

Article

# Qualifying the Sustainability of Novel Designs and Existing Solutions for Post-Disaster and Post-Conflict Sheltering

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Received: 27 November 2019; Accepted: 19 January 2020; Published: 24 January 2020

**Abstract:** During the course of 2018, 70.8 million people globally were forcibly displaced due to natural disasters and conflicts—a staggering increase of 2.9 million people compared to the previous year's figure. Displaced people cluster in refugee camps which have very often the scale of a medium-sized city. Post-disaster and post-conflict (PDPC) sheltering therefore represents a vitally important element for both the short- and long-term wellbeing of the displaced. However, the constrained environment which dominates PDPC sheltering often results in a lack of consideration of sustainability dimensions. Neglecting sustainability has severe practical consequences on both people and the environment, and in the long run it also incurs higher costs. It is therefore imperative to quickly transfer to PDPC sheltering where sustainability considerations are a key element of the design and decision-making processes. To facilitate such transition, this article reviews both 'existing solutions' and 'novel designs' for PDPC sheltering against the three pillars of sustainability. Both clusters are systematically categorized, and pros and cons of solutions and designs are identified. This provides an overview of the attempts made so far in different contexts, and it highlights what worked and what did not. This article represents a stepping-stone for future work in this area, to both facilitate and accelerate the transition to sustainable sheltering.

**Keywords:** city; post-disaster shelter; post-conflict shelter; transitional shelter; sustainable sheltering; emergency sheltering; refugees

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## 1. Introduction

According to the United Nations High Commissioner for Refugees [1], 70.8 million people around the world were forcibly displaced during 2018 due to natural disasters and conflicts, exceeding the previous year's numbers by 2.3 million people. Displacement is a complex challenge, which if not properly addressed could fuel existing tensions and create new conflicts [2]. This is something to consider when planning for sheltering, as is accounting for the local culture and the context of each individual situation. In post-disaster and post-conflict (PDPC) situations, it usually takes two to fifteen years to resolve land rights, which affects the reconstruction of damaged homes [3]. Therefore, providing shelters in the initial stages after disasters and conflicts is critical to ensure adequate levels of safety, security, protection and community health [4]. The UNHCR, IFRC and their operational partners, who are responsible for providing shelters to the affected population, usually

have limited time and funding to propose shelter solutions when a disaster occurs, which affects the quality of the shelters. There have been attempts by companies and researchers to design shelter solutions, but usually they prioritize the transportability and rapid deployment of the shelters. They rarely consider the social and cultural factors or the visual, acoustic and thermal performance [5].

Johnson [6] identified some of the main challenges facing PDPC shelters as high costs, delivery delays, remote and adverse locations, and poor design—generally unsuitable for both the users' culture and the local climate conditions. It also seems that the existing literature focuses more on solutions from outside the area involved, with little or no acknowledgement of the solutions found informally by the affected people and local communities [7].

In the global movement to urgently transfer into a more sustainable way of living, the humanitarian sector has been given insufficient attention. In the past, it was seen as an indulgence to consider the environment in PDPC responses, due to the significant size of the affected population and the crisis intensity. The fact that environmental damage contributes to natural disasters was surprisingly neglected [8]. The environmental impact of the aid shelters has been highlighted as a clear knowledge gap by Ramboll and Save the Children [8], and the need for further research is amongst their recommendations. The same gap was highlighted by Albadra, Coley and Hart [9] as their literature survey showed that in the past 38 years, only 60 academic papers have been published on the subject of 'emergency or temporary shelters', and only nine of them addressed the shelters' life cycle sustainability or environmental impacts.

