Assessment of Sustainability Requirements in Temporary Housing in the Municipalities of Estrela and Cruzeiro do Sul, RS, Brazil

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https://doi.org/10.1590/SciELOPreprints.16280

Submitted on: 2026-05-26
Posted on: 2026-06-03 (version 1)
(YYYY-MM-DD)

i-Rec Conference 2025: (in)formalities: Understanding different forms of agency in disaster risk reduction, climate action, and reconstruction

Title:

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Abstract

This research aims to assess the sustainability of modular housing units implemented as temporary shelters for populations affected by flooding in the municipalities of Estrela and Cruzeiro do Sul, in the state of Rio Grande do Sul, Brazil. The investigation adopted a qualitative and exploratory approach, applying two sustainability assessment methodologies: the framework proposed by Alshawawreh et al. (2020), which was designed for post-disaster contexts, and the MASP-HIS methodology developed by Carvalho (2009), originally applied to social housing projects. The analyses were based on technical site visits and documentation provided by the manufacturer. The results indicated that the units meet the minimum technical requirements and offer advantages such as rapid deployment, module reusability, and the use of industrialized construction systems. However, important limitations were identified, particularly regarding thermal comfort, the absence of user participation in the design stages, and low sociocultural adaptability. The sustainable performance of the housing was classified as partial, with significant room for improvement, especially in environmental and social aspects. The originality of this research lies in the combined application of two complementary methods within a real post-disaster scenario in southern Brazil. The findings contribute to improving public policies for temporary housing, emphasizing the importance of integrating environmental strategies, community participation, and long-term cost assessment.

Keywords:
Humanitarian architecture; sustainability; temporary housing; temporary shelters; socio-environmental refugees.

Introduction

The year 2024 was marked by social and environmental response crises, including conflicts and wars in several countries, as well as extreme weather events, such as the floods in the state of Rio Grande do Sul, Brazil. In response to these adversities, many people were forced to abandon their homes and seek shelter, often without any prospect of returning. Severe floods struck southern Brazil in May 2024, caused by a slow-moving low-pressure system that generated a persistent moist flow and prolonged heavy rainfall. This event affected 478 municipalities with high precipitation levels, river overflows, landslides, and several adverse consequences, impacting a population of 2,398,255 people, resulting in 182 deaths, 420,000 displaced individuals, and financial losses amounting to several billion dollars (WMO, 2025; SMAMUS, 2024; Defesa Civil RS, 2024).

In this scenario, temporary housing becomes an essential measure to help reestablish affected populations, assisting in the physical and psychological recovery of those involved, and offering at least dignity and basic well-being. However, the available housing units often fail to consider the cultural and social characteristics of the affected populations, nor do they efficiently use local materials and labor elements that are crucial for social, economic, and environmental sustainability.

Because of the challenges caused by natural disasters, the objective of this study was to evaluate the temporary housing units provided to displaced populations in a socio-environmental disaster, based on sustainability parameters established by two methodological approaches, considering environmental, social, and economic criteria. These housing units were supplied by the State Government of Rio Grande do Sul to populations affected by the floods in the municipalities of Estrela and Cruzeiro do Sul.

To meet the emergency housing needs caused by the May 2024 floods in Rio Grande do Sul, 114 single-family modular housing units were delivered and installed in August 2024 in the municipalities of Estrela and Cruzeiro do Sul, located in the Vale do Taquari region (RS, 2024).

In this context, the study by Carbonari and Librelotto (2022) contributes to understanding the conceptual differences between "shelter" and "housing" in disaster settings. According to the authors, the term “shelter” refers to provisional spaces used during and immediately after the disaster, when regular domestic routines are interrupted. In contrast, “housing” involves the resumption of daily activities and family responsibilities, marking a phase of greater stability for the affected population.

In temporal terms, Carbonari and Librelotto (2022) propose that the resettlement process can be divided into four distinct phases: emergency shelter, temporary shelter, temporary housing, and permanent housing. However, these phases often overlap and do not follow a rigid linear sequence, being influenced by social, cultural, political, and economic factors.

In the case analyzed in this study, the modular units can be characterized as medium-term temporary housing, intended for use after the emergency shelter phase, which took place mainly in gymnasiums and improvised facilities. These units serve to provide greater stability and privacy for displaced families while they await permanent housing solutions, playing a key role in the transition between emergency response and the long-term housing reconstruction process.

This investigation presents relevant practical implications for the development of public policies related to disaster management and emergency housing. By evaluating temporary housing through sustainability criteria, the study contributes to more efficient and resilient solutions, promoting greater integration of environmental, social, and economic aspects. The results may also support the formulation of guidelines for selecting appropriate technologies and materials, optimizing resources, and minimizing negative impacts. Furthermore, the analysis can assist municipalities and civil defense agencies in incorporating sustainable principles into urban master plans, thereby strengthening inclusive and strategic housing policies.

