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Global or local construction materials for post-disaster reconstruction? Sustainability assessment of twenty post-disaster shelter designs

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ABSTRACT

The number and intensity of natural disasters is growing every year, with 394 major events affecting over 268 million people worldwide in the past decade. The objective of this study was to identify whether it is more appropriate to use local or global materials in post-disaster reconstruction projects. Twenty transitional shelters were identified over 11 different locations worldwide, and their environmental, economic, and mechanical/technical performances were compared. The environmental and economic assessments were based on life cycle cost and life cycle assessment. In the mechanical/technical assessments, the relationships between hazard zones and their performances were assessed for earthquakes, wind loads and floods. Sustainability was assessed using a benchmark system that incorporates the results from these three categories. The results show that shelters with high technical performance can be achieved with low price/low environmental impact per functional unit regardless of the type of material used. Local materials withhold higher potential for low environmental impacts and costs and global materials have higher potential to produce better technical performances. Although local constructive systems can provide the best compromise between environmental impacts and cost, their structural design requires more effort.

1. Introduction

The number and intensity of natural disasters is growing every year, with 394 major events affecting over 268 million people worldwide in the past decade [1]. After a natural disaster, people whose homes have been destroyed will go to great lengths to secure shelter again [2]. Post-disaster shelters, also known as transitional shelters, have been defined by the International Federation of Red Cross and Red Crescent Societies as rapid post-disaster living quarters constructed from materials that can be upgraded to or re-used in more permanent structures or relocated from temporary sites to permanent locations [2]. Post-disaster shelters are designed to facilitate the transition of affected populations to more durable housing solutions. Transitional shelters respond to the fact that post-disaster shelters are often built by the affected population themselves and that this resourcefulness and self-management should be supported [3].

For over a decade, the need for a sustainability assessment of the built environment has driven the development of methods and tools [4] for assessing different types of residential, commercial and institutional buildings. These methods and tools emphasize the environmental impacts related to the life cycle of buildings; however, a building can only be considered sustainable after accounting for its economic, social and cultural dimensions [5]. Furthermore, these methods assess buildings against a set of predesigned criteria and are thus not useful for selecting optimal project options [6]. International efforts to measure sustainability have been conducted, but a multidimensional approach has only been considered in a few cases. Most cases focus on environmental aspects and overlook other aspects, such as economic, social, or cultural aspects [7]. The investigation of these aspects is hindered by methodological limitations and insufficient stakeholder integration [8]. Although the different dimensions of sustainability are usually considered complementary, it can be argued that connections and dynamics exist

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among them. Systems approaches accounting for these interconnections are very important to assessing sustainability and can be considered as one of the most difficult elements to implement in an assessment tool or method [9].

The utilization of this approach becomes even more challenging when aiming to assess the sustainability of buildings due to the intrinsic complexity of life cycle assessment (LCA) [10]. When constructing buildings, the most fundamental decisions are made during the design phase of the project. During this phase, little data are available regarding the amounts of materials, material producers, transportation, buildings life span and costs [11,12]. A significant amount of the lifetime impacts of buildings can be related to the decisions made during the early design stages. Thus, it is important for builders and designers to assess the sustainability of their choices even when data are lacking [13]. The selection of sustainable options for buildings projects depends strongly on a holistic approach that considers the technical and economic aspects as well as the environmental, cultural and social aspects [14].

Two main approaches are used for sustainability assessments: indicator-based and life-cycle-based approaches. The indicator-based approach is useful for projects in which data are available and demonstration buildings have already been constructed [15]. This approach facilitates the selection of pre-established options but is limited regarding its application to other projects outside of the pre-established options. On the other hand, LCA is an umbrella method that can be adapted to assess specific sustainability dimensions. The models used in LCA usually propose cause–effect relationships between the environment and human activities and highlight their impacts and consequences [16]. However, this same cause–effect relationship occurs in economic and social dimensions as well. To assess these dimensions, the life cycle cost [17] and social life cycle [18,19] can be used. The main advantage of this approach is that every dimension will be analysed using an overreaching methodology, which makes the results more consistent and meaningful. Nevertheless, the application of LCA faces many challenges, such as the allocation of impacts [20,21], end-of-life scenarios [22,23], and system boundaries [24]. More importantly, limited data availability and quality hinders the widespread application of LCA [25–28].

