Re-thinking material selection for large scale post-disaster reconstruction

Giulia Celentano, Vincent Hischier, Guillaume Habert, Edwin Zea Escamilla, Verena Göswein

Chair of Sustainable construction, Swiss federal institute of technology, ETH Zürich, Switzerland

ABSTRACT

The last fifty years have witnessed an unprecedented growth on the human population. At the same time the number and intensity of natural disasters has been escalating, due both to climate change and the growth of urban settlements in unsafe lands. This situation is unceasingly increasing the existing housing gap of the affected regions, already struggling to cope with the shelter demand.

The present study aims to better understand the key parameters driving the delivery of housing on post-disaster reconstruction projects and to propose a set of indicators to help support the decision making process of material selection. In this work 15 cases of post-disaster reconstruction projects in 10 locations were studied. Two types of housing units were identified: core and transitional. They used four distinctive construction materials: (i) bamboo, (ii) concrete, (iii) wood and, (iv) steel. These projects were executed by the International Federation of Red Cross (IFRC) between the years 2004 and 2011. From their assessment we highlighted a new way to approach material selection, analysing the output through different key parameters: material demand, cost, delivery time and man power requirement. These key parameters were considered at the housing unit level and then scaled up to the reconstruction project. Finally, we propose a benchmark based on the identified key parameters and integrated with the shelter environmental impact, which is able to assess the problem on its complexity. It allows to re-think the material selection process and to open the discussion on how to cope with the challenges of upscaling reconstruction projects.

KEYWORDS

Shelter, post-disaster reconstruction, upscaling, affordable housing, appropriate technology.

AUTHOR'S BIOGRAPHY:

Giulia Celentano, 1988, MSc in Architecture from the Polytechnic University of Milan, Italy. Her field of expertise is appropriate technologies implementation in developing countries, with specific practical training in earth construction and slum upgrade. Before joining the Chair of Sustainable Construction of prof. Habert at ETH Zurich, Department of Civil Engineering, Giulia has been deployed on field on various projects in Kenya, Egypt and Central America.

1 Introduction

The last fifty years have witnessed an unprecedented growth of the human population, shifting from rural towards urban settlements (UN-Habitat 2016). Meanwhile, the damages provoked by natural disasters have been escalating, due both to climate change and to the growth of informal settlements on unsafe lands (UN-Habitat 2011). According to the United Nations Office for Disaster Risk Reduction, just between 2000 and 2012 the world has suffered disasters affecting 2.9 billion people and damaging the local economy by 1.3 trillion US$ (UNISDR 2016) while increasing the existing local housing gap.

The complexity of large scale post-disaster reconstruction demands to balance speed and affordability of housing delivery (International Federation of the Red Cross 2012, from now on IFRC). Moreover, reconstruction projects are susceptible to bottlenecks, as lack of suitable resources (Russell 2005; Zuo and Wilkinson, 2008).

The uniqueness of every post-disaster situation is binding since resource availability is intrinsically related to the specific post-disaster context (Chang et al. 2011). Still, diverse technological options might be available, according to material, funds and logistic capacity at the emergency moment (IFRC 2012). A proper framework for an appropriate reconstruction is then necessary for assisting humanitarian organizations from a technical point of view (Da Silva 2010).This need has already been identified (Johnson and Davidson 2010) with no clear solution proposed.

The present study aims to better understand the key parameters driving the housing delivery of post-disaster reconstructions and to propose a set of indicators to support the decision making process of material selection, in the way to optimize resources and time while providing an affordable and sustainable large-scale response.

2 Data and Methods

2.1 *Data*

15 post-disaster reconstruction projects in 10 locations worldwide are studied. Two types of shelter units are identified: core and transitional. In these projects, four main construction materials are used: (i) bamboo, (ii) concrete, (iii) wood and (iv) steel. These projects were executed worldwide by the International Federation of Red Cross and Red Crescent Societies between the years 2004 and 2011, as shown in Figure 1.