The main sustainability challenges faced by current temporary housing solutions include cultural inadequacy, economic feasibility, and negative environmental impacts.

From a social perspective, the most significant aspects include: (i) active participation in shelter-related decisions; (ii) social connectivity; (iii) solidarity among beneficiaries; (iv) user satisfaction; and (v) safety and security of the shelter.

In environmental terms, the requirements involve: (i) planning flexible shelters that can be reused after their initial purpose; (ii) the use of natural materials; (iii) the adoption of industrialized materials; and (iv) the technical performance of the shelters. As for cost considerations: (i) material costs; (ii) transportation expenses; (iii) construction labor; and (iv) workforce costs are all included. In this study, infrastructure costs were excluded. The life span (longer-than-expected usage) may result in perceived inefficiencies in quality. It is essential not to rely solely on initial costs (a short-sighted perspective) but to consider operational and maintenance costs as well (Alshawawreh et al., 2020).

Sustainability in the construction sector must be understood in a comprehensive manner, involving a balanced integration of environmental, economic, and social dimensions — the latter also encompassing cultural aspects. Although these dimensions are interdependent, environmental impacts tend to have greater repercussions, especially due to the physical and often permanent transformations that construction activities impose on the territory. The central challenge lies in promoting economic development capable of meeting the expectations and needs of contemporary society, while preserving environmental integrity for future generations. In this context, the built environment, produced and maintained by the construction industry, plays a decisive role, as all human activity relies directly on the conditions provided by this environment (Agopyan and John, 2011).

It is essential to recognize that the environmental impacts generated by construction occur throughout its entire production chain, from the extraction of raw materials and manufacturing of products, through transportation, project design, and execution, to maintenance phases and, ultimately, demolition or disassembly and waste management. Each of these stages consumes natural, energy, and financial resources, with consequences that extend beyond the construction site and affect society at different levels. Achieving greater sustainability in this sector requires coordinated solutions across all phases and scales of the construction process, ranging from site selection and project decisions to the specification of systems and materials. Furthermore, it is crucial to respect local cultural specificities and social dynamics, avoiding the imposition of standardized solutions disconnected from community realities (Agopyan e John, 2011).

Climate change has intensified the occurrence of extreme weather events worldwide. According to EM-DAT Documentation (2025), a total of 668 disaster events were recorded globally in 2024 and early 2025 (as of April 2025), affecting 189,778,009 people. Among these, 22 occurred in Brazil, with one of the most significant impacting the state of Rio Grande do Sul, in southern Brazil.

The flood in Rio Grande do Sul, lasting from April 28 to May 7, 2024, is recorded in EM-DAT (2025) as having affected a total of 2,399,061 people.

Research Methods

This study employed a qualitative and exploratory methodology to evaluate the sustainability of modular housing units used as temporary shelters in post-disaster contexts. The investigation was conducted through on-site technical visits, accompanied by documentary analysis of the User Manual, which enabled the detailed observation and assessment of the construction characteristics, materials used, and functional solutions implemented in the housing units.

The evaluation focused on the three dimensions of sustainability — Environmental, Social, and Economic — based on two complementary methodological approaches. The first, proposed by Alshawawreh et al. (2020), assesses the sustainability of housing projects and solutions applied in post-disaster and post-conflict contexts, classifying decisions into advantages and disadvantages. The second, by Carvalho (2009), presents the MASP-HIS methodology, in which each requirement is evaluated through answers such as "yes," "no," or "not applicable," allowing for a subsequent overall assessment of the housing's sustainability performance.

Alshawawreh et al. (2020) qualified the sustainability of shelters designed for post-disaster and post-conflict scenarios, evaluating multiple projects during both design and implementation phases within the three sustainability dimensions, from a qualitative perspective. The authors emphasized that a degree of qualitative interpretation was necessary to classify the indicators, as the concepts involved cannot be framed in absolute terms. For example, to assess environmental impacts with greater accuracy, it would be necessary to adopt quantitative approaches, which are not incorporated into the methodology proposed by the authors. Additionally, not all constructive and cost-related characteristics of the shelters were available for consultation, representing a limitation of the study (Alshawawreh et al., 2020).

The evaluation parameters were based on sustainability criteria from the literature, as illustrated in Table 1.

