Towards climate-resilient social housing: thermal comfort assessment and renovation guidelines in the Brazilian mixed-dry climate zone

Rumo a habitação social resiliente ao clima: avaliação do conforto térmico e diretrizes de reforma para a zona brasileira de clima misto e seco

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ABSTRACT: Social Housing (SH) provided by the Brazilian *Minha Casa, Minha Vida* (MCMV) program often exposes residents to thermal stress and poor living conditions due to inadequate adaptation to the local climate. Self-built renovations that increase housing density exacerbate these issues by restricting natural ventilation and solar radiation, which in turn heightens thermal discomfort, energy demands, and health problems. This paper presents a climate resilience assessment of horizontal SH units from the MCMV program using the Resilience Ruler (RR), a Post-Occupancy Evaluation (POE) tool that measures resilience based on users' thermal comfort on a scale from 1 (not resilient) to 5 (very resilient). Conducted in a mixed and dry climate zone, represented by the city of Uberlândia, MG, Brazil, the analysis revealed an average resilience score of 2 (little resilience) for bioclimatic design and residents' climatic adaptability, highlighting priority areas for intervention. The study expands the understanding of the relationship between modifications in horizontal SH and climate resilience based on human thermal comfort. Furthermore, it provides renovation guidelines aimed at strengthening climate resilience in housing, making relevant contributions to Sustainable Development Goals (SDGs) 11 and 13. The research reinforces the importance of methodologies such as POE in supporting more effective design and management practices in SH, particularly in the face of global climate change challenges.

Keywords: thermal comfort; adaptability; affordable housing; Post-Occupancy Evaluation; health; SDGs.

***RESUMO*:** Habitações de Interesse Social (HIS) fornecidas pelo programa brasileiro Minha Casa, Minha Vida (MCMV) frequentemente expõem os moradores ao estresse térmico e a condições inadequadas de habitabilidade, devido à falta de adaptação ao clima local. Reformas autoconstruídas que aumentam a densidade das moradias agravam esses problemas ao restringirem a ventilação natural e a incidência de radiação solar, o que, por sua vez, intensifica o desconforto térmico, o consumo de energia e os problemas de saúde. Este artigo apresenta uma avaliação da resiliência climática de unidades horizontais de HIS do programa MCMV utilizando a Régua de Resiliência (RR), uma ferramenta de Avaliação Pós-Ocupação (APO) que mede a resiliência a partir do conforto térmico dos usuários, em uma escala de 1 (não resiliente) a 5 (muito resiliente). Conduzida em zona de clima misto e seco, representado pela cidade de Uberlândia, MG, Brasil, a análise revelou uma média de resiliência igual a 2 (pouco resiliente) em relação ao projeto bioclimático da habitação e à adaptabilidade climática dos moradores, indicando áreas prioritárias para intervenção. O estudo amplia a compreensão sobre a relação entre modificações em HIS horizontais e a resiliência climática com base no conforto térmico humano. Além disso, o estudo direciona diretrizes de reforma voltadas ao fortalecimento da resiliência climática nas habitações, com contribuições relevantes para os Objetivos de Desenvolvimento Sustentável (ODS) 11 e 13. A pesquisa reforça a importância de metodologias como a APO no apoio a práticas mais eficazes de projeto e gestão em HIS, especialmente frente aos desafios impostos pelas mudanças climáticas globais.

Palavras Chave: conforto térmico; adaptabilidade; habitação social; Avaliação Pós-Ocupação; saúde; ODSs.

1. INTRODUCTION

Adequate housing is essential for human life, providing protection, privacy, and a safe space for rest and socialization. Housing directly influences health and well-being, and therefore must ensure durability and habitability for a period of 40 years or more (ABNT, 2021), supporting sustainable development and resilience to challenges such as climate change (IPCC, 2023; Vardoulakis, *et al.*, 2015).

Human habitat serves as a vital evolutionary resource, capable of mitigating environmental adversities and supporting subsistence. Its qualities directly influence humanity's ability to positively cope with a wide range of challenges — whether social, economic, political, environmental, or climatic — while maintaining its core essence and functionality, thus demonstrating resilience. In the context of Brazilian social housing (SH), this issue is particularly relevant, as beneficiaries of government housing programs are predominantly socially and economically vulnerable groups (Elias-Trostmann *et al.*, 2018).

For this audience, passive, low-complexity, low-tech, and low-cost construction strategies that minimize energy dependence to provide environmental quality and enhance user awareness and participation in managing their own comfort should be prioritized in the face of climate change and the limited resources available for SH (Garcia, Vale & Vale, 2021; Salingaros, 2021).

However, SH offered through Brazil's "*Minha Casa, Minha Vida*" (MCMV) program has failed to adequately address these issues. Recent research has shown that SH units delivered by MCMV are unsuitable for the diverse climatic realities across different Brazilian regions[1]. Uniform construction models and specifications are repeated across the territory, leading to thermal discomfort and increased resource and electricity consumption in the pursuit of comfort during the operational phase. Highlighting this issue, satisfaction surveys have identified temperature as one of the primary sources of dissatisfaction among residents of SH developments in Brazil (Senado, 2008; Brasileiro, Morgado & Luz, 2017; Triana, Lamberts & Sassi, 2018; Oliveira, 2015; Amore, Shimbo & Rufino, 2015; Vasquez, 2017; IPEA, 2014), exposing this population to health risks associated with the frequent experience of thermal stress (Kovats & Hajat, 2008; Barros, 2021).

Additionally, the knowledge and behaviors of residents in addressing climate risks within the context of Brazilian housing are significantly lacking, as highlighted by Elias-Trostmann *et al.* (2018) and Pott (2022)[2]. Moreover, the limited access these residents have to information and architectural and urban planning services during renovations exacerbates the prognosis for the quality of housing in use (Salingaros, 2021). Renovations carried out by the residents themselves, without professional guidance, tend to result in the complete densification of the plot, compromising access to natural light and ventilation, thereby undermining thermal comfort, habitability, and the resilience of horizontal SH to climate threats (Simões, Leder & Labaki, 2021).

The MCMV program is Brazil's largest housing policy in terms of numbers, targeting the lowest-income and most vulnerable population. Between 2009 and 2020, more than 6 million housing units were produced, with a total investment of R$ 223.2 billion in public and private subsidies. Considering an average of 2.8 occupants per household in Brazil, it is estimated that at least 16.8 million people reside in this type of housing (IBGE, 2023), subject to and interacting with the urban fabric. Given the magnitude of the population served, its dynamics inevitably exert profound impacts on cities. These effects extend beyond the immediate beneficiaries, influencing urban dynamics, social equity, and economic development on a large scale.

Yet, the number of inadequate housing units[3] has been increasing in recent years, contributing to what is known as the qualitative housing deficit, which grew from 23 million in 2016 to nearly 25 million in 2019 (FJP, 2021). This represents a significant demand for

[1] Brazil is a country of continental dimensions, with its territory spanning from latitude 5°16' N to latitude 33°45' S, resulting in significant climatic variability.

[2] Available at: https://www.percepcaoclimatica.com.br/_files/ugd/6dff39_1b4e74741ceb4777839ace998e106d59.pdf . Acessed in: May 2022.

