as reported by the Architecture and Urbanism Yearbook (CAU, 2019), one could assume that the answer to this hypothetical exercise would be no.

In this context, the development and availability of simpler and more accessible tools for the general public, aimed at introducing discussions on thermal-energy performance in the early design stages, considering cost and other construction aspects, could help contribute to increasing the energy efficiency of new buildings. Although these types of tools do not allow for a detailed investigation of the project being analyzed, they offer initial guidance that can be accessed by a significant number of people.

Therefore, it is important to clarify that the use of RESIDE does not compete with the performance of detailed simulations for a given project. Instead, this tool aims to support discussions on energy efficiency in the early stages of residential project development.

Given the intended role of RESIDE, it is necessary for it to be accessible to a large number of users, capable of reproducing various typologies and urban contexts. For this to happen, a significant effort to create diverse database is required.

The construction of these databases, as previously described, involves multiple work stages that are intensive in two key demands. The first is the need for specialized labor in thermal and energy simulation and Python programming. The second is a robust computational infrastructure to speed up the simulations. In this research project, it can be said that the time spent on training and the limited infrastructure for simulations were significant drawbacks that limited the number of databases produced thus far. However, the results achieved may eventually support a significant number of users in Minas Gerais.

8. FINAL CONSIDERATIONS

The use of multicriteria decision-making (MCDM) tools represents an important step towards achieving sustainable development goals. Through these methods, it is possible to conduct an integrated analysis that considers the interdependencies and trade-offs between different criteria, providing a more comprehensive overview of design and construction choices that impact the entire lifecycle of a building. In other words, MCDM tools allow decision-makers to address the sustainability challenges inherent in projects with the necessary complexity.

The RESIDE software emerges as an instrument that supports designers and decision-makers who are willing to face increasing complexity with sustainable practices, starting from the early stages of architectural design. However, the use of RESIDE is conditioned on the prior existence of databases for various urban contexts, which are not currently available. The proposed procedure for identifying representative databases is a step forward in enabling the large-scale use of this software. It is understood that the overlap of socioeconomic, cultural, and political classifications, established for the entire Brazilian territory, and climate classifications allows for the identification of reference cities for intermediate regions. Identifying the most common construction typologies in these cities leads to databases that can be used in neighboring cities with similar climate conditions. This type of database simplification becomes feasible because ELECTRE-III is a method that responds well to situations where full confidence in the accuracy of the values assigned to the criteria cannot be relied upon, due to the process of overclassification, concordance, and discordance it performs to classify alternatives.

The procedure for developing the databases has so far resulted in databases for three construction typologies in 13 representative cities. The research will continue on two fronts: the ongoing construction of databases for other construction typologies and the development of a website to make both RESIDE and its databases available to the general public.

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