The importance of sustainable development is explained in the definition of the Brundtland Report as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [10]. In the PDPC scenarios, Potangaroa [11] argues that building informal shelters could have adverse effects on the environment and deplete resources, which might also raise the cost of materials and labor, and potentially lower the quality of life by ignoring the previous social structures and cultural spaces. However, Potangaroa [11] adds that designing sustainable shelters would avoid these issues and have long-lasting positive impacts. This article aims therefore to contribute to ongoing global efforts to design more sustainable shelters. To do so, an important and useful first step is mapping the range of 'existing solutions' and 'novel designs' to identify their strengths and weaknesses. Since sustainability is a holistic concept that involves not only the environmental dimension, but also economic and social aspects [12], these three elements constitute the key parameters against which the review presented here is carried out. In the next section, the existing literature is reviewed and the adopted shelter terminologies and typologies in this paper are clarified. The section also discusses the main arguments regarding the three pillars of sustainability. In Section 3, the methodology that was adopted in this paper is clarified and the chosen case studies are analyzed in comparative tables that show the pros and cons of each case. The results of the comparisons are presented in Section 4, and discussed in Section 5. Lastly, Section 6 concludes the article and sets the challenges and recommendations for future research.

## 2. Literature Review

In PDPC situations, decision makers generally prefer to direct most of the money and effort into the reconstruction phase rather than the initial relief sheltering. However, previous cases teach us that such an approach may have major issues. The shelter response after the earthquakes in Ardabil and Lorestan Provinces in Iran, for instance, is an example where unexpected events delayed the reconstruction process, resulting in thousands of people living in emergency tents for up to two years, remaining unprotected from the harsh weather [13]. Hadafi and Fallahi [13] also argued that if people were consulted in the first place about how to deal with the post-emergency, they might have chosen a different approach, and therefore the adverse effects would have been lessened. In order to address the literature on PDPC shelters, an agreement on terminology is necessary. Therefore, a reflection on the history of the terms and the confusion in their usage is presented, followed by the common shelter categorization, prior to reviewing key social, environmental and economic aspects.

According to Chang et al. [14], the availability of resources in PDPC situations is very challenging and could cause environmental and economic obstacles. Moreover, the same study

concludes that stakeholders' collaboration and advanced planning would allow the market, donors and governments to successfully manage the available resources. This is explained in more detail in the Humanitarian Emergency Response Review [15] as it describes the gap between the humanitarian challenge and the world's ability to cope as a lost race. The report referred to two major challenges in dealing with humanitarian crisis; first, the global economic crisis and second, the rising security threat that affects the performance of the humanitarian workers in the field and makes the assessment of affected people in PDPC situations a harder mission. However, there is an argument that the real reason behind the failure of shelters is the undeveloped understanding of the topic by the working institutions despite their progress in the field [16]. Moreover, few external agencies enter the field of shelters, due to its complexity and high consumption of time, cash and energy [16].

### 2.1. Shelter Terminologies

There are no agreed terminologies regarding sheltering, and the existing terms are usually confusing. United Nations Disaster Relief Organization [17] suggested eight phases of shelter provision: tents, imported designs and units, standard designs incorporating indigenous materials, temporary housing, the distribution of materials, core housing, hazard-resistant housing, and accelerating reconstruction of permanent housing. Thirteen years later, Quarantelli [18] proposed a different shelter categorization based on the life span of the shelters and people's behavior, which included four stages: emergency sheltering, temporary sheltering, temporary housing and permanent housing. Quarantelli [18] explained that these terms are the ideal categories and do not necessarily reflect the actual reality. The unique addition of this study was the terms' differentiations he proposed. Specifically, he distinguishes between *emergency* and *temporary* shelters—mainly in the behavioral aspects, where the temporary responds to where and how the daily activities are held. He also distinguishes between *sheltering* and *housing*, where in housing the users resume their routine household responsibilities and activities, which does not happen in sheltering. Finally, he distinguishes between *temporary* and *permanent* housing, where the users in the latter live in a repaired, rebuilt or new permanent physical structure. However in reality, some temporary housing was never vacated and was transformed into permanent homes [18]. Barakat [19] proposed different definitions for *shelter* and *housing*. He defines the shelter as a structure intended for temporary use in spite of the real duration of its usage. Housing instead provides either a permanent solution or a solution that supports the affected communities until they can rebuild their own homes. Hadafi & Fallahi [13] clarify that housing is not only about the physical shelter structure but instead a system that is concerned with people's social, psychological and spiritual needs. More recently, the International Federation of Red Cross and Red Crescent Societies (IFRC) suggested six shelter duration levels of what they call 'approaches' instead of the typical 'response phases'. The approaches, which mainly depend on the context of each case, are: emergency shelter, temporary shelter, transitional shelter, progressive shelters, core shelters, and permanent housing [20].

