Advancing Transitional Shelter Provision Through Innovative Structural Solutions

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ABSTRACT: The overarching goal of this study is to equip researchers and developers in the structural and associated sectors with the information they need to prioritize, in the creation of suitable and effective aid for emergency housing that can keep up with the projected future increase in demand. Using the grounded theory method and a series of case studies, the paper presents a compiled list of user-reported structural problems, the difficulties authorities have had in resolving those problems, and some ideal solutions, derived from the theoretical coding. The emergency shelter requirements in this study highlight the need for an economic (cost-effective), lightweight, reusable (especially if transitional), easily and efficiently manufacturable, constructable (with few in-situ installation inputs) and transportable housing solutions. Based on the structural requirements identified and acknowledged, a spectrum of innovative structural approaches, including modular and adaptable systems, site-specific designs, hybrid materials, and sustainable construction techniques have been proposed as to facilitate the development of new shelter designs and to support and enhance the usability of existing designs. These approaches emphasize the integration of advanced materials, computational tools, and resilient design principles to create shelters that are not only robust and safe but also environmentally conscious and culturally sensitive. Finally, the paper summarizes the key concerns in terms of sustainability and structural aspects of proposed designs and concludes with recommendations and suggestions to enhance the applicability of such designs, based on emergency requirements and shelter deployability. This article catalyses transformative change in the field of emergency shelter provision serving as the base for confrontation on alternative designs and materials and will support further studies on the structural and architectural design and organization of emergency shelter provisions.

KEYWORDS: Shelter Emergency, Post-disaster, Emergency Housing, Sustainable Structures, Timber – Steel Composite.

1.0 INTRODUCTION

Emergency shelters become crucial when living conditions fall below humanitarian standards. However, most crises last significantly longer than anticipated, over 80% of refugee situations extend over ten years, and stabilization in conflict-affected regions can take upwards of 23 years (European Commission 2017). With climate change and global conflicts exacerbating displacement, durable transitional solutions are increasingly critical (United Nations Office for Disaster Risk Reduction 2022). Transitional shelters are those aimed to offer habitable, secure, safe, and healthy living spaces as an initial step towards recovery, even amidst prevailing uncertainties bridging the gap between temporary stay and permanent housing (Corsellis 2012). They are put in place when loaning mechanisms and accompanying measures to enhance the resilience of the affected population are not possible. Research on transitional shelters is fragmented, with design strategies varying widely across contexts (Beatini et al. 2022; Cerrahoğlu and Maden 2022; Beatini 2015) and the design community leaning toward adaptable solutions. The civil engineering community leans towards prefabrication (Pan 2022) and emphasizes structural testing (Caimi et al. 2014). Occasionally, these approaches conflict; for example, the push for testing clashes with the use of local materials like earthen blocks or timber, which may lack fully explored structural properties and construction techniques. a notable gap persists in research addressing the challenges of designing transitional shelters under uncertain conditions. Post evaluation surveys have been promoted as a mean to contextualize solutions (Portieles 2021), but Transitional shelters are the most challenging to design because they must address issues akin to permanent housing within an uncertain timeframe, with constrained budgets and shorter construction periods. The risk of either overdesigning or substandard construction is notably high.

In a previous study (Beatini et al. 2022), we employed Grounded Theory Analysis to create a knowledge base of structural-related challenges. That analysis involved mapping 84 emergency shelters used in actual emergency scenarios and led to the identification of persistent structural-related challenges. Those results are here translated in design principles and criteria to propose innovative structural solutions. An innovative structural design for transitional shelters is conceptualized, combining steel and timber. This mixed-material design minimizes steel usage to enhance structural stability and reliability—key challenges in lightweight shelters. By integrating standardized light gauge elements, the design not only aims to improve viability and feasibility but also holds the potential to significantly boost sustainability on a broader scale.