Regarding reconstruction efforts after disasters and/or crisis, sustainability assessment can help ensure that the necessary quantity and quality of environmental resources upon which the community relies are maintained [29]. Every post-disaster reconstruction project is faced with the challenge of quickly responding to the crisis at hand using either global or local materials [30]. In post-disaster scenarios, a large amount of resources is needed. However, in many cases, no capacity is available for transforming these resources into housing units. Furthermore, in many cases, the skilled labour force is not large enough to undertake reconstruction efforts [31]. The question of global vs. local materials goes beyond the availability of the materials in a crisis situation. Local materials can be characterized by their use on traditional and vernacular architecture, like bamboo, earth/soil and wood. The constructive practices related to them are usually geographically and culturally constrained. Global materials are generally industrialized and engineered construction materials like concrete and steel. This materials are widely applied not only on infrastructure projects but also housing regardless of the location and/or culture. Local materials require an emphasis on structural design to produce structures that can withstand natural hazards, which increases their economic and environmental costs and requires specialized engineers and construction workers. In contrast, global materials can provide efficient structures that can resist natural hazards with much higher embedded energy than local materials. For this type of project, the low skill labour and minimal engineering proficiency often available in the affected regions are sufficient.

In this study, twenty transitional shelters were identified in eleven different locations worldwide: Afghanistan, Bangladesh, Burkina Faso, Haiti, Indonesia, Pakistan, Peru, Philippines, Sri Lanka, Vietnam and Nicaragua. Six construction materials were assessed: bamboo, bricks, concrete, steel, stone, and wood. Two types of shelters were identified: transitional and core shelters [2,3,32,33] as it can be seen on Table 1.

The objective of the study was to identify which strategy for post-disaster reconstruction is most appropriate: using local or global materials. To compare different transitional shelters, their environmental, economic, and mechanical/technical performances were compared using a benchmark system.

2. Methodology

For the sustainability assessment of the shelters, three categories were defined. The environmental impact category accounted for the effects on the natural environment of the production and transport of construction materials and the construction of shelters. Cost was associated with the purchase and transport of construction materials and the erection of shelters. Finally, technical performance was related to the risk zones in which the communities live as well as the mechanical performance of the shelters during the occurrence of a natural hazard event, such as earthquakes, winds, and/or flooding. The aim of this methodology is to compare the sustainability performance of the shelters. To achieve this goal, it was necessary to develop a functional unit for each category. These functional units allow the comparisons across not only shelters but also categories, which increases the consistency of the results. The two main factors we identified for the development of functional units: life span and area covered. The life span of the shelters accounts for the fact that some of these structures are temporary, intended to be relocated or dismantled, and thus might require less material. This is very important because if the life span is not considered, then the best-performing shelters are those that are the lightest and least durable, which is not always the best solution for a post-disaster reconstruction project. The expected shelter's lifespans used on the calculations were taken from the reports of the International federation of red cross societies [2,3]. These reports present estimated lifespans for the studied shelters

Table 1
Shelters' location, structural material and type.

Code	Location	Structural material	Type
B1	Afghanistan	Bamboo	Transitional
B5	Indonesia	Bamboo	Transitional
B8	Philippines	Bamboo	Core
C2	Bangladesh	Concrete	Core
C6	Pakistan	Brick	Core
C8	Philippines	Concrete/Timber	Core
C9	Sri Lanka	Concrete	Core
C11	Nicaragua	Ferrocement	Core
S4	Haiti	Steel	Transitional
S5	Indonesia	Steel	Transitional
S10	Vietnam	Steel	Transitional
W3	Burkina Faso	Timber	Transitional
W4(A)	Haiti	Timber	Transitional
W4(B)	Haiti	Timber	Transitional
W4(C)	Haiti	Timber	Transitional
W5	Indonesia	Timber	Core
W6	Pakistan	Timber/Stone	Transitional
W7(A)	Peru	Timber	Transitional
W7(B)	Peru	Timber	Transitional
W8	Philippines	Timber	Transitional

Source [2,3,32,33].