Most 'novel designs' and 'existing solutions' claim to fall under the transitional shelter category, which is inaccurate in most cases. Such a misattribution is due to two major misconceptions: (1) the view that transitional shelter is a product, and (2) the use to describe approaches to permanent construction [3]. The transitional shelter is the incremental process that provides sheltering to the affected families while they are seeking to maintain other recovery options. This happens through its five characteristics; upgradability, reusability, ability to be relocated, ability to be resold and recyclability [3]. Transitional shelters usually represent a first step prior to relocation to more durable sheltering solutions and are usually built on a temporary site [20]. Since the studied shelters in this paper are classified into 'novel designs' and 'existing solutions' despite their phase or approach, this paper does not adopt any terminologies for the phases/approaches. In addition to the confusion in the phases' terminologies, the general term used to refer to the sheltering response is not agreed on, but the terms 'emergency shelters' and 'temporary shelters' are commonly used amongst scholars. However, since the previous two terms are used to describe specific approaches/phases in some categorizations including the IFRC [20], 'PDPC shelters' is proposed as an umbrella term in this article.

## 2.2. Shelter Typologies

Scholarly classification of shelters is diverse. Albadra, Coley and Hart [9] categorized the shelters in terms of their manufacturing approach or location into ‘transportable shelters’ and ‘built on-site shelters’. They clarify that transportable shelters include any shelter that is manufactured off-site and then shipped to the intended location. This category covers both basic shelters such as tents, and more developed flat-packed solutions. Conversely, the built on-site shelters are usually constructed using locally available materials. In most cases, the beneficiaries are provided with tool kits and training sessions to allow them build their own shelters. A similar categorization was created by Felix, Branco and Feio [21]. They grouped the shelters based on their readiness level into ‘ready-made units’ and ‘kit supplies’. The ready-made units are fully constructed in a factory environment and transported to the location as one item. They could be divided into separate but somewhat large parts to be assembled on site. Kit supplies instead solve the problem of heavy transport systems by producing smaller elements that can be erected by local people on-site.

The challenge with the previous two categorizations is twofold. Firstly, there will be a confusion in when to consider the parts as a ready-shelter that is divided into pieces (transportable) or parts of a kit (built on-site). Secondly, the applicability of the shelters is not considered, as many ideas are logical in theory but have never been tested in real PDPC situations.

Quaglia, Dascanio and Thrall [22] analyzed the existing US military solutions in order to present their origami-inspired proposals for what they called ‘rapidly deployable shelters’. They categorized the military shelters depending on the wall attributes into ‘non-expandable rigid wall shelters’, ‘expandable rigid wall shelters’, and ‘soft wall shelters’. Analyzing the military shelter solutions alongside the PDPC shelters is problematic, as the context and needs of the military and shelters for PDPC persons differ significantly. This research instead adopts a categorization method based on the historical application of the shelters, which will be discussed in the methodology section.