Table 1. Parameters adopted from Alshawawreh et al., 2020 (Source: Adapted from Alshawawreh et al., 2020)

	Social	Environmental	Economic
Design phase	Involve residents in the design phase	Use renewable energy	No available cost data in the design phase
	The living space must adequately accommodate the number of residents, taking into account age and gender composition	Passive heating and cooling Vernacular architecture	
	Include private facilities whenever necessary	Consider shelter lifespan	
	Include spaces for pets	Must be reusable or recyclable	
Material selection	Familiar or culturally accepted materials	Use natural, biobased, or recyclable materials	Material costs should be around US$ 1,300
	Sustainable materials	Use locally manufactured materials whenever possible	
	Available materials	Use seasonal materials when possible	Total material cost must not exceed US$ 5,600
	Temporary solutions when land tenure is uncertain	Mixed construction using prefabricated and natural materials can be appropriate	

The MASP-HIS method (Sustainability Assessment Methodology for Social Housing Projects), developed by Carvalho (2009), was originally conceived to assess the sustainability of social housing projects during the design phase. However, its application in this study is justified due to the typological similarity to the modular units analyzed, even though these had already been implemented. The methodology was therefore adapted to consider data obtained in the field and from technical documentation, extending its original use to broaden the understanding of the sustainable performance of these construction solutions in post-disaster housing emergency contexts.
For each sustainability dimension, indexes were generated based on questionnaires and calculations that allowed for identifying the strengths and weaknesses of the project. Positive responses were assigned a score of 1, and negative responses a score of 0. Statements could be excluded by marking them as "not applicable" or "no data available." Detailed explanations and justifications for the applied responses are provided in the annexes. It should be noted that no adaptations were made to the methodology itself, and there is an acknowledged degree of subjectivity in the evaluation of certain criteria.

The tool evaluates questionnaire responses through simple calculations, considering, for each subcategory, the ratio Qs/Qt, where Qs is the sum of "yes" responses and Qt is the sum of valid responses. The partial indices of each category are defined by the ratio between the sum of the subcategory indices and the total number of subcategories, multiplied by 100, as shown in Equation (1):

$$\textbf{Subcategory} = \mathbf{Qs / Qt} \quad (1)$$

The partial index for each sustainability dimension (environmental, social, and economic) is calculated by the ratio between the sum of the partial indices of its categories and the total number of categories. To obtain the overall result for each dimension, the average of the subcategories is calculated according to the number of criteria in each, following Equation (2):

$$\mathbf{A} = \sum \textbf{Subcategories / Number of subcategories} \times \mathbf{100} \quad (2)$$

For each dimension (environmental, social, and economic), a partial result R is obtained based on Equation (3), where the X values represent the partial indices of the dimension's internal categories:

$$\textbf{Rdimension} = \mathbf{(X1 + X2 + Xn) / n} \quad (3)$$

The overall sustainability index of the project under study is the average of the indices for the environmental, social, and economic dimensions, with values equal to or greater than 50 considered a positive sustainability assessment.

Research Question/Hypothesis

This study seeks to answer the following question: Do modular temporary housing units used in post-disaster contexts in Brazil meet the sustainability criteria established by Alshawawreh et al. (2020) and Carvalho (2009)? From this, the hypothesis is formulated that the temporary housing units demonstrate satisfactory sustainable performance in the environmental, social, and economic dimensions.

Research Objectives

The primary objective of this study was to assess the sustainability of modular housing units used as temporary housing in disaster contexts, considering the environmental, social, and economic dimensions. To this end, the study sought to identify the technical characteristics of the units through on-site visits and documentary analysis. In addition, these housing units were qualitatively evaluated based on the sustainability criteria proposed by Alshawawreh et al. (2020) and Carvalho (2009). Finally, the study compared the results obtained from both methodologies to identify the strengths and weaknesses of the adopted construction solutions.

Research Results

Technical Characteristics

The buildings analyzed were contracted by the Government of the State of Rio Grande do Sul as part of the emergency response to the 2024 floods. The contract summary published in the Official Gazette of the State of Rio Grande do Sul described the provision of 500 (five hundred) modular transportable housing units for use as temporary dwellings, with a built area of 27 m², designed to accommodate 4 to 6 people, and delivered fully assembled for installation on-site, allowing for multiple relocations throughout their useful life (RS, 2024, p. 1). The total contract value was R$ 66,672,190.00 (sixty-six million, six hundred and seventy-two thousand, one hundred and ninety Brazilian reais), resulting in an approximate unit cost of R$ 133,344.38 (one hundred and thirty-three thousand, three hundred and forty-four reais and thirty-eight centavos) per unit (RS, 2024).