[3] A dwelling is considered inadequate when it lacks basic infrastructure (water, sewage, electricity, and garbage collection), exhibits severe structural problems or poor habitability conditions (issues with ventilation, lighting, waterproofing, and safety), and provides insufficient space for the residents.

renovations and an opportunity to prepare SH for climate resilience. This resilience is understood as the ability of the housing system to positively cope with impacts without losing its functionality and essence, with varying skills depending on the nature of the impact (Garcia & Vale, 2017; Rodin, 2015; Pickett I*et al.*, 2014).

In this context, the present article aims to present the results of a climate resilience assessment in horizontal SH in use under the MCMV program and its implications for informing professional guidance in renovations. The study is based on the understanding that resilience to climate impacts in SH is achieved when thermal comfort is provided, which, in turn, depends on building environmental and human capacities (Attia *et al.*, 2021; Homaei & Hamdy, 2021; Schweiker, 2020; Brooks, 2003).

The article is derived from a doctoral thesis aimed at understanding and measuring climate resilience in horizontal social housing units (SH) under the MCMV program, located in a mixed and dry climate zone represented by Uberlândia, MG, Brazil (Bortoli, 2023; Machado *et al.*, 2024). Based on this, the study proposes strategies for renovations within this climatic context. The thesis was structured around six key questions proposed by Meerow & Newell (2016): resilience "1. To what?", "2. Where?", "3. Why?", "4. For whom?", "5. When?", and "6. How?". This article presents part of the doctoral research findings, focusing on understanding "how" to enhance resilience in MCMV SH, with an emphasis on thermal comfort. To this end, it combined a literature review and Post-Occupancy Evaluation (POE) techniques using a Resilience Ruler (RR) to define evaluation criteria, investigate a dual case study, and propose renovation strategies.

The study is part of the institutional research initiative [RESILIENT HOUSE][4], which seeks to understand and promote resilience in SH as a contribution to Sustainable Development Goals (SDGs) 11 and 13, aimed at creating more resilient, sustainable cities and addressing climate change impacts. According to this initiative, the resilience of SH depends on key qualities: thermal comfort, energy efficiency, flexibility, and accessibility for the elderly (Villa, Bortoli & Oliveira, 2025).

This article emphasizes thermal comfort as a critical quality for mitigating climate impacts, detailing the development of the RR (Villa, Pena & Barbosa, 2023; Villa, Bortoli & Vasconcellos, 2023) and its application in a case study of SH in Uberlândia. The evaluation criteria provided by the tool serve both to assess existing conditions and guide renovations within the same climatic context. In doing so, the RR empowers architects, urban planners, service providers, and residents to create more climate-resilient homes, contributing to better-prepared cities capable of facing contemporary challenges.

2. MATERIALS AND METHOD

The city of Uberlândia is located in the mesoregion of *Triângulo Mineiro* and *Alto Paranaíba*, in the state of Minas Gerais, Southeast Brazil. The city is located at 18° 55' South and 48° 17' West, with an average altitude of 865 meters. Positioned in the southern part of the Intertropical Zone, Uberlândia is influenced by both tropical and extratropical atmospheric systems. The climate is shaped by continental air masses, including the Equatorial and Tropical as well as Atlantic-origin air masses.

The city experiences a tropical rainfall pattern, with the rainy season occurring from November to March (spring and summer) and a well-defined dry season from April to September (autumn and winter). Around 80% of the annual precipitation falls during the rainy

[4] Institutional research project titled "[RESILIENT HOUSE] Design strategies for promoting resilience in social housing from post-occupancy evaluation methods", underway from 2022 to 2025, funded by the National Council for Scientific and Technological Development (CNPq) through a Research Productivity Scholarship (Grant No. 311624/2021-9). See in detail at: https://morahabitacao.com/pesquisas-em-andamento-2/resiliente-house-design-strategies-for-promoting-resilience-in-social-housing-from-post-occupancy-evaluation-methods/

season, with an average annual rainfall of 1,606.1 mm based on 1981-2010 climatological data. Historical extremes in precipitation were 1,959.3 mm in 2000 and 1,086.2 mm in 2008 (SEPLAN, 2021). When analyzing the thermal and energy performance of buildings across the national territory, Uberlândia reflects the climatic conditions of 601 Brazilian municipalities and is classified as “3B” under the new Brazilian Bioclimatic Zoning (ABNT, 2024), corresponding to a mixed and dry climate, with outdoor temperature of 20.9 °C $\leq$ TBSm < 22.9 °C and annual average outdoor relative humidity RH $\leq$ 73.2%. Accordingly, climate analyses and the resulting guidelines developed for Uberlândia can inform strategies for other municipalities within the same bioclimatic zone (Bortoli *et al.*, 2024).

In the neighborhoods of SP and PQ[5], two horizontal SH developments from the MCMV program have been selected for case studies. These are the Residencial Sucesso Brasil (RSB) and the 2A4 plot, referred to simply as "RSB" and "2A4", respectively, chosen as the units of analysis. RSB and 2A4 represent distinct phases of the MCMV program in Uberlândia, with the former delivered between 2010/2011 and the latter between 2016/2017, both targeting the MCMV income bracket 1 (ranging from 0 to 3 minimum wages). They differ in several aspects, such as construction techniques: the RSB uses ceramic bricks (19 cm, CT = 153 kJ/(m².K)), while the 2A4 features solid concrete walls cast in situ (10 cm, CT = 240 kJ/(m².K)), with both being load-bearing (ABNT, 2005). The roofing systems also vary, with ceramic tiles in RSB and concrete tiles in 2A4. Additionally, the RSB employs a semi-detached house layout, while the 2A4 houses are individually situated on the plot.

The aim of the case study was not statistical generalization but rather analytical, contributing to qualitative characterization of scenarios, expansion, and generalization of theories (Yin, 2005). Thus, the reported differences between the two developments, within a similar context, enhanced the representativeness of the collected data. Figures 1, 2 and 3 summarizes construction information about the selected case study projects.

The research employs an exploratory approach and the phenomenological stance of the Design Science Research (DSR) methodology, which focuses on creating artifacts or prescriptions based on understanding a problem (Santos, 2018; Dresch, Lacerda & Antunes, 2015). The premise of the research is that to enhance the resilience of a system, you need to know where you are starting from — which implies measuring something — and you need to know where you are going, which implies mapping future possibilities (Garcia & Vale, 2017).