## 2.3. Social, Environmental and Economic Aspects

The main sustainability challenges facing current PDPC shelters are the lack of cultural adequacy, economic viability and negative environmental impacts [21]. The recognition of the importance of users’ participation in order to have culturally sensitive designs has been acknowledged by NGOs, policy makers and scholars, specifically in reconstruction. Thirty-six years ago, the UNDRO [17] concluded that the key to success in reconstruction is the local community’s participation. Opdyke, Javernick-Will and Koschmann [23] found that early user involvement in PDPC shelter projects, support the resilience and the sustainability of the project outcome. The local input could empower the affected people, encourage the social connectivity and promote solidarity between the beneficiaries themselves [24]. Although it is not always easy to measure the success of a shelter project, but user satisfaction and shelter safety are major indications of that success [24], which could be evaluated through surveys and observations such as the shelter assessment that was done in Zaatari camp [25] and Azraq camp [26]. However, sometimes the lack of users involvement leads to an obvious project failure when the assistance is not accepted by the people, such as the refusal of using the steel caravans in Gaza [27]. It should be noted, however, that engagement the affected people might be in practice challenging in several cases where there is a great urgency to act, the people are in trauma, and potentially not well placed to be consulted, which would also lead to further delay in the aftermath of an emergency. The case study of Al-burjan village in Lebanon is an example, where the main lesson learnt was that reconstruction must be culturally rooted, i.e., responds to the cultural needs and the perceptions of the local people, which could only be met by involving the affected people in the rebuilding process from its early stages [28]. Barakat and Zyck [29] proposed a ‘hybrid approach’ in reconstruction that combines the ‘owner driven’ and ‘contractor driven’ existing approaches that are used in Southern Lebanon. The purpose was to ensure the structural integrity of the house through a contractor constructing the foundation and the frame, while at the same time allowing the owners to design the layout. Not only does the cultural inadequacy in designing shelters result in uncomfortable living conditions, but it also causes serious social problems within the communities. However, little is known about how and when to apply the

principles of participation in the PDPC sheltering design. Early participation provides better and more satisfying design results. It also empowers the affected population and allows them to be active again in the society, instead of being perceived as passive help-recipients. Unfortunately, this dimension has been neglected in existing literature [30]. The shelters in the Jordanian Syrian-camps are examples of cultural inadequacy which was obvious through the adjustments made by the residents to their own shelters, such as adding dividers to the one-room design in order to separate the sleeping areas for family members of different age and gender [31]. The Sphere Association [32] emphasizes the importance of considering the needs, preferences and habits of various age, gender and disability groups.

In regard to the environmental perspective, Felix, Branco and Feio [21] recommend planning flexible shelters that could be reused after the initial purpose or period ends. A study by Escamilla and Habert [33] argues that while global materials could provide structures with high embodied energy and high resistance levels against natural hazards, local materials need extra attention on the structural details to withstand the possible hazards and therefore could increase the economic and environmental costs. Therefore, the study concluded that sustainable shelter solutions can be produced using either global or local construction materials, as global materials will most likely provide better technical performance while the local materials will likely lower both costs and environmental impact. They also found that cost and environmental impact do not necessarily affect the technical performance of shelters. Escamilla and Habert [33] consider the global materials as “industrialized and engineered construction materials like concrete and steel”, while consider the local materials as those used in “traditional and vernacular architecture, like bamboo, earth/soil and wood”. In a follow-on study, Celentano et al. [34] found that the material supply (local or global) is the main factor affecting the speed of the construction in the construction technology scale, and noted that using local materials decreases the cost but increases the construction time, while the use of industrialized materials does the opposite. However, when focusing on the scale of the shelter unit, they found that the roof’s complexity is the main factor affecting the speed and not the source of the materials. Therefore, they suggest using local materials with a small input of industrialized materials to increase the speed with no noticeable impact on costs. The International Organization for Migration (IOM) recommends the selection of culturally appropriate materials (i.e., local materials that are already used for traditional and vernacular architecture within the existing culture), as it helps protecting the natural resources, and reflects the local expertise in resource management—which consequently, will reduce the shelters carbon footprint through minimizing the energy consumption and pollution [3].

The shelter’s total cost usually includes the cost of materials, transportation, construction work and the workforce, but excludes the cost of the camps’ infrastructure, which results in having inaccurate comparisons. Additionally, the cost of waste management that results from materials’ manufacturing should be considered [35]. The intended short lifespan of PDPC shelters makes the investment in their quality appear inefficient as it could result in them costing more than permanent housings [21]. This however generally proves false for two reasons: shelters usually stay in their place, and are occupied, for much longer than initially anticipated (1) and considering only the initial costs when comparing solutions is short-sighted, as the operational costs differ widely when a well-designed shelter is used for a long time (2). This calls for a greater adoption of life cycle thinking in future PDPC sheltering solutions as the missing link between design and sustainability.