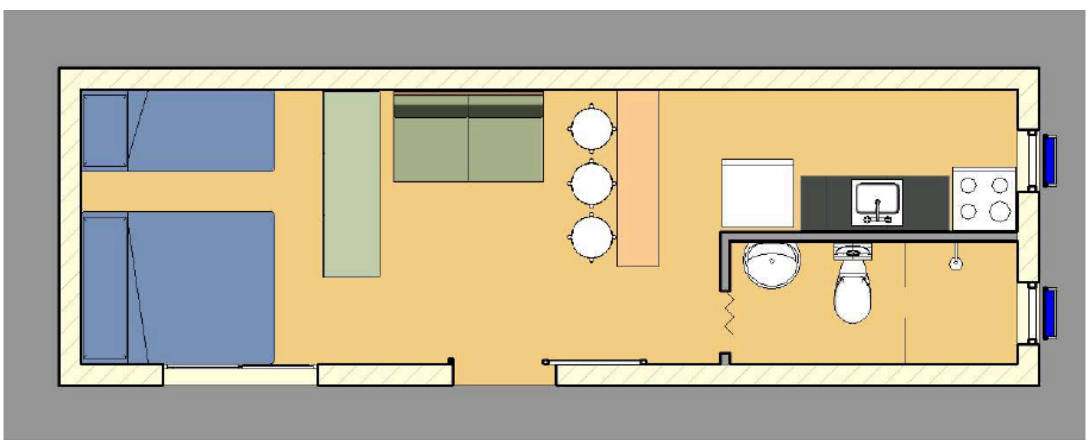
The technical characteristics of the housing units were obtained from the user manual,
provided alongside the units to residents, and through observations during technical visits. Each module measures 3×9 meters, totaling 27 m² of built area, with a free ceiling height of 2.7 meters. The modules are prefabricated for later transport and assembly of their subsystems. The construction and material characteristics are detailed in Table 2.

Table. 2. Modular Unit Construction Characteristics (Source: Author, 2025)

Stage	Characteristics
Structures	Metal pillars and beams, Z100 tubes measuring 60x40 cm, with 1.55 mm thickness
Floor	25 mm cement boards with 2 mm LVT vinyl flooring
Roof	Metal roofing
Thermoacoustic insulation	50 mm ISOVER glass wool applied to ceilings and external walls
External sealing	GRC/GFRC (Glass Fiber Reinforced Concrete) panels; Stud-frame system; joints sealed with flexible sealant
Internal sealing	10 mm cement boards
Frames	External: Aluminum alloy 6060 - Temper 15 (doors and windows); Internal: Folding PVC (bathroom)

The internal layout of the units consists of a private bathroom, kitchen, living room, and bedroom, as shown in Figure 1.

Fig. 1. Internal layout of the unit (Source: Author, 2025)