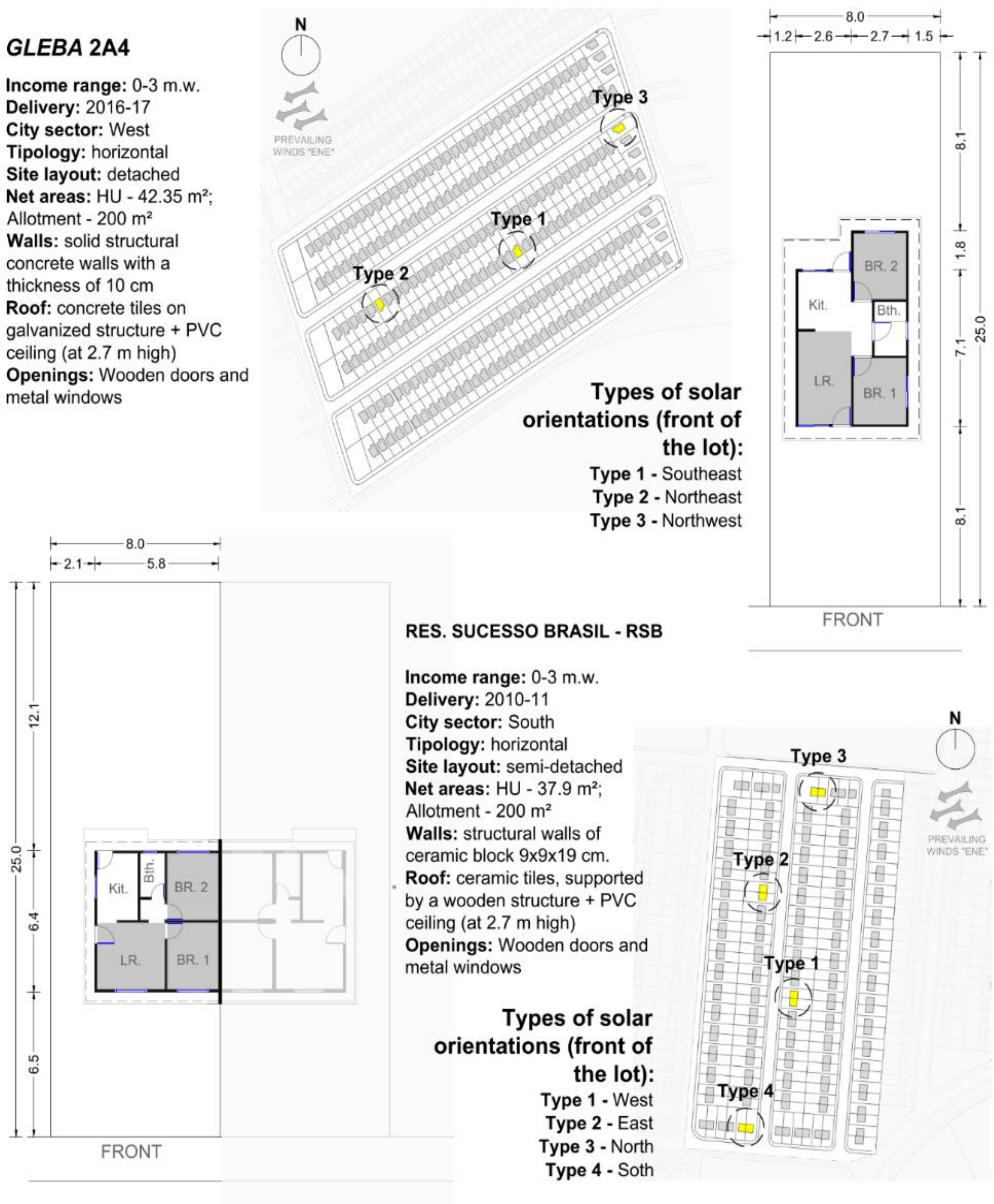
Thus, it is essential to understand the behavior of certain attributes of the built environment that describe the desired resilience for SH before intervening in them. This understanding is achieved through Post-Occupancy Evaluation (POE), a methodology widely used to assess project quality through consistent diagnostics related to aspects that characterize the built environment (Ono *et al.*, 2018; Villa and Ornstein, 2013).

Contributing to institutional research conducted by the group [MORA] Housing Research at the Faculty of Architecture and Urban Planning and Design at the Federal University of Uberlândia[6], the study evaluates horizontal SH under the MCMV program in Uberlândia using a tool known as the Resilience Ruler, or “RR”. The RR is a POE instrument whose conceptual and methodological framework was developed by the group (Villa, Pena & Barbosa, 2023; Villa, Bortoli & Vasconcellos, 2023), enabling the tracking of physical characteristics of the environment and behavioral aspects of individuals in the context of SH that describe their level of resilience — referred to as attributes. Drawing from the group's experience with POE in MCMV SH since 2009, and aligning with global priorities for cities, especially those outlined by the SDGs No. 11 and 13, attributes of resilience proposed for SH include thermal comfort, energy efficiency, flexibility, and accessibility for the elderly (Villa *et al.*, 2022).

[5] Abbreviations adopted to ensure the anonymity of research participants.
[6] Link: https://morahabitacao.com/

The RR functions as a checklist for resilience and is organized around attributes (as mentioned above), indicators, sub-indicators, items, aspects, and evaluation requirements along with their references. Inspired by the work of Elias-Trostmann *et al.* (2018), which aimed to assess community resilience to extreme climatic events, the RR measures the resilience of SH scale, based on requirements distributed across a 5-point scale and corresponding qualitative assessments, with 1 being "not resilient" and 5 being "very resilient". Figure 4 illustrates the evaluation scale and structure of the resilience scale for thermal comfort attribute, which will be further detailed in the following sections.

Figure 1 - Synthesis of constructive information.



Source: Bortoli (2023).

Figure 2 – Gleba 2A4 housing units as delivered (embryo).

Source: Bortoli (2023).

Figure 3 – Residencial Sucesso Brasil (RSB) housing units as delivered (embryo).

Source: Bortoli (2023).

Figure 4 – Structure of the Resilience Ruler (sample).

IMPACT: CLIMATE									
RESILIENCE ATTRIBUTE: THERMAL COMFORT									
Indicator	Sub-indicators	Evaluation items	Evaluation aspects	1 Not resilient	2 Little resilient	3 Moderately resilient	4 Resilient	5 Very resilient	References
Bioclimatic Building	Construction systems considering interactions with solar radiation and ventilation	Thermal and optical properties of construction components	Average heat absorption of external walls	Outside the intervals			α ≤ 0,6 - U ≤ 3,7 α ≥ 0,6 - U ≤ 2,5		EEDUS (2022); ABNT - NBR 15575-4 (2021)
			Average heat absorption of roofs	Outside the intervals		α ≤ 0,6 - U ≤ 2,3 α ≥ 0,6 - U ≤ 1,5	α ≤ 0,6 - U ≤ 1,5 α ≥ 0,6 - U ≤ 1	α ≤ 0,6 - U ≤ 1 α ≥ 0,6 - U ≤ 0,5	EEDUS (2022); ABNT - NBR 15575-5 (2021)
			Average heat transmission of external walls	Outside the intervals			α ≤ 0,6 - U ≤ 3,7 α ≥ 0,6 - U ≤ 2,5		EEDUS (2022); ABNT - NBR 15575-4 (2021)
			Average heat transmission of roofs	Outside the intervals		α ≤ 0,6 - U ≤ 2,3 α ≥ 0,6 - U ≤ 1,5	α ≤ 0,6 - U ≤ 1,5 α ≥ 0,6 - U ≤ 1	α ≤ 0,6 - U ≤ 1 α ≥ 0,6 - U ≤ 0,5	EEDUS (2022); ABNT - NBR 15575-5 (2021)
	...	...	...	...					...

Source: Bortoli (2023).

2.1 Thermal Comfort and resilience in Brazilian horizontal SH

Various disciplines, such as physics, ecology, psychology, and urban planning, have studied the resilience. However, research linking the themes of "resilience in the built environment", "climate," and "thermal comfort" is still relatively recent. Homaei & Hamdy (2021) argue that, given the uncertainties brought about by climate change, buildings as facilities with significant costs must be able to respond to these changes and maintain their performance and functionality. The authors concluded that the introduction of passive design strategies in buildings would significantly enhance their resilience during disruptive events.