2.0 MATERIAL AND METHOD

2.1 The transitional shelter typology

Shelters can be classified either as temporary sheltering, transitional, or permanent housing, Figure 1. According to the classic definition in (Quarantelli 1995), the first is a temporary stay arrangement such that the person suspends daily activities. Transitional shelters are temporary housing arrangements such that the persons recover routines but are supposed not to stay permanently. Finally, permanent housing is the institutionalized restoration of permanent residential conditions, often through the construction of a permanent yet small space, or 'one-room shelter'. A common form of temporary shelter is the tent, for which international agencies have provided increasingly optimized solutions. These solutions are adaptable to the specific climate challenges of different scenarios (UNHCR 2016). An illustrative example of permanent housing is the terraced Villa Verde houses in Chile, designed by Elemental (O'Brien and Carrasco 2021). Each house can be expanded vertically by the owners at their own pace. Transitional shelters were first implemented on a large scale in 2005, following the South Asia Tsunami (Corsellis 2005), as a strategic response to avoid expensive cycles of delivery of temporary shelters. The varied duration of this period for individuals complicates efforts to maximize their benefits and sustainability (Flores and Kloer 2012).

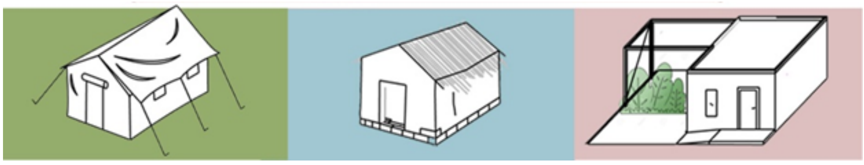

Figure 1: From left to right, a pictorial representation of a temporary shelter, a transitional shelter and permanent housing. Source: Adapted from (Beatini, Rajanayagam, and Poologanathan 2022).

2.2. Method

The methodology integrates inductive (problem identification) and deductive (solution development) phases, applied in parallel (Figure 2). The inductive phase comprises *stakeholder insights*, which analyses design visions, constraints, and processes promoted by funding agencies; to this follow *design requirements* and their metrics, as outlined by agencies guidelines. *design strategies* are visualized through a case study analysis. In line with the prior Grounded Theory Analysis (Beatini et al. 2022), which revealed causal links between structural challenges and sustainability goals, the structural design solutions of the two case studies are evaluated through a sustainability framework (Institutional sustainability, Environmental performances, Socio-cultural adequacy and Economic effectiveness). In the deductive phase, we elaborate *design principles* that respond to those criteria. We eventually propose a *concept implementation* into a novel structural design concept for transitional shelters, informed by case study insights. Finally, the *concept validation* action reviews the concept against real-world complexity. This iterative approach prioritizes adaptability, ensuring solutions evolve through feedback between problem identification and implementation.

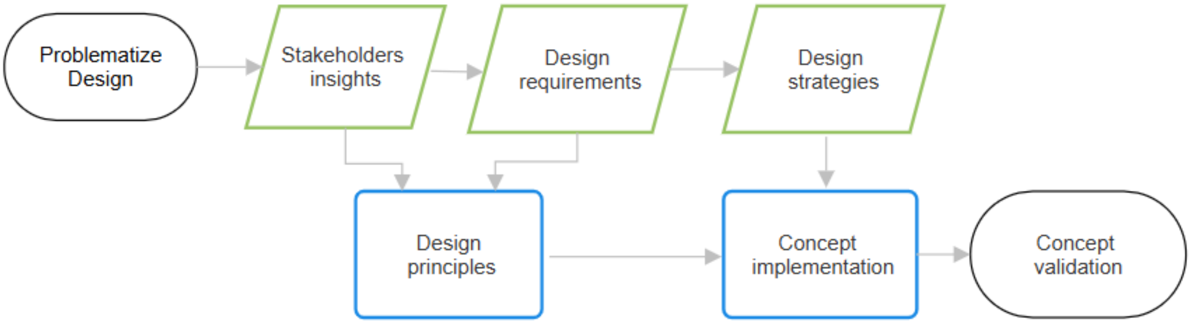

Figure 2: Diagram of the method employed to conceptualize an innovative shelter structural solution. Source: (Authors 2024)