### 3. Methods

Building on the literature review, desk-based research was conducted in order to identify the global and regional solutions for PDPC sheltering as this information is not available within existing academic literature. These designs have been categorized according to their historical application into ‘novel designs’ and ‘existing solutions’. Novel designs are defined in this research as shelter designs developed by researchers or companies but not necessarily ever used. Existing solutions are instead those applied in the field as a response to PDPC shelter needs, most commonly by UNHCR, IFRC or their partners. In order to clarify the difference between the two categories, any shelter that was

prototyped and used by more than 100 refugee families is categorized as ‘existing’, while other shelter designs that were never prototyped or were prototyped and used by less than 100 refugee families, are categorized as ‘novel designs’. While the information about ‘novel designs’ were collected from their official web pages and magazine articles, the data for the ‘existing shelters’ were sourced from the organization documents, mainly Shelter Projects [36]. Two considerations influenced the choice of the cases; the quantity of available information and the variety of shelters—by material and geographic spread.

The shelters in both clusters have been investigated against three dimensions (social, environmental and economic) from a qualitative perspective. This approach is well accepted in the sustainability field [37,38], adopted in UN-endorsed research [39] and across sectors, spanning from the circular economy [40] to oil and gas operations [41]. Arguably, a quantitative approach could have provided richer information but we fully agree with Janoušková and colleagues [42]: sustainability indicators are useful but they must also be relevant. For instance, Matard et al. [43], recently analysed embodied energy and embodied greenhouse gas (GHG) emissions of a 81 refugee shelters worldwide. This is a significant research endeavor but at a closer look the relevance of their findings comes into question since “lists of materials were inferred from pictures and details mentioned in the narratives” [43] (p. 33) and their values are fully based on an old version of the ICE database [44], which is specific to the UK construction industry and not reviewed. Why should it therefore produce results that are appropriate for and relevant to shelters in developing countries? Using numbers to produce other numbers is relatively easy, ensuring relevance in the process very less so. For this reason, and due to the lack of data about the shelter designs that would allow to quantify the sustainability dimensions meaningfully, we resisted the temptation of a quantitative approach in this article.

Following the qualitative approach just explained, pros and cons (as emerged from the literature review and outlines in Section 2.3) have been noted for each dimension for each shelter solution. The following two tables illustrate the examined 24 cases with the comparisons; 12 cases were categorized as ‘novel designs’ within **Error! Reference source not found.**, while the other 12 cases were categorized as ‘existing solutions’ and are shown in **Error! Reference source not found.**. Tables with full details are available in the supplementary material. Specifically, Table S1 for the ‘novel designs’, and Table S2 for the examined ‘existing solutions’. However, it is important to note that the information in the tables is based on how the projects are reported in the references used and the availability of information and therefore could be limited or not verified. Again, a degree of qualitative interpretation was needed to classify the indicators into pros and cons. This is mainly obvious in the environmental sustainability, which is a concept that cannot be classified in terms of absolute pros and cons, as the paths leading to it will differ in each country or sector [45]. Additionally, if environmental sustainability is to be measured it must first be quantified. We therefore suggest the use of environmental impact assessment tools, such as Life Cycle Assessment (LCA), in order to inform environmentally-sustainable decisions. The work of Matard and colleagues [43] is an excellent first step in this direction, and it is hoped that future works will use appropriate datasets and reliable quantities, and be expanded beyond the cradle-to-gate boundary.

For the scope of this article, based on the available information, and for the sake of our categorization, we have clustered, for instance, on the pros side of environmental sustainability examples where local materials were reported to be used (materials used in the traditional and vernacular architecture) and on the cons side cases where global materials (industrialized) were used. This choice reflects their lower reliance on fossil fuels, lower energy- and carbon-intensive supply chains, and the likely availability within shorter distances from the site where they are employed, thus reducing global transportation impacts. There remain however instances where a categorization would be misleading. This is the case of using perlite in the Tentative Concept design, for example, which is on the one hand a natural material and, on the other, a possible cause of rhinitis and pneumonia [46]. A similar consideration could also apply to stone wool.

Table 1. Novel designs sustainability comparison.