Attia *et al.*, (2021) defined a set of criteria — vulnerability, resistance, robustness, and recovery capacity — that influence the resilience of buildings (in the context of overheating risk). Additionally, they suggested essential considerations for designing thermally resilient buildings, such as identifying the climatic impacts and events against which buildings must be resilient; the critical comfort thresholds and conditions of the system; and the factors that influence a building's ability to be climate-resilient, among others.

Shweiker (2020) highlights the role of human behavior in achieving resilience through thermal comfort. The author suggests that the interplay between the resilience capabilities of both people and the building itself directly impacts the thermal environment experience and the magnitude of energy consumption required to cope with the climate. Furthermore, an examination of the literature in the field reveals an association between these resilience skills and paradigms in the area of thermal comfort, highlighting two key concepts: thermal neutrality, which is based on the robustness and elasticity of buildings; and adaptive comfort, which is based on the resistance, adaptability, and recoverability of people (Brooks, 2003).

Building on the works and ideas presented, buildings need to be resistant, robust, adaptable, and elastic, while people need to be aware, prepared, adaptable, and capable of recovery (Schweiker, 2020; Homaei & Hamdy, 2021; Garcia & Vale, 2017; Rodin, 2021; Meerow & Newell, 2016; Brooks, 2003) to manage the climate and its changes resiliently. From this reflection, the study proposes resilience indicators based on thermal comfort for the RR, titled "Bioclimatic Building" and "Climatic Adaptability", respectively.

A bioclimatic building is one designed considering principles that utilize the suitability to the place, its climate, and its culture as fundamental design parameters, reducing its exposure and enhancing its potentials (De La Jara, Hidalgo & Hansen, 2011; Romero & Fernandes, 2015; Widera, 2014; Ozarizoy & Altan, 2021; MMA, 2016). In parallel, climatic adaptability is understood as a human capacity to perceive the influence exerted by climatic conditions, and their succession over time, on vulnerable individuals and the physical environment, and to act to mitigate their negative effects (Ayoade, 2013; Mendonça, 2021).

Resilience from the perspective of thermal comfort can be analyzed through two indicators: *Bioclimatic Building* and *Climatic Adaptability*. Regarding Bioclimatic Building, resistance refers to the ability to absorb changes without collapsing or losing stability (Garcia & Vale, 2017; Rodin, 2015; Maguire & Cartwright, 2008); robustness describes well-designed systems that maintain their function under internal or external environmental changes, often supported by redundant construction strategies (Homaei & Hamdy, 2021); adaptability of the environment reflects the capacity to adjust, apply resources flexibly, and modify behaviors to cope with changing circumstances (Rodin, 2015; Costa *et al.*, 2019); and elasticity involves the activation of supplementary stabilization measures, such as energy-dependent systems during extreme events (Pickett *et al.*, 2014; Homaei & Hamdy, 2021).

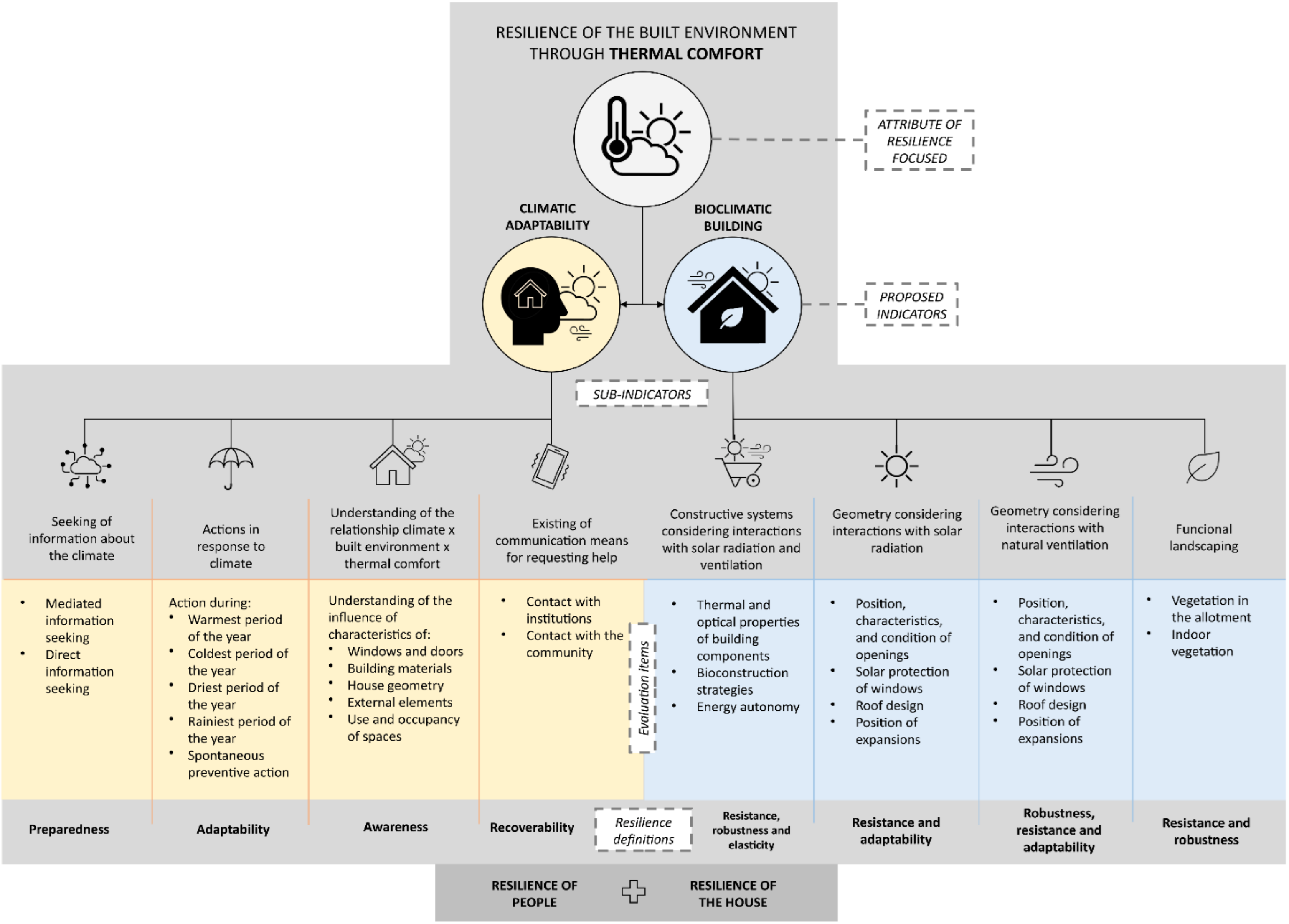
In parallel, Climatic Adaptability considers awareness, defined as knowledge of strengths, vulnerabilities, and risks, including continuous situational assessment (Rodin, 2015); preparedness, which reflects the system's readiness for disruptive events while minimizing adverse impacts (Homaei & Hamdy, 2021); adaptability of people, the ability to modify behavior or system characteristics to better cope with stresses (Brooks, 2003); and recoverability, the capacity to return to target performance after disruption, enhanced by prior experience and learning (Homaei & Hamdy, 2021; Schweiker, 2020).