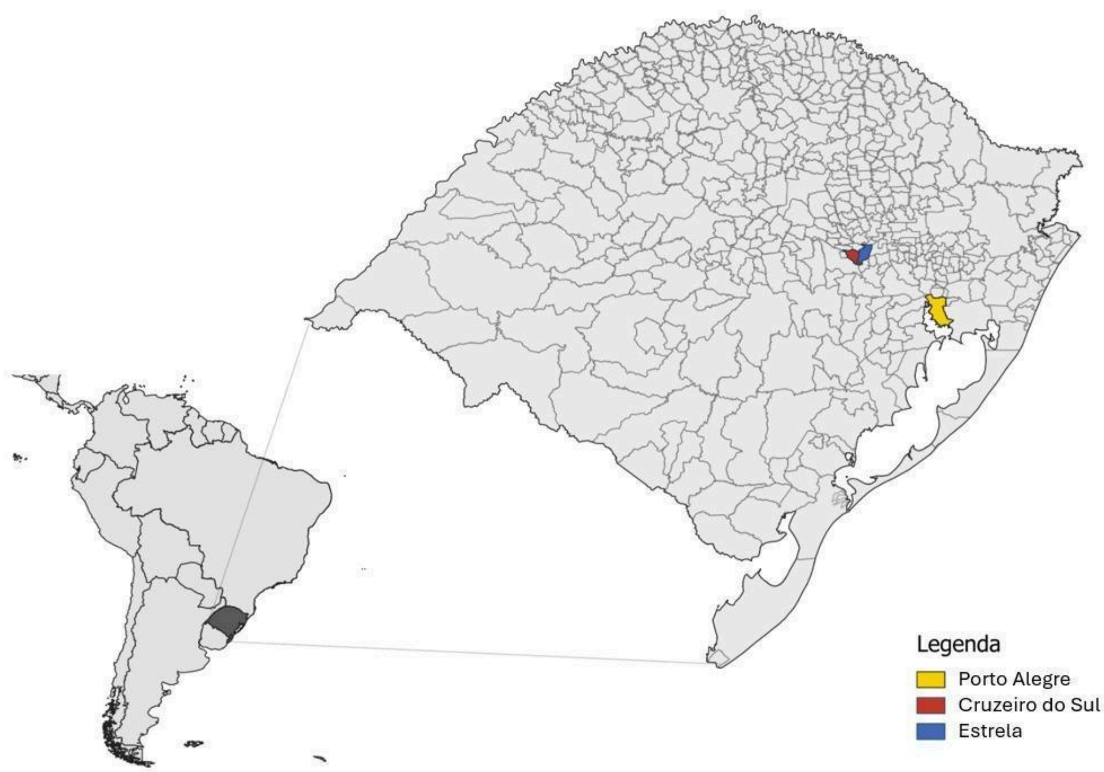


The user manual also provides guidelines on the handling, storage, and cleaning of the units for installation and use throughout the service life of the modules. It highlights the connection systems for water, sewage, LPG gas, electricity, and the lightning protection system (SPDA) linking the modules to the respective external networks. Additionally, it specifies and provides instructions for the equipment, appliances, and furniture installed in the buildings.

Technical Visit

The technical visit was carried out in the municipalities of Estrela and Cruzeiro do Sul on November 13 and 14, 2024, by the Virtuhab Research Group team. The region is located approximately 120 km from the state capital, Porto Alegre, within the Taquari-Antas River Basin, as shown in Figure 2.

Fig. 2. Map indicating the location of the technical visit (Source: Author, 2025)



During the on-site technical visit, several aspects regarding the installation of the units on the ground and the practical use of the modules by the residents were observed. Specific characteristics related to the sustainability of the constructions, which would not be possible to verify solely through project documentation, were noted. These included: (i) lack of adequate shading for the units; (ii) reports of high indoor temperatures causing thermal discomfort; (iii) expansions and *modifications carried out by the residents themselves; and (iv) absence of protective covering for areas housing washing machines. Photographs 1, 2, 3, and 4 illustrate the external installation of the housing units.*

Plate 1. Housing installation in Estrela - RS (Source: Author, 2024)

Plate 2. Housing installation in Estrela - RS (Source: Author, 2024)

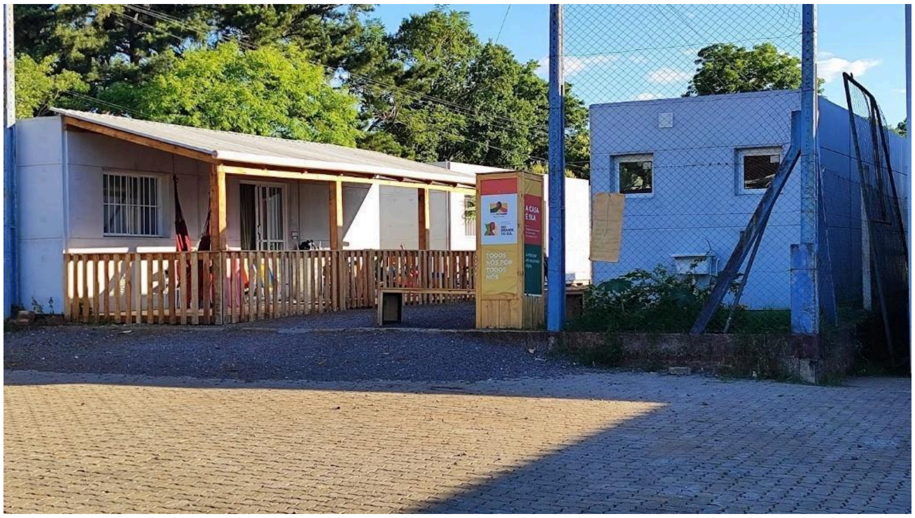


Plate 3. Housing installation in Cruzeiro do Sul - RS (Source: Author, 2024)

Plate 4. Housing installation in Cruzeiro do Sul - RS (Source: Author, 2024)

Evaluation According to Alshawawreh et al. (2020)

The assessment based on Alshawawreh et al. (2020) indicates that classifying the indicators as pros or cons requires some qualitative interpretation, following the examples presented in the referenced study. In the specific case of the requirement related to minimum dimensions, the parameters established by Carbonari (2021) were adopted as a reference. It was verified that the housing units are technically suitable for occupancy by up to six people; however, they were officially allocated for up to two adults and two children. Although these minimum requirements were met and the dwellings are classified as medium-term temporary housing, in practice it was identified that these dimensions do not provide adequate comfort for the families — a limitation clearly observed in the qualitative analysis. Table 3 presents the evaluation of the housing features, separating them into pros and cons. It is important to highlight that no information was available to assess sustainability in the economic dimension.