3.0 SETTING A DESIGN FRAMEWORK

3.1. Design brief and process

A robust design framework shall start from understanding the needs and vision of the client. The Shelter Centre, a prominent humanitarian NGO based in Switzerland and backed by the UN's International Organization for Migration (IOM), has established a set of guidelines intended for a diverse audience that includes beneficiaries, government task forces, coordinating and implementing agencies, and donors (Corsellis 2012). Accordingly, transitional shelters shall be affordable and economically sustainable, supporting the beneficiaries to restore their income. The shelters shall not only be habitable but also serve as a potential economic resource. The shelter should be adaptable for recycling, upgrading, repurposing, selling to generate income, or transferring from a temporary to a permanent site. Recommendations include sourcing materials locally to benefit the local economy and leveraging culturally familiar technologies to facilitate reselling or other intended uses. Community involvement is critical to ensuring shelters meet local needs and remain economically viable post-deployment (Kennedy et al. 2008). However, the document does not discuss in detail how after usage choices affect the design process and priorities. In terms of the design process, funding agencies often favour incremental solutions with short-term, quantifiable impacts (Gray and Bayley 2015). To counteract potential stifling of innovation, the Shelter Centre released a draft of Transitional Shelters Prototypes in 2014, encouraging participation from international manufacturers. This draft proposed a transitional shelter that could evolve from plastic sheeting to sustainable local materials with a lifespan of two to five years. Unlike earlier guidelines, it emphasized the shelter's transportability, focusing on total weight and packaging size, without mentioning the usage of local materials at that juncture.

In conclusion, the design briefs and guidelines promote a sustainable economic model for transitional shelters, but there are significant challenges particularly in maximizing the shelter's value towards the end of its lifecycle. Engaging the affected community in the design process could help ensure that the shelter retains its value; however, this might result in unpredictable outcomes. On the other hand, outsourcing solutions guarantees quality but may compromise the overarching goal of enhancing the resilience of the beneficiaries. These dilemmas highlight the complex balance between maintaining control over design quality and involving the community to ensure the shelter's long-term sustainability and relevance.

3.2. Design requirements

Establishing design requirements for transitional shelters is inherently challenging due to uncertain deployment scenarios and limited contextual knowledge. Agencies like UNHCR have developed sustainability frameworks to evaluate shelters across environmental, economic, socio-cultural, and technical criteria (UNHCR 2021). A shelter’s merit often hinges on its adaptability to changing conditions and its capacity to mitigate risks, highlighting the tension between outsourced solutions (standardized quality) and local manufacturing (situational responsiveness). Structural performance, for instance, is assessed by categorizing failure risks (high, medium, low) to determine context-specific thresholds.

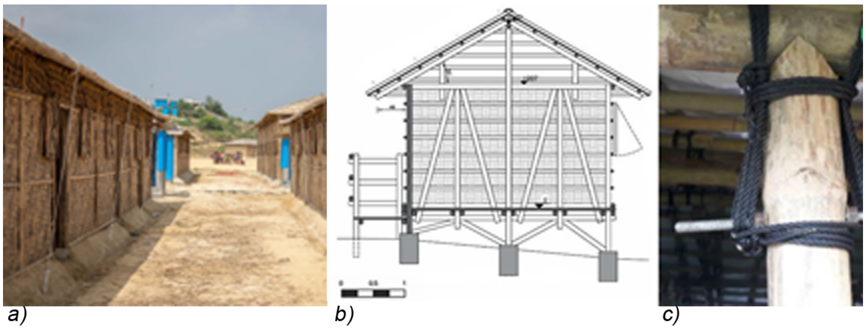
a) b) c)

Figure 3: Bangladesh 2019–2020 / Rohingya Crisis. (a) The constructed shelter. (b) section drawings (UNHCR 2021) (c) Details of a roof joint. Source (all images): (Global ShelterCluster. 2021).