These indicators and their associated definitions of resilience in the context of thermal comfort evoke qualities of design and the built environment in use, including the behavior of the inhabitants. These derived qualities, which elaborate on the indicators and bring them closer to practical application in design, are defined as sub-indicators.

For the "Bioclimatic Building" indicator, the sub-indicators include: construction systems that consider interactions with solar radiation and natural ventilation; geometry that considers interactions with solar radiation; geometry that considers interactions with natural ventilation; and functional landscaping. For the "Climatic Adaptability" indicator, the sub-indicators are: seeking information about the climate; taking action to cope with the climate; understanding the relationship between climate, the built environment, and thermal comfort; and the existence of communication means for requesting assistance.

From these sub-indicators, aspects and evaluation items were inferred, based on normative bibliographic references in the field, as well as on the study of exemplary architectural projects that demonstrate the benefits related to their consideration. These can be seen in detail in (Bortoli, 2023). Figure 5 summarizes the complete structure of the RR for the study of thermal comfort, linking the sub-indicators to the definitions of resilience addressed by the assessment. The full RR, including its parameterization and specific theoretical references, can be obtained upon request from the authors.

Figure 5 – Conceptual framework for resilience assessment – attribute Thermal Comfort.



Source: Bortoli (2023).

2.2 Instruments of POE and sampling

The sampling for the performance of the RR for thermal comfort was qualitative, contingent upon the residents' consent to enter their homes and conduct photographic documentation, sketches, and notes. The guided visits (Walkthroughs) served as the instrument that informed the evaluation for the "Bioclimatic Building" indicator in the occupied dwellings, applied in 42 homes, with 21 in each unit of analysis. The "Bioclimatic Building" indicator was also assessed for the dwellings as delivered by the MCMV program (original structures - embryos) in their different solar orientations (see Figure 1), through a technical analysis of the project plans provided by the municipality.

Questionnaires administered to residents informed the evaluation of the "Climatic Adaptability" indicator, with 106 residents participating — 53 from each development. A statistical sample was defined to determine the number of households where the questionnaires would be administered. Initially, a sampling error of 7% was considered, leading to a calculated requirement of 164 questionnaires across the population represented by the developments (half in RSB and the other half in gleba 2A4).

However, during attempts to administer the questionnaires in both units of analysis, a high rate of refusals was encountered. Consequently, the sampling error was adjusted to 8.15%[7], resulting in the administration of 106 questionnaires through convenience sampling. The method used to calculate the sample size for finite populations (N) was as described by Eq. 1.

$$N = Z^2 . p . q . N . d^2 (N-1) + Z^2 . p . q \qquad \text{(Eq. 1)}$$

Where:
Z = standard normal deviate (1.96)
p. q = data variability, assumed as ¼ = (0,25)
N = population size (383)
d = sampling error (0.0815 or 8.15%)

Both instruments were applied in occupied dwellings that had undergone some degree of modification (expansions), with different solar orientations, between February and May 2023. By administering questionnaires to residents and conducting Walkthroughs in their homes, the necessary data for the RR performance were collected. These data were recorded through evaluation reports by indicator (using spreadsheets in MS Excel), which automatically calculated the overall scores for attributes, indicators, sub-indicators, and resilience skills individually. The instruments were duly reviewed and approved by the Research Ethics Committee for human subjects (CEP/CONEP/UFU), under CAAE nº 56151522.3.0000.5152.

3. RESULTS AND DISCUSSION

3.1 Results for the indicator "Bioclimatic Building"

The resilience assessment for the "Bioclimatic Building" indicator was informed by Walkthroughs in dwellings in use and technical analyses of the project for the embryos. Table 2 summarizes the results obtained for the RR of thermal comfort in the two units of analysis, encompassing both in use dwellings and those as originally delivered (embryos).

[7] Under the guidance of Prof. Dr. Lúcio Borges de Araújo, a professor at the Faculty of Mathematics at the Federal University of Uberlândia.

Table 2 – Results by evaluation item: bioclimatic building indicator.

		ALL HOUSES			
		OBTAINED RESILIENCE LEVEL			
		IN USE		AS DELIVERED (EMBRYOS)	
SUB-INDICATORS	EVALUATION ITEM	RSB	2A4	RSB	2A4
Construction systems considering interactions with solar radiation and ventilation	Thermal and optical properties of building components	2.99	1.27	3.50	1.00
	Bioconstruction strategies	1.00	1.00	1.00	1.00
	Energy autonomy	1.00	1.00	1.00	1.00
	Average	**1.66**	**1.09**	**1.83**	**1.00**
Geometry considering interactions with solar radiation	Position, characteristics, and condition of openings	3.03	3.46	3.06	3.53
	Solar protection of windows	2.03	2.03	1.67	1.67
	Roof design	2.03	3.31	2.00	4.00
	Position of expansions	2.79	3.41	4.00	4.00
	Average	**2.47**	**3.05**	**2.68**	**3.30**
Geometry considering interactions with natural ventilation	Position, characteristics, and condition of openings	2.20	2.52	2.46	2.60
	Roof design	1.64	1.77	2.50	2.50
	Dimentions of rooms	2.37	2.01	4.00	4.00
	Position of expansions	2.79	3.26	4.00	4.00
	Average	**2.25**	**2.39**	**3.24**	**3.28**
Functional landscaping	Vegetation in the allotment	2.46	2.08	2.50	2.50
	Indoor vegetation	1.00	1.00	1.00	1.00
	Average	**1.73**	**1.54**	**1.75**	**1.75**

Source: Bortoli (2023).

It is observed that the embryos in both developments exhibit low resilience general scores, averaging 2.49 in RSB and 2.33 in 2A4. This indicates, at first glance, a situation of low resilience in the case study. The expansions observed in the dwellings visited more often exacerbated the situation rather than mitigating it, as demonstrated by the average sub-indicator scores for in use dwellings.

For nearly all sub-indicators, dwellings in use maintained or worsened their resilience scores compared to the embryos. The sub-indicator "Construction systems considering interactions with solar radiation and ventilation" is the only one for which a slight improvement was observed in 2A4, increasing from 1 to 1.09 in the sub-indicator's average score and from 1 to 1.27 in the average score for the item "thermal and optical properties of building components" — still insufficient, however, to raise the resilience level of the sub-indicator. This change was due to the frequent use of ceramic blocks in walls during expansions, which are better rated than solid concrete walls according to the RR requirements for the climatic context (Figure 6).

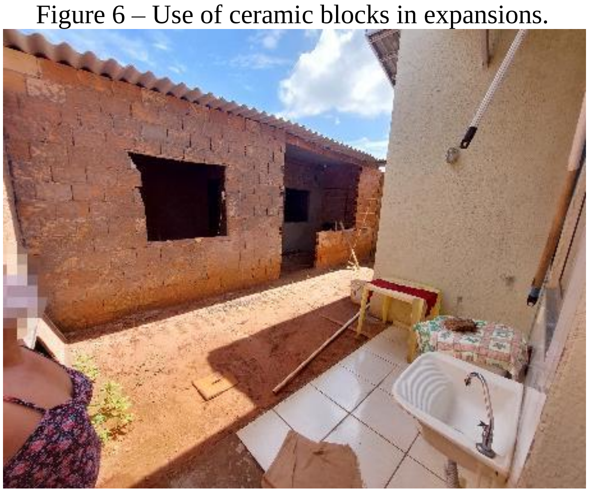
In the RSB, the opposite occurred. Due to the predominant use of fiber-cement roofing without ceiling or slab as the material for expansions (Figure 7), and considering that this material is rated lower by the RR than the ceramic tiles used in the embryo, there was a decrease in the average ratings for the item "thermal and optical properties of building components", from 3.50 to 2.99 — classifying it as "little resilience". With this, the evaluation for this sub-indicator in dwellings in use remained the same as in the embryos, classified as "not resilient" — with a score of 1.66 in RSB and 1.09 in 2A4.