Table 3. Sustainability evaluation according to Alshawawreh et al. (2020) (Source: Author, 2025)

Social		**Environmental**	
Pros (+)	**Cons (-)**	**Pros (+)**	**Cons (-)**
Adequate dimensions for up to 6 people (27 m²)	No community involvement in the design phase	Units can be recycled and easily transported to other locations	Non-sustainable materials, but with a good lifespan
Culturally acceptable materials and layout	No use of local labor for construction	Prefabrication allows faster delivery and less waste	No passive heating and cooling techniques applied
Raised floor relative to ground level	No provisions for domestic animals	Durability Adequate service life	No biobased or recycled materials
Private kitchen and bathroom per family	No private bedrooms separated by age and gender	Adequate structural safety	No renewable energy use
Easy transport and installation	Layout does not ensure privacy at the main entrance	Adequate acoustic insulation	Inefficient thermal insulation
Considers social needs	Lack of community gathering spaces	-	-

Evaluation According to Carvalho (2009)

For the sustainability index assessment proposed by Carvalho (2009), each item was evaluated with "Yes," "No," or "No specific information," with the justifications available in the Appendix.

In the environmental sustainability indicators, notable points include the absence of shading around the modules and in the outdoor areas, leading to overheating in summer, problems during rain, a lack of laundry area protection, and insufficient community spaces. Another important issue concerns habitability, functionality, and flexibility: while the project does not allow for internal alterations, it was observed during the technical visit that residents made external modifications and extensions through self-construction.

In this dimension, items B2 and C5 were not assessed due to a lack of specific information. Additionally, the category partial indexes reached 42.05% for category A, 37.83% for category B, and 51.89% for category C, as shown in Table 4.

Table 4. Environmental sustainability evaluation (Source: Author, 2025)

Categories	Subcategories		Yes	No	NA/SD	Valid total Yes/No	R 1[1]	R 2[2] %
A Resource, Energy and Mass Flow Consumption	A1 - US	Land Use	5	13	10	18	0,28	42,05
	A2 - CA	Water Consumption	10	11	2	21	0,48	
	A3 - CE	Energy Consumption	1	5	1	6	0,17	
	A4 - CM	Material Consumption	2	9	6	11	0,18	
	A5 - R	Waste	2	0	15	2	1,00	
B Internal Housing Quality Comfort and Health	B1 - QV	Air Hygiene and Quality	5	1	3	6	0,83	37,83
	B2 - CEM	Electromagnetic Comfort	0	0	2	0	0,00	
	B3 - CTA	Tactile and Anthropodynamic Comfort	6	10	3	16	0,38	
	B4 - V	Ventilation	2	11	0	13	0,15	
	B5 - CA	Acoustic Comfort	1	3	3	4	0,25	
	B6 - CL	Lighting Comfort	11	3	1	14	0,79	
	B7 - CHT	Hygrothermal Comfort	1	3	3	4	0,25	
C Product Quality (Housing)	C1 - DM	Durability/Maintainability	4	3	1	7	0,57	51,89
	C2 - S	Safety: Structural, Fire, and Operational	15	1	9	16	0,94	
	C3 - E	Watertightness	8	2	1	10	0,80	
	C4 - HFF	Habitability, Functionality, and Flexibility	2	5	1	7	0,29	
	C5 - C	Constructability	0	0	10	0	0,00	

[1] R 1 - Subcategory: SC=Qs/Qt

[2] R 2 - Category: R = ∑ subcategories / Number of subcategories *100

The environmental dimension index was calculated by averaging the three categories, **R_environmental = (A + B + C) / 3**, which resulted in **43.92%**.

Regarding the social indicators, it was observed that the modules were delivered to the users without prior community participation, due to the emergency context. It was also evaluated that the units adequately meet the users' basic needs, presenting acceptable appearance, good quality, and minimum functionalities for the resumption of daily routines — considering their temporary use until definitive housing solutions are provided. However, issues related to internal and external privacy, the absence of cultural identity, lack of community involvement, and other relevant aspects were identified.

An important observation refers to the disregarded items: **D1 - surrounding infrastructure (schools, health posts, public spaces)** was excluded because the installation sites had distinct and specific characteristics. Additionally, items **G, I, J, K1, and K2** were excluded for being specific to the assessment of materials used in vertical sealing systems. **Item E - Cultural Heritage** obtained a partial index of zero since all sub-items were marked as negative for not meeting any criteria.
Partial valid indexes obtained were: **20.00%** for category D, **69.44%** for category F, and **100%** for category H, as shown in Table 5.