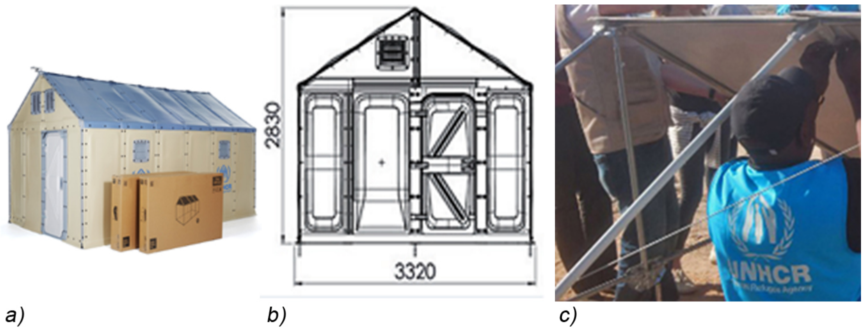
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Figure 4: Refugee Housing Unit (RHU). (a) the constructed shelter Source: (UNHCR Shelter and Settlement Section 2024). (b) section drawings. Source: (UNHCR Shelter and Settlement Section 2023). (c) construction details of a roof joint. Source: (UNHCR Shelter and Settlement Section 2024).

3.3. Design strategies

Two design strategies emerge, outsourced and locally sourced shelters, which significantly affect design decisions. To visually articulate the nexus between design strategies and implementation, two shelters are presented that exemplify these strategies. While both approaches prioritize recyclable and/or biodegradable materials and have proven effective in the field, their design processes differ starkly.

- On-site manufactured shelter (Figure 3): bamboo-steel shelters used in the Rohingya Crisis (2017–present), iteratively improved towards permanent dwelling. Features include biodegradable materials (bamboo framing and panelling), steel joints, hipped roof with gutter, flood-resistant geotextile/sandbags, and a concrete plinth with polythene damp barriers (Shelter Cluster 2020; UNHCR 2021).
- Outsourced shelter (Figure 4): Prefabricated Refugee Housing Units (RHUs) developed by UNHCR and Better Shelter with support from the IKEA Foundation, subjected to large testing before full scale implementation, in line with the Prototype Design Guidelines Designed for transportability and upgradability, it features recyclable steel frames stiffened by steel cross wires, polymer panels, and heat-reflective aluminium roofs with options for installing solar panels (UNHCR Shelter and Settlement Section 2023) (UNHCR Shelter and Settlement Section 2024).

3.4. Case study analysis

The two shelters are analysed across four dimensions: Institutional Sustainability, Environmental Performance, Socio-Cultural Adequacy, and Economic Effectiveness.

Institutional sustainability. Onsite shelters face risks from material repurposing (e.g., here, bamboo bracing was felt not necessary and diverted to other means, which required redesign with steel ropes). Fool-proof designs have are recommended, such as corner half-steel columns and diagonal timber bracings (Portieles 2021; O'Brien and Carrasco 2021), which are less likely to be repurposed. Inadequate local material testing has also been reported elsewhere (Beatini, Rajanayagam, and Poologanathan 2022).

In terms of hazard adaptation, both designs include flood protection, offsite solutions offer traceable fire-resistant materials, but fire safety remains critical—spatial constraints and infrastructure gaps exacerbate wildfire/vandalism risks. A 2020 fire necessitated dismantling and rebuilding the onsite shelter (Shelter Cluster 2020), underscoring economic impact. Shelters' foundations are also highly impacted by the common lack of land rights: adaptable footings allow easy removal, but prefabricated shelters struggle on uneven terrain, requiring ground anchors or concrete slabs (Terne 2022).

Environmental performances. The use of bamboo in the locally sourced shelter notably offers a lower carbon footprint. However, while bamboo was an appropriate choice in this context due to its abundance in the region and rapid growth rate, agencies have raised concerns about the broader use of local materials: a high risk of contributing to deforestation has been reported when timber is used indiscriminately, and masonry construction carries landslide risks. The long-term performances hinges on proper construction, installation, and ongoing maintenance. In the case of the bamboo shelter, detailed attention to joinery was crucial to prevent moisture penetration, leveraging local traditional knowledge (see Figure 2c). This sophistication in design is expected to encourage effective maintenance practices. A bamboo treatment facility was also installed nearby that benefits the local population and enhances material quality. Conversely, the outsourced shelter, while benefiting from simpler installation processes explained through video tutorials, may face more complex maintenance challenges due to its industrialized production methods. Over time, the intention is to phase out the initial shelter's shell, which has limited durability, in favour of more sustainable local materials.