Additionally, the scores for the items "bioconstruction strategies" and "energy autonomy" were the lowest for both the embryos and the visited houses in both developments, due to the absence of such strategies, which are essential for achieving the robustness and elasticity required for good sub-indicator performance.

The evaluation of the sub-indicator "Geometry considering interactions with solar radiation" showed that the average score for dwellings as delivered in 2A4 remains slightly higher than in RSB (3.3 in 2A4 versus 2.68 in RSB). However, the dwellings in use in both developments experienced a decrease in their ratings in relation to the embryos, scoring 3.05 in 2A4 and 2.47 in RSB. This decline can be explained by the fact that, in several houses, windows were removed or simply not installed in newly created spaces (Figure 8). In other cases, solar orientation was unfavorable — for example, with bedroom windows facing west or south — thus lowering the rating particularly for the items "position, characteristics, and condition of openings" and "expansions position".

Another change that benefited the rating of this item in RSB, though it did not alter the average sub-indicator rating, was a slight increase in the effective lighting area of windows. This is because the preferred window model in newly created bedrooms and living rooms is the tempered glass type, which offers a larger transparent area compared to the original model — primarily due to the absence of extensive fixed metal frames, allowing the glass to occupy nearly the entire window opening (Figure 9). However, the absence of blinds in the bedrooms and living rooms was penalized in the visited houses, as absolute transparency can also negatively impact thermal comfort.

Figure 6 – Use of ceramic blocks in expansions.



Source: Bortoli (2023).

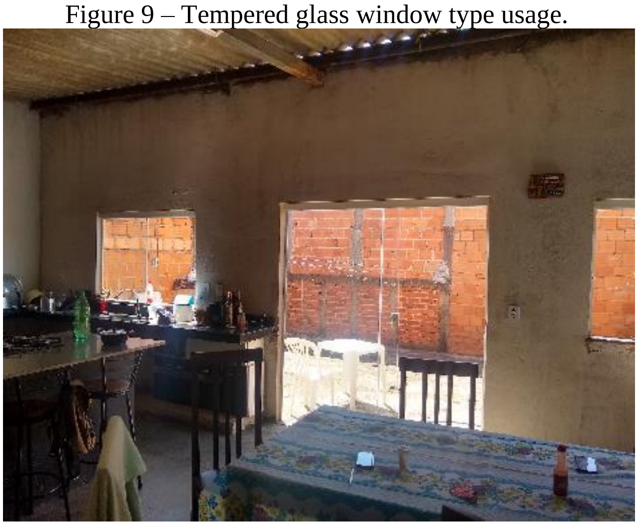
Figure 7 – Use of fiber-cement roofing without ceiling.

Source: Bortoli (2023).

Figure 8 – New room without windows.

Source: Bortoli (2023).

Figure 9 – Tempered glass window type usage.



Source: Bortoli (2023).

Simultaneously, the creation of expansions frequently obstructed existing windows entirely, occurring more often in the RSB, which degraded the evaluation for both developments in the item “position of expansions” (which decreased from 4 to 3.41 in 2A4 and from 4 to 2.79 in RSB). On the other hand, the installation of new windows with blinds and the use of curtains as temporary sun-blocking measures contributed to an increase in the rating of the visited houses compared to the embryos for the item “solar protection of windows” — rising from 1.67 to 2.03 in both developments.

The evaluation of the sub-indicator “Geometry considering interactions with natural ventilation” showed a considerable decline when comparing embryos and houses in use (from 3.24 to 2.25 in RSB and from 3.28 to 2.25 in 2A4). Similar to solar orientation, orientation relative to prevailing winds was also negatively affected by the creation of spaces without windows or the removal of windows in the RSB. Concurrently, the partial or complete obstruction of windows caused by the creation of expansions contiguous to the embryo also resulted in a lower rating for the visited houses (Figure 10).

In some expanded houses, only one window provided ventilation to large areas (Figure 11). Additionally, there were cases where windows with a greater proportion of transparent areas were installed, but with a smaller total opening and effective ventilation area, which negatively impacted the rating.

In many expansions, the roof continued the eaves of the embryo, resulting in a noticeable reduction in the ceiling height in the newly created spaces compared to the embryo, adversely affecting the evaluation. The absence of strategies such as permeable vertical sealing elements, flexible windows, selective ventilation, and exhaust strategies also failed to provide the houses with redundancy in interaction with natural ventilation, further impairing the assessment.

Regarding the sub-indicator "Functional Landscaping", the final component of the "Bioclimatic Building" indicator, the primary cause of the reduction in resilience scores for dwellings in use compared to the embryos (which were already low) was the removal of permeable areas and vegetation from the sidewalks, coupled with an increase in built area and lot paving (Figures 12 and 13). This led to a decline in resilience scores, from 1.75 to 1.54 in 2A4 and from 1.75 to 1.73 in RSB.

Given these results, the lack of properly informed architects and urban planners during the design and subsequent renovation phases is considered to significantly affect the climate resilience and thermal comfort of these housing units, directly impacting the well-being and quality of life of residents (D’Amore, 2019; Jorge *et al.*, 2017; Amore & Moretti, 2018).

Figure 10 – Obstruction of existing windows.

Source: Bortoli (2023).

Figure 11 – Insufficient ventilation areas.

Source: Bortoli (2023).

Figure 12 – Increase in lot paving – 2A4.

Source: Bortoli (2023).

Figure 13 – Increase in lot paving – RSB.

Source: Bortoli (2023).

3.2 Results for the indicator "Climatic Adaptability"

The resilience assessment for the "Climatic Adaptability" indicator was informed by a questionnaire performed by researchers collecting residents perceptions, focusing on the verification of practices and knowledge about the climate that contribute to resilience. Table 3 summarizes the results obtained by sub-indicators and evaluation items.

Table 3 - Results by evaluation item: climatic adaptability indicator.

		ALL HOUSES OBTAINED RESILIENCE LEVEL	
SUB-INDICATORS	**EVALUATION ITEMS**	**RSB**	**2A4**
Seeking of information about the climate	Mediated information seeking	2.26	1.45
	Direct information seeking	1.00	1.06
	Average	**1.76**	**1.29**
Actions in response to climate	Action during the warmest period of the year	2.93	2.83
	Action during the coldest period of the year	2.83	2.62
	Action during the driest period of the year	2.73	2.43
	Action during the rainiest period of the year	2.77	2.71
	Spontaneous preventive action	1.28	1.85
	Average	**2.72**	**2.60**
Understanding of the relationship between climate and built environment characteristics over thermal comfort	Understanding of the influence of window and door characteristics	3.29	3.03
	Understanding of the influence of building materials	3.01	2.83
	Understanding of the influence of house geometry	3.36	2.68
	Understanding of the influence of external elements	3.46	3.50
	Understanding of the influence of use and occupancy of spaces	2.57	2.40
	Average	**3.18**	**2.95**
Existence of communication means for requesting help in case of emergency	Contact with institutions	1.06	1.06
	Contact with the community	1.43	1.51
	Average	**1.28**	**1.33**

Source: Bortoli (2023).