Shelter Solution	Social Sustainability		Environmental Sustainability		Economic Sustainability		Ref
	Pros (+)	Cons (-)	Pros (+)	Cons (-)	Pros (+)	Cons (-)	
1 Conrad Gargett's	-Flexible -No mechanical fixings	-Does not consider SN -One room -No private T&K	-Use of wood	-Use of plastic		'Unknown cost'	[47,48]
2 Exo stackable shelter	-Easily deployed -No tools needed -Can attach multi units	-Does not consider SN -One room -No private T&K	-Use of wood -LED light display -Recyclable	-Use of Aluminum -Steel in floor		Unaffordable	[49–51]
3 U-dome	-Easily deployed -Can incorporate LM	-Does not consider SN -One room -Small size -No private T&K	-Compatible to RES	-Use of plastic -Use of Nylon		Above average	[52–54]
4 TranShel	-Easily deployed -Expandable -Possibility of LM	-Does not consider SN -One room -Small size -Low roof height -No private T&K	-Reusable -No off gassing -Recyclable -Possibility of LM	-Use of plastic		Above average	[55,56]
5 Concrete Canvas shelter	-Various sizes -Easily deployed	-Does not consider SN -One room -No private T&K	-Durable -Covered by earth	-Use of concrete -Plastic inner -Vehicle needed		Unaffordable	[57,58]
6 The Liina Transitional Modular Shelter	-Easily deployed -Various rooms -Private K	-Does not consider SN -Small size -No private T	-Use of wood -Insulated panels -Durable	-Use of Nylon		'Unknown cost'	[59,60]
7 The Pallet House	-Easily deployed -Adaptable -LM (P)	-Depends on the availability of materials -No private T&K	-Use of wood -Wood/straw roof (P) -Possibility of LM	-CS roof (P)		Below average (Basic material)	[61]

Table 1. Cont.

8	Life shelter	-Easily deployed -Adaptable -LM (P) -Durable	-Does not consider SN -One room -Small size -No private T&K	-Stone wool insulation -Durable -Reusable	-Stone wool insulation -Use of steel -Cement cladding roof	Below average (For large quantities)	[62,63]
9	Rapid Deployment Module (RDM)	-Easily deployed -Integrated floor	-Does not consider SN -One room -Small size -No private T&K	-Passive cooling and heating -Reuse shipping box -Durable	-Unknown walls materials -Questionable TC	Unaffordable	[64–66]
10	Tentative Concept	-Raised floor	-Small size -No private T&K	-Use of fiberglass -Use of textile with Pe -Collects water on roof	-No TC -Use of Pe	'Unknown cost'	[67,68]
11	Hex house	-Sufficient size -Various rooms -Can attach multi units -Private T&K	-Does not consider SN	-Durable -RES, Biogas toilet and rainwater harvesting -Use of foam insulation	-Use of steel	Unaffordable	[69,70]
12	Weaving a home	-Culturally acceptable	-Short-term solution -No private T&K	-RES and rainwater harvesting	-Use of plastic	'Unknown cost'	[71,72]

T—Toilet/K—Kitchen/SN—Social Needs/M—Materials/L—Local/G—Global/RES—Renewable Energy Sources/TC—Thermal Comfort/P—possible/Pe—Perlite/CS—Corrugated Sheets.



Table 2. Existing solutions sustainability comparison.