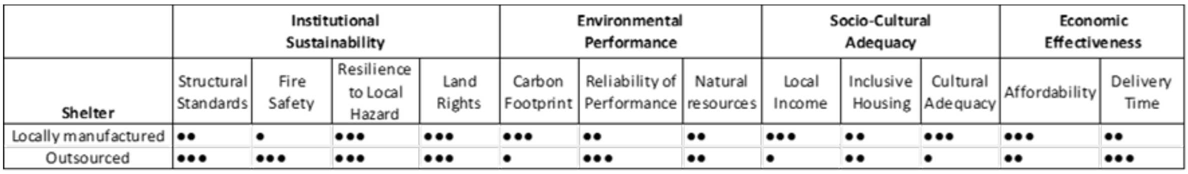
Socio-cultural adequacy. Involving local contractors fosters community benefits, such as reviving traditional techniques (e.g., bamboo construction) and enhancing local economies. Success hinges not on local materials alone but on aligning technology with local capabilities. For example, post-2018 Indonesia earthquake shelters combined light gauge steel frames and silica boards with locally produced concrete blocks, building local processing and installation skills (Global Shelter Cluster 2021).

Psychological well-being depends on features like privacy and sturdy walls/floors, which both approaches address. Cultural adequacy may extend beyond performances (Caia, Ventimiglia, and Maass 2010): internationally procured solutions are typically favoured if they appear well cared, reliable, and aesthetically pleasing. Conversely, local techniques might be viewed unfavourably if they are not widely adopted internationally. On the contrary, in terms of design inclusivity, locally sourced shelters allow customization (e.g., mezzanine additions). Conversely, outsourced shelters prioritize standardized designs, which may led to limited or "artificial" personalization.

Economic effectiveness. Delivery time and spike of material costs during emergencies are typical economic challenges. For the cases at hand, the RHU shelter has a unit cost of $2,156 for 17.5 m² and a lifespan of up to 3 years without upgrades, resulting in a total cost of $22.6 USD/y/m². The cost could lower significantly for the upgraded versions, but field or test data has not yet been published. The locally manufactured shelter costs $1,465 for the same area and boasts an expected lifespan of 10 years, bringing the cost down to $8.4 USD/y/m².
The RHU is packed in two 160 kg boxes, which fit a pellet, and assembled in 4–6 hours by two trained workers. The local shelter has Long bamboo poles transported via river, assembled in 8 days by one skilled and two unskilled workers. Celentano et al. (2019) notes that incorporating 10% - 20% imported elements within a construction technology optimally balances speed and cost, particularly for roofing.

In conclusion, while both shelters address key challenges (Figure 5), trade-offs persist:
- Outsourced: Higher costs if not used for an extended period, but rapid deployment and standardized quality.
- Local: Lower long-term costs but reliant on community involvement and constant monitoring and funding.

Cultural adequacy and environmental performance remain tied to durability, with neither approach universally superior when all factors are weighted equally.



	Institutional Sustainability				Environmental Performance			Socio-Cultural Adequacy			Economic Effectiveness	
Shelter	Structural Standards	Fire Safety	Resilience to Local Hazard	Land Rights	Carbon Footprint	Reliability of Performance	Natural resources	Local Income	Inclusive Housing	Cultural Adequacy	Affordability	Delivery Time
Locally manufactured	●●	●	●●●	●●●	●●●	●●	●●	●●●	●●	●●●	●●●	●●
Outsourced	●●●	●●●	●●●	●●●	●	●●●	●●	●	●●	●	●●	●●●

Figure 5: Visual articulation of the nexus between the challenges and potential design strategies. Source: (Authors 2024)

4.0. NOVEL STRUCTURAL CONCEPT

4.1. Design principles for sustainable emergency shelters

Section 3 has highlighted how the interlaced challenges situate the design for emergencies in the broader realm of sustainable design. Building on this foundation, the following design criteria are proposed, that aim to contribute situating emergency shelters within the global sustainability goals.

- Local Economic Integration: Utilize locally sourced materials to stimulate the local economy and involve local contractors to foster community engagement.
- Health and Safety Standards: Ensure safe and healthy living conditions through high construction quality, adaptable to local construction practices.
- Contextualized Innovation: Develop solutions that combine outsourced elements in the measure appropriate to enhance local resources and ensure adequate performances.
- Technology Utilization: Leverage local carpentry, woodworking, or available skills, supporting existing production and testing facilities.
- Performance Improvement: Implement re-engineering processes of existing technologies, to enhance structural performance and adapt to ongoing technological advancements.