The highest resilience scores for the sub-indicator "seeking of information about the climate" were observed for the item "mediated information seeking" (RSB – 2.26 and 2A4 – 1.45, indicating "little" and "not resilient", respectively), which involves consulting mobile applications for weather information.

This result highlights, on one hand, the lack of awareness about climate and weather conditions in the case study, as evidenced by the low scores obtained. On the other hand, it underscores the effectiveness of electronic devices, particularly mobile phones, in popularizing this type of information among various others. The sub-indicator "understanding the relationship between climate and built environment characteristics over thermal comfort" received the highest resilience scores in the case study, achieving a classification of "moderately resilient" in RSB (score of 3.18) and almost the same in 2A4 (2.95). It is estimated that the longer time spent living in the house, observed in the RSB, contributed to the development of this heightened awareness in comparison to 2A4, as experience with various issues in the dwelling may have led to greater resident awareness of the housing-atmosphere relationship.

However, when questioned about "actions in response to climate", the overall average of respondents who do not adopt any actions is considerable. Thus, despite reasonable awareness of how built environment characteristics affect thermal comfort (as demonstrated by the previous sub-indicator average scores), many still do not deliberately take actions at home to better adapt during climatic events. There is, therefore, a noticeable gap between knowledge and action/engagement for a significant portion of the sample. Consequently, regarding the sub-indicator "actions in response to climate", considerably lower scores are observed compared to the previous sub-indicator in both developments (RSB – 2.72 and 2A4 – 2.60), classifying both as "little resilient."

Regarding the "Existence of communication means for requesting help in case of emergency", the number of individuals reporting the absence of such means was surprising, resulting in the corresponding sub-indicator receiving the lowest average evaluation from the RR for both developments (RSB – 1.28 and 2A4 – 1.33 – indicating non-resilience).

Looking at the overall results for this indicator, the longer time since the delivery of the RSB (2010–2011) and accumulated experience with housing problems may explain its slightly better evaluation than the 2A4 in terms of climate-related preparation, knowledge, and actions. However, the difference is minor, and both developments remain classified as “little resilient” (scores 2–3). There is a general lack of habit in proactively seeking climate information, with the sub-indicator “search for climate information” scoring low (RSB – 1.76; 2A4 – 1.29) and “availability of communication means for requesting help” even lower (RSB – 1.28; 2A4 – 1.33). Those who do prepare rely mainly on mobile apps and social networks (RSB – 2.30; 2A4 – 2.10), supporting findings on the effectiveness of ICTs in climate risk preparedness (Gianfrate *et al.*, 2017).

Overall, most sub-indicators scored low, with the RSB achieving only 3.18 in climate awareness, classifying it as “moderately resilient” for this sub-indicator, but no development showed adequate adaptability in climate-related action. Awareness alone is insufficient for effective adaptation (Elias-Trostmann *et al.*, 2018; Haines & Mitchell, 2014). Residents rely heavily on technology, such as air conditioners and fans, while simple adaptive actions provided by the house itself, like opening windows or blinds, remain underestimated. This reflects the gap between knowledge and action identified in Brazilian contexts (Pott, 2022; Bigolin, 2018), highlighting economic, cultural, and technical barriers.

Achieving true thermal comfort resilience requires integrating public awareness and participation (Climatic Adaptability) with the passive, bioclimatic features of social houses (Bioclimatic Building). Figure 14 summarizes the results by sub-indicators and associated resilience skills, showing that the case study received an overall evaluation of 'little resilient'.

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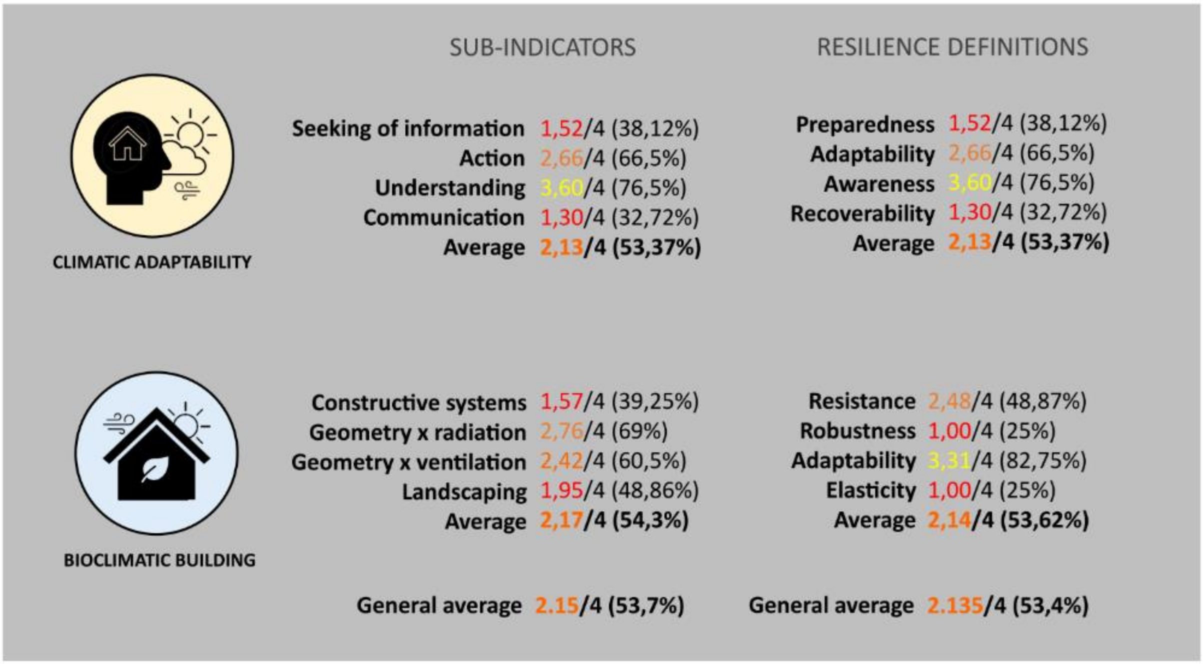
Figure 14 – Summary of results by sub-indicator and resilience definition.



Source: Bortoli (2023).

3.3 Referral for guidances

The results provided insights into the behavior and actions of users aimed at achieving thermal comfort, revealing gaps between knowledge and action that require further investigation in the future. It was observed that, in their efforts to improve living conditions, SH users undertake substantial renovations in their homes, investing significant time and money. However, these actions are often poorly optimized and can be detrimental to thermal comfort, which is crucial for resilience, especially for the most vulnerable populations. Given that thermal comfort as a resilience attribute relies on achieving passive buildings (environmental resilience) and adaptive behaviors (personal resilience), it is crucial that further research focuses on translating these insights into practical guidance for designers, service providers, and users. In this context, this study contributes by identifying deficiencies in the case study and outlining strategies to provide relevant information to interested parties, based on the proposed indicators of Bioclimatic Building and Climatic Adaptability. It underscores the importance of bridging technical and academic knowledge with civil society to address the real needs of the "informal city" (D'Amore, 2019).