Table 5. Social sustainability evaluation (Source: Author, 2025)

Categories	Subcategories		Yes	No	NA/SD	Valid total Yes/No	R 1[1]	R 2[2] %
D Social	D1 - IF	Infrastructure	0	0	11	0	0,00	20,00
	D2 - CS	Comfort and Health	4	6	1	10	0,40	
	D3 - QP	Housing Quality	6	4	0	10	0,60	
	D4 - CL	Community Relations	0	6	0	6	0,00	
	D5 - P	Participation	0	8	1	8	0,00	
E Cultural	E1 - HC	Cultural Heritag	0	8	0	8	0,00	0,00
F Political and Institutional	F1 - PP	Public policies	7	11	0	18	0,39	69,44
	F2 - EA	Environmental Education	1	0	2	1	1,00	
G Income Management and Social Responsibility	G1 - EC	Construction company	0	0	18	0	No data available	
	G2 - EP	Design company	0	0	50	0		
	G3 - F	Suppliers	0	0	9	0		
	G4 - U	User	0	0	5	0		
H Safety	H1 - S	Safety	2	0	2	2	1,00	100,00
Socio-Cultural Aspects Vertical fencing systems	I1	Participation	0	0	0	0	Specific sealing materials and coatings. No data available Not considered	
	J1	Cultural Heritag	0	0	0	0		
	K1	Suppliers of materials and components for masonry	0	0	0	0		
	K2	Suppliers of coating materials (apply to sand, lime, cement - extraction and production)	0	0	0	0		

[1] R 1 - Subcategory: SC=Qs/Qt

[2] R 2 - Category: R = ∑ subcategories / Number of subcategories *100

The social dimension index was calculated by averaging the four categories, **R_social = (D + E + F + H) / 4**, resulting in **22.61%**.

The economic dimension was not evaluated due to a lack of consistent data, although it was possible to comment on the local and nearby community impacts. The selected locations for installing the units in the municipalities require significant improvements in basic infrastructure, such as sanitation services, electricity, telecommunications (especially in rural areas), waste collection, public transportation, urban amenities (schools, health posts, parks), employment and income generation, and the valorization of local commerce, among other developments.

Regarding the economic feasibility of supplying the modules, it is worth noting that the funds were allocated under emergency conditions following the floods in May 2024 and through a waiver of public tender procedures. As for operating and maintenance costs, it can be stated — according to the detailed guidelines in the user manual — that these costs are relatively low. Table 6.

Table 6. Economic sustainability evaluation (Source: Author, 2025)

Categories	Subcategories		Yes	No	NA/SD	Valid total Yes/No	R 1[1]	R 2[2] %
Economic	L1 - FEL	Strengthening the local economy	0	0	0	0	Not rated due to lack of detailed information	
	L2 - VE	Economic viability	0	0	0	0		
	L3 - C	Cost of construction / operation / maintenance	0	0	0	0		
	L4 - CEP	Economic criteria for the company executing the project	0	0	0	0		

Considering the indices obtained from the environmental, social, and economic dimensions, the overall sustainability performance of the temporary modular housing units was evaluated. When including only the environmental and social dimensions — due to the unavailability of consistent economic data — the combined average reached 33.27%, falling below the recommended sustainability threshold of 50% suggested by Carvalho (2009). This result highlights important limitations in both environmental and social aspects, despite the technical adequacy and potential for reuse of the modules.

If considering the three dimensions — assigning a zero value to the economic dimension due to insufficient information — the overall index drops to 22.18%, emphasizing the critical importance of integrated economic sustainability indicators for a comprehensive and fair assessment. In both scenarios, the results confirm that, although the modular units address basic technical requirements and offer logistical advantages, their sustainability performance remains partial and insufficient to be classified as sustainable according to the established benchmarks.

These findings reinforce the need for improvements, especially regarding environmental strategies such as passive thermal performance and material origin, as well as social indicators like community participation, cultural adequacy, and enhanced habitability standards. Future projects of this nature must incorporate broader sustainability measures from the early design stages to ensure more resilient, inclusive, and effective emergency housing solutions.

Discussion and Conclusions

The study presented the technical characteristics of the modular temporary housing units, delivered to the municipalities of Estrela and Cruzeiro do Sul (RS), detailing the materials and construction technologies used. The qualitative analysis of the modules, based on the sustainability criteria defined by Alshawawreh et al. (2020) and Carvalho (2009), enabled a comprehensive evaluation of these units in each of the sustainability dimensions. It was concluded that these modules demonstrate satisfactory performance in several aspects, notably their potential for reuse, quick assembly, and compliance with minimum technical housing standards. The evaluation framework proposed by Carvalho (2009), originally developed for social housing projects, also proved effective for temporary housing, contributing to a critical understanding of the impacts and limitations of such emergency solutions.