4.2. Composite timber-steel modular building system

Material selection. A range of locally available construction materials have been identified in various studies that do not rely on heavy manufacturing capabilities. These include stone, timber, laterite, clay, mud, bamboo, but also sustainable aggregate potentially reinforced via natural fibres such as sisal and jute (Mathur 2006). However, materials that require complex processing are more difficult to be implemented due to a lack of knowledge on maintenance of required machinery, and inability to produce the material at large scale (Dosumu and Aigbavboa 2019). Recycling of heavy material like greener concrete requires supportive policies which tend to lack even in more developed countries (Kota and Rama 2021). Disregarding novel composites thereof, here, it is chosen to investigate a possible timber structural system.

System Selection. Three possible structural systems have been considered to ensure adaptability and fast deployment amidst logistic uncertainties: deployable – foldable units, modular load bearing panels, and dry - connected linear elements, Figure 6. The last concept is preferred, aligning with design for disassembly principles, it offers significant flexibility for future modifications and mitigates risks associated with logistical constraints (Rajanayagam et al. 2024). While it presents a larger number of onsite connections compared to deployable units, it offers larger adaptability to post emergency scenarios and is less reliant on outsourced, special components. Structural panels, while reliant either on local or outsourced materials, provide the least logistic flexibility and are therefore disregarded.

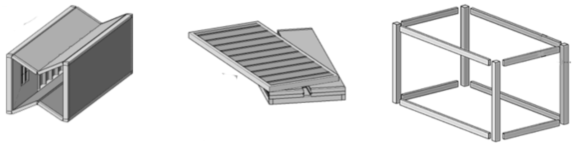


Figure 6: Alternative concepts of structural systems: from left to right, horizontal foldable, vertical foldable, demountable panels, and demountable frame. Source: (Authors 2024)

*Structural requirements***.** Structural reliability must be ensured under both expected and unexpected conditions. Lightweight components are crucial for manual handling. To mediate between these constraints, it is proposed to use composite steel-timber beams and columns. Referring to Figure 7, which compares the specific strength and specific stiffness of timber and steel, steel offers excellent strength and stiffness, but it is heavy, whereas timber provides notable strength and stiffness relative to its density. This composite action allows the two materials to function as a single structural unit, maximizing the benefits of both. Composite timber – steel elements have already been proposed to leverage the environmental benefits of timber and the structural reservoir of steel (Chen et al. 2024). Here, special attention is given to timber's stiffness and the potential for local buckling in steel. Steel C-sections are stabilized against buckling by timber, enabling the use of thinner, cost-effective cold-formed Light Gauge Steel (LGS) sections commonly used in non-emergency small building constructions. The proposed system, hereinafter Timber – Light Gauge Steel (Tim-LGS), is therefore a modular building composed of composite GLS – timber beams and columns.

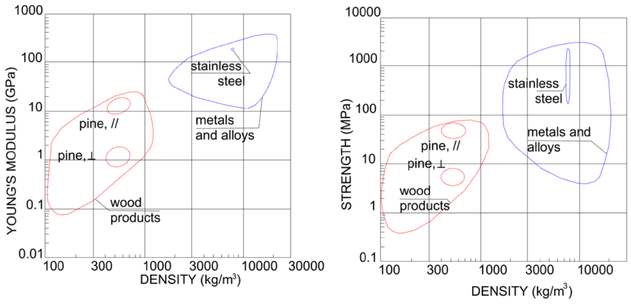


Figure 7: Specific stiffness and specific strength of metals versus timber products, with focus on stainless steel and pine Derived from: (Ansys Granta Materials Data for Simulation). Source: (Authors 2024)