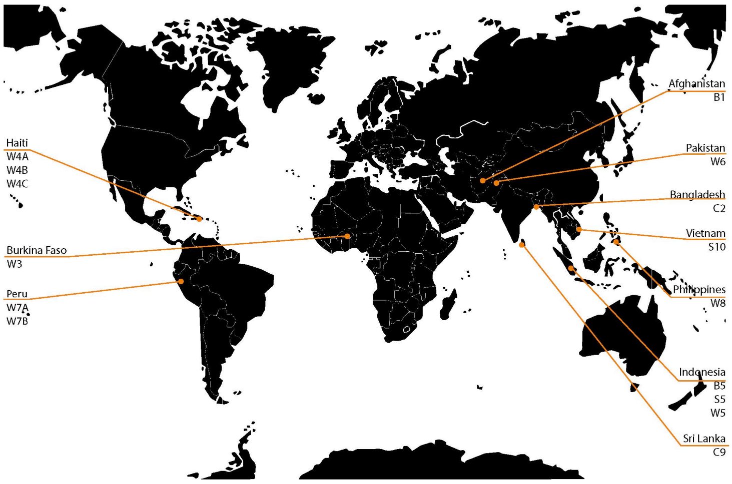
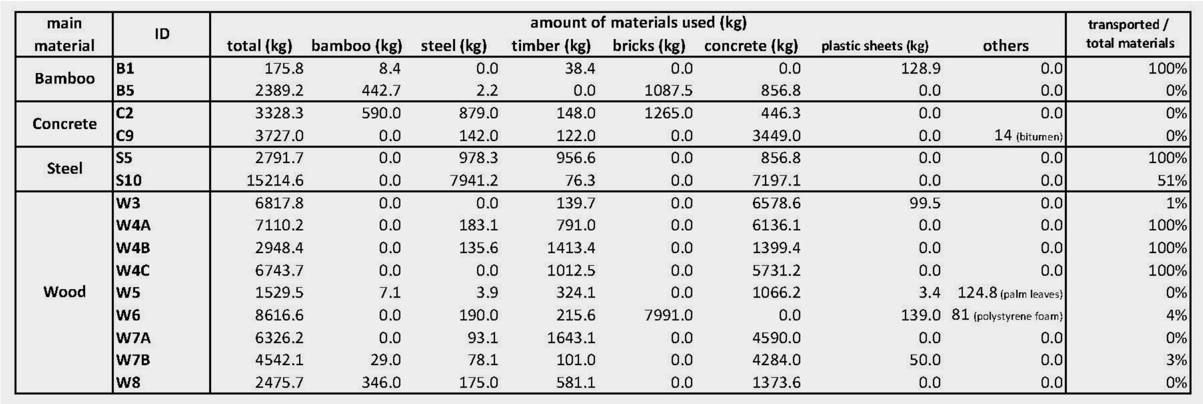


Figure1. Project locations

Locations:_Afghanistan, Bangladesh, Burkina Faso, Haiti, Indonesia, Pakistan, Peru, Philippines, Sri Lanka, Vietnam.

The data collected for the research (location, year of execution, type of shelter, covered living space, construction time, number of people required for the construction, project and material cost) were extracted from the reports published by the Federation: “Transitional shelters – Eight designs” and "Post-disaster shelter: Ten designs” (IFRC 2013; IFRC 2011). The shelter performance proposed by previous studies, combining hazard risks at each location and expected shelter performance for a natural disaster (Zea, 2015), was considered as an additional qualitative indicator. Furthermore, the environmental impact of the shelters was adopted by the same source. The data related to material amount and procurement are presented in table 1.



main material	ID	amount of materials used (kg)								transported / total materials
		total (kg)	bamboo (kg)	steel (kg)	timber (kg)	bricks (kg)	concrete (kg)	plastic sheets (kg)	others	
Bamboo	**B1**	175.8	8.4	0.0	38.4	0.0	0.0	128.9	0.0	100%
	B5	2389.2	442.7	2.2	0.0	1087.5	856.8	0.0	0.0	0%
Concrete	**C2**	3328.3	590.0	879.0	148.0	1265.0	446.3	0.0	0.0	0%
	C9	3727.0	0.0	142.0	122.0	0.0	3449.0	0.0	14 (bitumen)	0%
Steel	**S5**	2791.7	0.0	978.3	956.6	0.0	856.8	0.0	0.0	100%
	S10	15214.6	0.0	7941.2	76.3	0.0	7197.1	0.0	0.0	51%
Wood	**W3**	6817.8	0.0	0.0	139.7	0.0	6578.6	99.5	0.0	1%
	W4A	7110.2	0.0	183.1	791.0	0.0	6136.1	0.0	0.0	100%
	W4B	2948.4	0.0	135.6	1413.4	0.0	1399.4	0.0	0.0	100%
	W4C	6743.7	0.0	0.0	1012.5	0.0	5731.2	0.0	0.0	100%
	W5	1529.5	7.1	3.9	324.1	0.0	1066.2	3.4	124.8 (palm leaves)	0%
	W6	8616.6	0.0	190.0	215.6	7991.0	0.0	139.0	81 (polystyrene foam)	4%
	W7A	6326.2	0.0	93.1	1643.1	0.0	4590.0	0.0	0.0	0%
	W7B	4542.1	29.0	78.1	101.0	0.0	4284.0	50.0	0.0	3%
	W8	2475.7	346.0	175.0	581.1	0.0	1373.6	0.0	0.0	0%