Based on the categorization framework proposed by Villa, Bortoli & Oliveira (2024), as well as on studies and validation with the target audience (Villa & Júnior, 2024; Faria & Villa, 2023), the problems most frequently observed for each indicator, sub-indicator, and aspect were analyzed to determine the most effective way to guide renovations in the existing housing stock through informational sheets. These sheets are concise manuals in which the resilience requirements corresponding to a score of 4 (resilient) on the RR are presented as practical guidance, assuming that achieving this level should be the primary objective for promoting resilience through thermal comfort in projects similar to those evaluated in the case study. Aiming to meet the needs of a diverse audience comprising users, service providers, and architects, the sheets are organized into 7 sections:

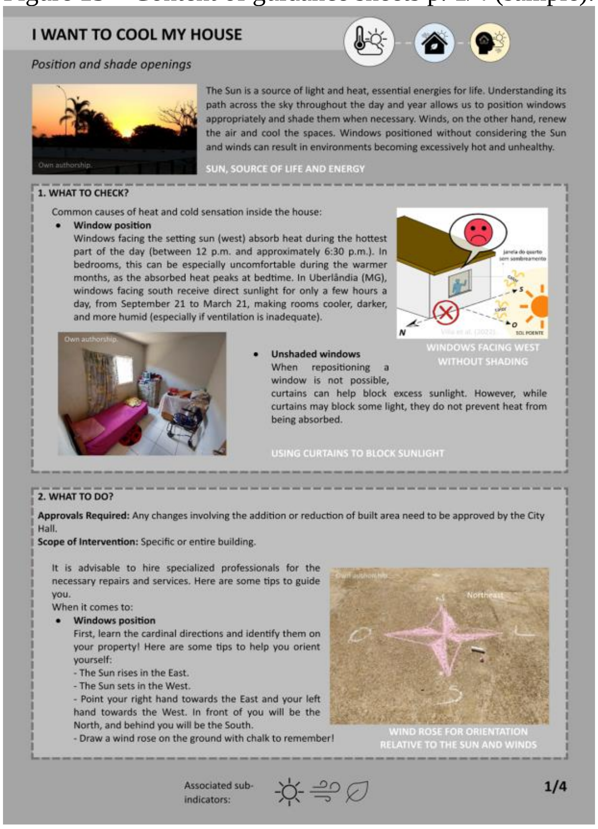
1. *What to check:* Provides a diagnosis and details of the aspects related to the problem that needs solving.
2. *What to do:* Offers a detailed presentation of potential solutions to the identified

problems.

3. *What will be needed:* Describes the tools, materials, and other resources required to address the problem.
4. *Precautions:* Outlines safety procedures to protect against risks.
5. *Who to hire:* Lists the professionals essential for solving the problem.
6. *Importance for health:* Explains how the problem relates to health issues to emphasize the need for resolution.
7. *References to consult:* Lists important standards and documents relevant to solving the problem.

Figures 15 and 16 illustrate the content of the guidance sheets, titled: Choosing Materials and Construction Techniques; Installing an Electrical Generation System; Positioning and Shading Openings; Adapting to Temperature and Humidity; Creating Conditions for Ventilation and Lighting. The content of these sheets contributed to the development of the Web App "*Reforma na Palma da Mão*"[8] for resilient renovations guidance on SH, and can be viewed in full at Bortoli (2023) or, partially at: https://reformacasa.facom.ufu.br/.

Figure 15 – Content of guidance sheets p. 1/4 (sample).



Source: Bortoli (2023).

Figure 16 – Content of guidance sheets p. 2/4 (sample).

Source: (Bortoli, 2023).

Through the development and validation of a resilience assessment method, which informed the creation of guidance sheets for housing renovations — both detailed in this study — this work contributes to the planning of more resilient cities. It focuses on equipping urban environments to tackle contemporary challenges, particularly those arising from climate change

[8] It can be translated as "Handy Home Improvements". This platform is the result of sponsorship provided by CAU-MG to the research group affiliated with the authors, between 2021 and 2022, through Public Notice No. 01/2021, which focused on the theme "Healthy Home – Dignified Housing." The initiative aimed to develop measures to address the COVID-19 pandemic within the context of Social Housing.

and its impacts, while improving thermal comfort for residents.

By deeply addressing the needs of a significant portion of the population in vulnerable situations, represented by SH in the studied climatic zone, the study aligns with the commitments established by the SDGs 11 and 13, specifically by:

- Promoting adequate, safe, and climate-adapted housing;
- Fostering environmental education by highlighting public knowledge gaps regarding the relationship between housing, thermal comfort and climate;
- Providing practical tools (assessment methodologies and guidance sheets) to build capacity for addressing climate risks;
- Supporting Architects and Urban Planners in delivering technical assistance for renovations and new projects that are more resilient to climate change.

This set of initiatives underscores a commitment to practical and inclusive solutions, contributing to the development of more sustainable and equitable cities.

4. CONCLUSION

The study presents the development of a method for assessing thermal comfort as a component of climate resilience in social housing located in Brazil's mixed-dry climate zone. It also reports the results of applying this method in a dual case study conducted in a representative city (Uberlândia, MG, Brazil), demonstrating its effectiveness in identifying priorities for improvement and in providing more targeted technical assistance in this context.

The results classified the case study as "little resilient" (average score of 2.135), revealing the vulnerability of both the physical environments and the occupants of the social housing units. Materials, based on their thermal properties, were negatively assessed, particularly due to the inadequacy of their composition to the local climate characteristics. Items such as solar protection and on-site vegetation also received low ratings due to their absence or suppression. Consequently, the "Bioclimatic Building" indicator scored 2.17, classifying it as "little resilient". Simultaneously, results for the "Climatic Adaptability" indicator revealed that, despite some knowledge about the relationship between climate, building, and thermal environment experience exists, residents struggle to adapt and access climatic information, as well as to take action to prepare for climatic impacts. This resulted in the evaluation of the occupied homes also as "little resilient" for this indicator, with a score of 2.13 points.

In response to these findings, guidance sheets for renovations were developed, focusing on enhancing thermal comfort and increasing the resilience of housing to climate impacts. These sheets are designed for designers, service providers, and users, supporting the technical assistance process for effective renovation management. The sheets have limitations, such as their generalized nature and specific focus on horizontal housing in Brazilian mixed-dry climate zone, as well as not addressing resilience to future climates due to the lack of specific standards that would guide the development of appropriate RR requirements. However, it is understood that the RR will evolve alongside updates to regulatory frameworks, incorporating requirements essential for the study and intervention in housing climate adaptation.

The findings highlight the role of Brazilian Federal Law No. 11.888/2008 (ATHIS), which guarantees free technical assistance for housing construction and improvement for low-income families. In this context, applying the Resilience Ruler (RR) — focused on thermal comfort — together with renovation guidance sheets developed from the evaluations, supports the creation of more climate-resilient social housing. Aligned with ATHIS principles, this approach enhances the capacity of architects, urban planners, and other stakeholders to deliver effective, climate-adaptive solutions, improving the quality of life for vulnerable populations while advancing urban resilience and sustainability.

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