Principles of Robustness. Excessive loads or construction and maintenance errors can lead to sudden and progressive structural failures. The inherent brittleness of timber under tension (see Figure 8) and challenges in transmitting tensile forces at connections often contribute to failures under tensile, bending, and shear stresses. To address these vulnerabilities, robustness principles for structural timber (Sørensen et al. 2011) are implemented, which address the single shelter as a whole, its components, and the design of the single elements. Each modular unit—shelter—is designed to be structurally independent. This compartmentalization strategy enhances flexible site planning and prevents the propagation of local failures, thus boosting overall structural resilience. To resist lateral loads, alternative paths and redundant design are advisable, and here implemented through strategic joint design and the incorporation of shear walls, Figure 10. Ductility is crucial for providing visible warning signs before catastrophic failure. Given timber's lack of ductility (Figure 8) and the potential for steel sections to fail under associated timber failures, ductility is typically achieved at the level of the joint (Čizmar 2014). Enhanced ductility at joints means that large deformations occur due to the deformation of the joint, before the main structural elements fail (Rebouças et al. 2022). Among other means, this can be achieved here by incorporating carefully sized steel fin plates, welded to the columns without significantly impacting transportation volume, Figure 9.

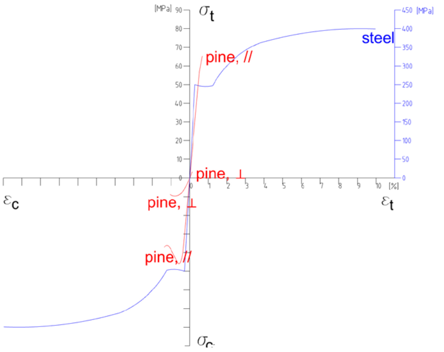


Figure 8: Stress-strain comparison of steel and white pine. Source: Adapted from (Stiemer, et. al. 2012).

Implementation Strategies. The design is relatively simple, but uncommon, therefore, it incorporates foolproof features. It intentionally uses few structural elements and omits bracing ties, which shall not appear redundant even to the inexperienced eye, thus reducing the potential for misuse by end-users. Similarly, the LGS sections shall appear not study enough if used on their own, and the timber elements would require new joints if connected without the LGS.

Schematic design alternatives. The system allows alternative facades design and flooring, key for environmental performances and users' comfort, Figure 10. Similarly, the short span of the roof and the straight beams can meet various roofing technologies. A detailed study may be required in case of pitched roof for snow environments, ensuring that rafters or simple trusses can be easily connected to the timber within the horizontal beams. Uneven terrains require adaptable foundation solutions. Typically, timber elements in small housing are organized in modules with very little span, about 60 cm to 80 cm, which requires numerous anchors to the ground. The proposed solution conversely uses a few columns, which may be integrated with options such as telescopic legs and jacks to provide flexibility and stability.

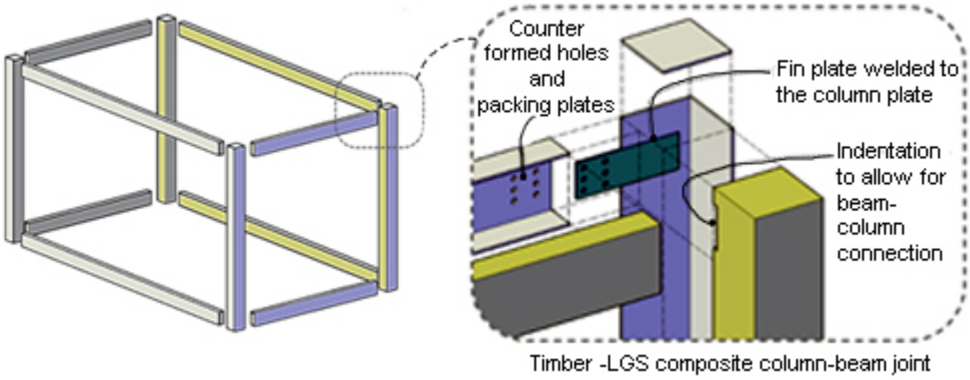


Figure 9: Detailed view of the composite frame of Tim-LGS. Source: (Authors 2024)

4.3. Concept performance analysis

While this study is conceptual, it is critical to assess the quality of the structure concerning integrated design aspects at this stage. As noted by (Corneliusen et al. 2022), modifications made later in the design process may be unfeasible or costly.