Table 1. Shelter material specification

The different key parameters: (i) covered surface, (ii) expected lifespan, (iii) project cost, (iv) amount of materials, and (v) construction time per manpower, are presented in figure 2. Each parameter is represented by circles, which dimensions are given by the parameter value for the shelter case. The shelter performance is colour coded having red as unsatisfying and green as optimal performances.

Figure 2. *Shelters data visualization*

For the assessment at settlement scale, data were collected from the official Operations Updates recorded by IFRC on each executed project (IFRC 2016) in order to better understand the upscaling dynamics of post-disaster reconstruction projects.

2.2 *Methodology*

In this study, we focused on two scales: the shelter unit and the settlement.

At the shelter level, a new way to approach material selection is proposed. Cost, time of construction and amount of materials are calculated for a single functional unit which has been defined as the covered area over an expected lifetime. The indicators are presented in table 2. Additionally, the location of the materials has been recorded and the shelters have been classified depending on the share of imported materials required, ranging from 100% imported, 50% imported, 2% imported and all local materials. Finally, the environmental impact of the shelter's construction has been calculated. The method IMPACT2002+ has been used. Detailed calculation can be found in Zea and Habert (2015).

Indicator	Unit
Project cost / covered surface / lifespan	CHF/m^2/months
Construction time per team per manpower required / covered surface / lifespan	man-days/m^2/months
Amount of material / covered surface / lifespan	kg/m^2/months

Table 2: shelter scale indicators

The second part of the work focuses on the larger scale of the whole settlement. The objective here is to address the speed and pace of a reconstruction program in order to see if common pattern could be identified. The indicators used for this phase represent the relation between the number of shelters build over time and their construction time. They are presented on Table 3.

Indicator	Unit
Ratio of shelters build among the total	%
Ratio of reconstruction time since when the reconstruction started among the total	%

Table 3: settlement scale indicators and units

Diverse factors significantly impede the reconstruction process in disaster-affected countries (Chang et al. 2010), as the ability to pool resources, the lead time of procurement and transportation into the disaster zone (Potangaroa 2010), disruption of access to available resources (Green, Bates, and Smyth 2007), and limited ways of material procurement (Brunsdon et al., 1996; Oxfam Australia, 2007). At this scale the location of the materials has therefore also been identified in order to understand if this could be a driving parameter for changes in reconstruction pace.

3. *Results*

The shelters were first ranked according to the investments required for their construction (project cost, construction speed, lifespan and amount of material), as represented in Figure 3a, 3b and 3c. The shelters were named according to their location and type of material (locations: 1 Afghanistan, 2 Bangladesh, 3 Burkina Faso, 4 Haiti, 5 Indonesia, 6 Pakistan, 7 Peru, 8 Philippines, 9 Sri Lanka, 10 Vietnam. Materials: B-Bamboo, C-Concrete, S-Steel, W-Wood).

A correlation between investment and output is visible in all the indicators studied. Moreover, it is possible to see that an increase in the economic investment usually leads to a better performance (Figure 3a) as well as in the case of a longer construction time (Figure 3b). On the contrary an increase in the construction material amount does not lead to a performance implementation as shown in Figure 3c.

It is important to notice that some exceptions (shelters C9 Sri Lanka concrete, W5 Indonesia wood,S5 Indonesia steel) achieve good performance scores despite a low initial investment in two of the indicators. Nevertheless, none of the case studies showed a positive correlation between the three selected indicators.

Figure 3a. Project cost

Figure 3b. Construction time

Figure 3c. Material amount

A benchmark system was developed to better understand the correlation between the three indicators. This not only allowed to evaluate the shelters under the new lens of the project optimization, but also provided a new reference for future projects.