Environmental Sustainability:

Environmentally, the units performed satisfactorily. The metal frame structure and the use of Glass Fiber Reinforced Concrete (GRC/GFRC) panels promote reuse in different locations, extending the units' service life and reducing waste in future construction processes. The adoption of industrialized materials with good durability reduces the need for frequent maintenance, contributing to lower environmental impacts throughout the operation period. However, the absence of systems such as rainwater harvesting, efficient cross-ventilation, or solar panels, for instance, limits the ecological potential of the housing, reducing its capacity for autonomous and environmentally optimized operation. Additionally, no performance indicators for energy use or carbon emissions related to the production and transport of materials were identified.

Social Sustainability:

The social dimension yielded more ambiguous results. Although the units technically meet the minimum size requirements defined for medium-term temporary housing by Carbonari (2021), empirical perception and the assessment of criteria proposed by Alshawawreh et al. (2020) and Carvalho (2009), based on technical visits, indicate user discomfort. The compact internal spatial organization with a basic integrated layout—bathroom, kitchen, living room, and bedroom—while functional, compromises privacy and may negatively affect family well-being during prolonged stays.

Moreover, no direct involvement of the affected community in the project decisions or in the customization of units was identified, which compromises the social acceptance and cultural appropriateness of the dwellings. Excessive standardization and a lack of opportunities for personalization or expansion reflect a disregard for local family dynamics and specific needs. On the other hand, the fact that the units were delivered with basic infrastructure for electrical, plumbing, and furniture installations represents progress compared to more precarious emergency models.

Economic Sustainability:

Economically, data from the Official Gazette of the State of Rio Grande do Sul indicate a cost of R$ 66,672,190.00 for the supply of 500 units. Although this value includes the supply of the modules themselves, it does not cover external infrastructure, which limits a comprehensive cost-benefit analysis. The possibility of relocating and reusing the modules in different scenarios is a factor that justifies the high initial investment, especially in the context of recurring emergencies. However, there are significant gaps regarding the long-term durability of components and the actual maintenance costs. As highlighted by Alshawawreh et al. (2020), economic sustainability analysis should not be limited to initial costs (a myopic perspective) but should also consider operational and maintenance expenses throughout the product's life cycle. In this sense, further studies are necessary to measure these indicators and support future investment decisions in modular temporary housing.

Integrated Analysis:

The combined application of the methods proposed by Alshawawreh et al. (2020) and Carvalho (2009) enabled a critical and comparative evaluation of the solutions adopted in the analyzed housing units, revealing that, although they meet minimum technical requirements, their overall sustainability performance remains partial. The main strengths identified refer to the feasibility of the construction system, the rapid deployment, and the possibility of reusing the modules. Conversely, significant weaknesses persist in sociocultural and environmental aspects, with limitations in comfort, user participation, and consideration of operational costs. These adjustments are essential to enhance the effectiveness and sustainability of housing solutions in emergency contexts.

Key Lessons Learned

The data analysis allowed the extraction of important lessons related to the application of temporary modular housing in disaster contexts. Firstly, it was found that meeting the minimum floor area criteria (27 m²), although technically suitable for up to six people, does not by itself

guarantee adequate comfort and privacy for medium-term stays. This finding reinforces the need to associate regulatory requirements with indicators of real habitability.
Additionally, it was observed that the standardization of modules, while contributing to faster transportation and assembly, compromises the sociocultural adaptability of the units.
From an environmental perspective, the possibility of reusing and relocating the modules represents a significant advance. The use of long-lasting industrialized materials contributes to waste reduction and extends the useful life of the units.
Finally, it was verified that the absence of community involvement in the initial stages of the project negatively affects both the perceived functionality and the sense of belonging, elements that are fundamental for consolidating dignified and sustainable housing solutions.

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Conflict of Interest Statement - Declaração de Conflito de interesses

The authors declare that there are no conflicts of interest related to this research. This study did not receive funding that could generate potential financial, institutional, or personal conflicts of interest.

Author Contributions (CRediT Taxonomy) - Contribuição de autoria

Bibiana Zanella Ribeiro was responsible for data collection and treatment, field investigations, data analysis, manuscript writing, and presentation of the research results. Gabriela Willemann Siviero Maximo contributed to the writing process and critical revision of the manuscript. Lisiane Ilha Librelotto was responsible for the supervision and guidance of the research, methodological development, and critical review of the study. All authors reviewed and approved the final version of the manuscript.

Data Availability Statement - Declaração de Disponibilidade de Dados

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to the nature of the field investigations and technical documentation analyzed, some data may be subject to access restrictions.