Concerning Institutional Sustainability, here lies the core innovation of the Tim-LGS system, which enhances structural integrity while allowing for adaptability to local material properties. This approach not only reduces costs but also tailors the system to varying local timber characteristics.

Concerning socio-cultural adequacy, the design provides ample space for customization, allowing architectural customizations within the overall design framework. Considering the vision of the stakeholders, while the initial investment may be higher than traditional emergency shelter solutions, the long-term benefits are significant, allowing users to adapt, reuse, recycle the elements and material with easy. If the timber elements deteriorate, they may be substituted.

Concerning Environmental Performances, this system uniquely combines the sustainability of timber with the durability of lightweight steel, creating an environmentally friendly solution suitable for emergency scenarios. The potential for recycling and reusing timber and steel components, allowed by the usage of dry connections only, highlights the system's sustainability.

Concerning Economic Effectiveness, the Tim-LGS system benefits significantly from prefabrication, which accelerates the construction process and enhances overall project efficiency. However, the quality of execution, especially in the assembly of joints, is critical for ensuring structural performance. The precision of these joints largely depends on two factors: the correct alignment of the fin plate with the steel elements, and the accurate placement of fasteners. The first step is typically guaranteed through pre-welding but may burden logistic. The placement of fasteners is theoretically straightforward with the help of a blueprint, but the actual installation can still lead to errors or under-joining. These potential issues are present both within the assembly and disassembly phases. To solve them in a viable manner, a strategy is to disassociate the uppermost part of the column from the rest. This approach would allow specifically trained workers to focus solely on the joint assembly, optimizing labour resources and potentially reducing the overall skill requirements for other construction stages. Moreover, the ad hoc joint would not need to be dismantled in case of disassembly.

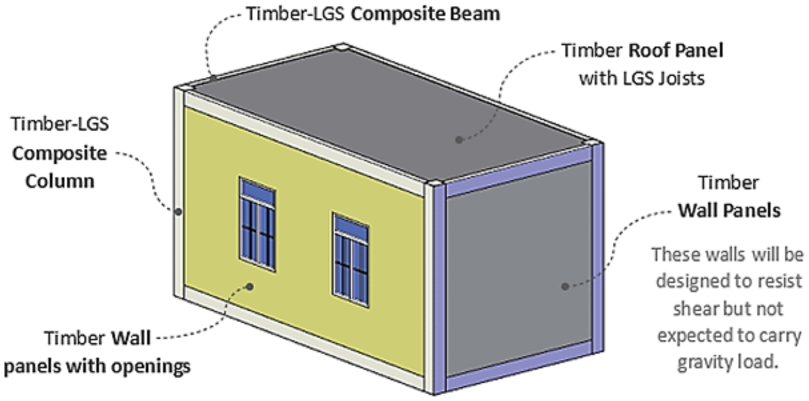


Figure 10: Proposed Tim-LGS Modular Building Unit. Source: (Authors 2024)

CONCLUSION

As the demand for emergency housing surges, this research provides actionable insights and recommendations for developing effective, affordable, and sustainable shelter solutions. Building on previous research, this work advances the understanding of structural challenges in transitional shelters and their interplay with broader socio-economic and environmental issues. By translating these insights into a design framework, we propose the Timber–Light Gauge Steel (Tim-LGS) modular building system, which leverages the composite action of steel and timber to address rapid deployment, cost-effectiveness, and resilience while enhancing sustainability.

The Tim-LGS system represents a multifaceted approach optimized for emergency scenarios but adaptable to broader applications. Its modular design, dry connections, and use of locally available materials offer significant environmental and economic benefits, while its structural robustness ensures reliability in diverse conditions. However, the system's performance, particularly in joint reliability and compatibility with other shelter components, requires further validation through detailed studies. Additionally, contextualized analyses of return on investment and long-term adaptability are needed to fully assess its viability.

This study highlights the potential of innovative, composite material systems to transform emergency shelter provision, moving from short-term relief to sustainable housing solutions. By fostering contextualized research and open debate, this work contributes to the development of design methodologies that address the complex challenges of transitional shelters. Future research should focus on refining the proposed system, exploring its integration with other shelter components, and evaluating its performance in real-world scenarios to ensure its applicability across diverse emergency contexts.

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