4. Discussion

The results are presented on a benchmark with *Construction time per workforce / covered area / lifespan* on the X axis and on the Y axis *project cost / covered area / lifespan.* The indicator *Amount of materials / covered surface / lifespan* was represented by the size of the circles. Additionally, the performance score was added in colour. The full assessment is presented in *Figure 4.*

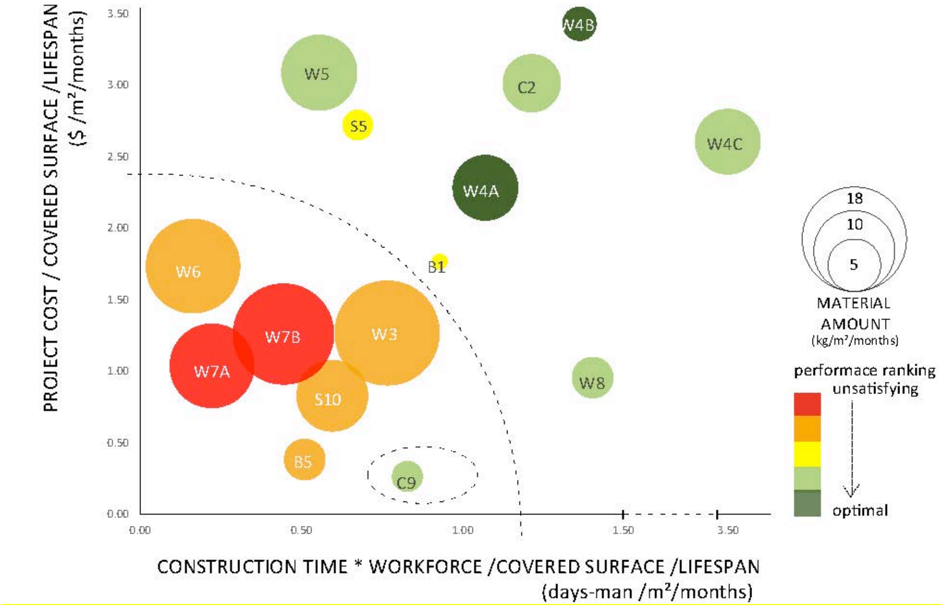


Figure 4 shelters benchmark: performance and investment

Shelters locations: 1 Afghanistan, 2 Bangladesh, 3 Burkina Faso, 4 Haiti, 5 Indonesia, 6 Pakistan, 7 Peru, 8 Philippines, 9 Sri Lanka, 10 Vietnam.

Shelters materials B Bamboo, C Concrete, S Steel, W Wood.

The figure shows that an increase in the project cost leads to a better performance while affecting the construction speed negatively. Rapid constructions seem instead to be achieved with smaller economic investment, but at the expense of the performance achieved. The only notable exception is shelter C9 (Sri Lanka concrete), performing highly despite the low construction time requirement and a very limited economic investment. Its material amount as well is extremely low if compared to the others. High potential for improvement is recognized for shelter B5 (Indonesia bamboo) similar to C9 (Sri Lanka concrete) for economic investment, material amount and even more advantageous in terms of construction speed. Its performance is instead below the standard and would so require design implementation.

From the same benchmark, more results can be observed by considering the material procurement of the shelters, displayed in colours, and the environmental impact related to them, represented by the circle size in Figure 5.

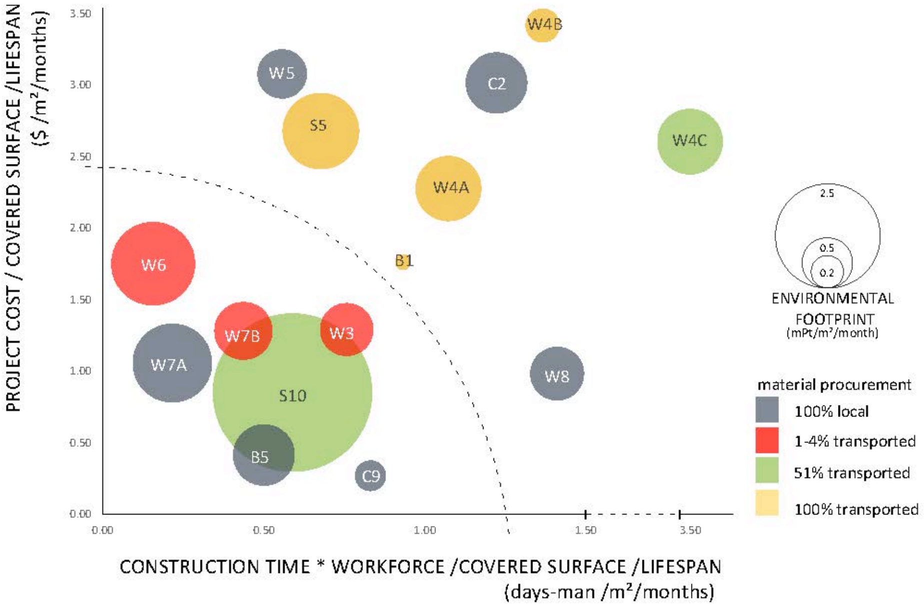


Figure 5. shelters benchmark: material procurement and environmental impact

Shelters locations: 1 Afghanistan, 2 Bangladesh, 3 Burkina Faso, 4 Haiti, 5 Indonesia, 6 Pakistan, 7 Peru, 8 Philippines, 9 Sri Lanka, 10 Vietnam.
Shelters materials B Bamboo, C Concrete, S Steel, W Wood.

Shelters erected mainly with transported material produced low results both from an economic investment and construction speed point of view. On the contrary, shelters manufactured with locally procured materials show variable results. In particular, the cases W7A Peru wood, B5 Indonesia bamboo and C9 Sri Lanka concrete displayed an interesting proportion between project cost and construction time. The shelters constructed with a reduced input of imported materials (below 5%) have very positive results and can be acknowledged as good practices. Despite the promising results of the partially transported shelters, design revision is for them recommended so to implement their performance

Moreover, considerable challenges arise in post-disaster reconstruction situations as the context is characterized by a lack of access, logistical issues and inadequate human resources (Davidson et al. 2007; Ophiyandri et al. 2010; IFRC 2010), becoming so an extremely complex problem to deal with (Bilau et al. 2015). For this reason, the research focused then on the camp level, looking for potential upscaling effect boosted by technological choices. The reconstruction processes related to the 15 case studies is represented in figure 6, where the shelters build among the total, on the Y axis, are combined with the elapsed project time, on the X axis.

Figure 6. camp development: % elapsed project vs. % shelters completed

The reconstructions followed an S-curve trend. This development, even if diverse among the cases, seemed to be affected by the material sources procurement: shelters built with mainly local materials in fact displayed a more accelerated development.

The benchmark was used to rank the case studies in a new comprehensive system and allowed for the identification of strategies that better combined the listed above indicators. Despite an overall coherence between investment growth and performance achieved, suggestions of design revision are also recommended for the partially transported ones that seemed promising for a good balance between the indicators but did not perform adequately. From the material procurement point of view, the use of local materials emerged as an interesting element, able to boost the speed of the construction at the camp scale. This information did not emerge at the unit scale: this shows that a multiscale approach for material selection is fundamental when dealing with large scale reconstruction projects.

5 Conclusion

In this study, 15 post-disaster projects delivered worldwide by the International Federation of the Red Cross and Red Crescent Society were assessed with the goal of investigating how different material choices affected the project delivery process as well as the large scale reconstruction process. The development of new indicators allowed in first place to rank and evaluate the existing projects under a new perspective.

This work shows that an increase of the project cost usually leads to a better performing shelter, but often negatively affects its speed of construction. Moreover, the majority of the rapidly erected shelters were considered as affordable but not satisfying from the proposed technical performance. It is also possible to conclude that these variations in construction time, costs or performance are not material related. However, the importation of any kind of construction materials for the shelter usually contributes to the construction of high performing shelters, but heavily impacts both on the project cost and the construction time. Moreover, the import of a minimum amount of material per shelter seems to have a high potential. These type of shelters can be considered as most cost-effective from the studied sample. Nevertheless, their technical performance instead requires further improvements. Finally, the results showed that the use of locally procured material does not drive costs nor time of construction at the shelter level, but seems to be able to have a leverage effect at the settlement level where very effective increase in reconstruction program could be achieved.

From these results it is possible to conclude that a multiscale approached can better support the decision making process on large scale reconstruction. Opportunities for project implementation and upscaling should be further investigated as a fundamental issue since the planning phase. Finally, by rethinking material selection for large scale post disaster reconstruction, it is possible to maximize the use of the available resources, overcoming the challenges faced on post-disaster reconstruction project while providing a rapid sustainable response to the affected population. This study also serves as a reference for the evaluation of new project proposal, assuring the relevance of the proposed indicators a future assessments.

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