Shelter solution	Social Sustainability		Environmental Sustainability		Economic Sustainability		Ref
	Pros (+)	Cons (-)	Pros (+)	Cons (-)	Pros (+)	Cons (-)	
1 Refugee Housing Unit	-Easily deployed -Moveable	-Does not consider SN -One room -Small size -No private T&K	-Small solar panel	-Short lifespan -Use of steel -Use of plastic	Below average		[73,74]
2 Bangladesh 2007	-Expandable -LM	-Small size -T&K (unknown)	-Wind protection -Flooding protection -Self-built -LM- ex. Bamboo	-Permanent base -CS roof -Use of concrete		Above average (Material Costs)	[75]
3 Kenya-Dadaab 2009	-Culturally acceptable -Women participation	-Small size -T&K (unknown)	-Self-made mud blocks -Durable	-CS roof -Limited by MA -Unplanned excavation	Below average (Material Costs)		[75]
4 Haiti 2010	-Sufficient size -Outdoor porch -Traditional techniques -Flexible & Accessible	-Internationally procured materials -T&K (unknown)	-Use of Traditional M- wood/ mud (p) -Passive C -Durable	-Use of concrete -Corrugated bitumen roofing		Above average (Material Costs)	[20]
5 Philippines 2011	-Traditional techniques -Easily deployed -LM	-Small size -T&K (unknown)	-Durable -Use of wood -LM	-CS roof -Use of concrete	Below average (Material Costs)		[20]
6 Ethiopia 2011	-Various sizes -Built by refugees - LM -Separate private T	-Does not consider SN -No planned animals' shelters -K (unknown)	-Passive C&H -Use of LM, such as bamboo, grass and mud	-Sourcing issues -Transporting issues -Seasonal materials	Below average (Material Costs)		[76]
7 Madagascar 2012	-Culturally acceptable -Easily deployed -LM	-Small size -T&K (unknown)	-Use of wood -Thatch roof (P) -LM	-Unconsidered LM -CS roof (P)	Below average (Material Costs)		[76]

Table 2. Cont.

8	Fiji 2012	-Sufficient size	-T&K (unknown)	-Prefab elements -Withstands cyclones -Raised earth floor	-Use of plastic -CS roof	Above average (Material Costs)	[77]
9	Myanmar 2012	-LM	-Small size -Collective shelter -Does not consider SN -T&K (unknown)	-LM	-Seasonal materials	Below average (Material Costs)	[77]
10	Philippines 2012	-Various sizes -Separate T -LM	-Small size -K (unknown)	-Use of salvaged M -Use of fallen trees -LM	-Lack of salvaged M	Below average (Material Costs)	[77]
11	Jordan 2013	-Easily deployed	-Does not consider SN -One room -Small size. -No private T&K	-Use of foam	-Short lifespan -Use of steel & CS -Unsealed walls	Above average (Material Costs)	[31,77,78]
12	Iraq 2015–2016	-Locally procured GM -Divided interior -Private T&K	-Small size -Not flexible	-Wood & fiberglass -PU insulation -Durable	-Use of steel	Within existing range (Material Costs)	[27]

T – Toilet/K – Kitchen/SN – Social Needs/M – Materials/L – Local/ G – Global/C – Cooling/H – Heating/P – Possible/CS – Corrugated Sheets/Al – Aluminum/A – Availability.

The average material costs of the 12 examined ‘existing solutions’ which were funded by UNHCR or IFRC was calculated in this research as \$1300. The maximum material costs of the 12 cases was \$5500 for the Iraq 2015–2016 project [27]. These two costs along with their average (\$3400) formed the basis for describing the costs in Table 3 that were used in Table 1 and Table 2.

**Table 3.** Cost classification adopted in this research.

Materials Costs	< \$1300	\$1300–\$3400	\$3400–\$5500	> \$5500
Description	Below average	Above average	Within existing range	Unaffordable

## 4. Results

As explained in the literature review section, the shelter terminology is not always agreed upon between NGOs and academia. In addition, designs and solutions with assigned shelter types do not always meet the specifications of that type. Most of the ‘novel designs’ were considered as global shelters or as a one-size-fits-all solution, which is recognized as an inadequate approach as it neglects the social context and cultural needs [19,78]. Conversely, ‘existing solutions’ were designed for a specific case (full details given in the supplementary material). With respect to portability, most of the ‘existing solutions’ were fixed even though some of them were originally designed to be relocatable, but changes occurred during implementation such as the case of Jordan in 2013 (Azraq camp T-shelters). All of the ‘novel designs’ were transportable and 92% of them can be easily deconstructed; in most cases, they were flat packed (76%), but other techniques were also used such as being stackable, foldable, or able to be disassembled into smaller parts (details can be found in the supplementary material). Each sustainability dimension is discussed in detail in the following sections.

### 4.1. Social Sustainability

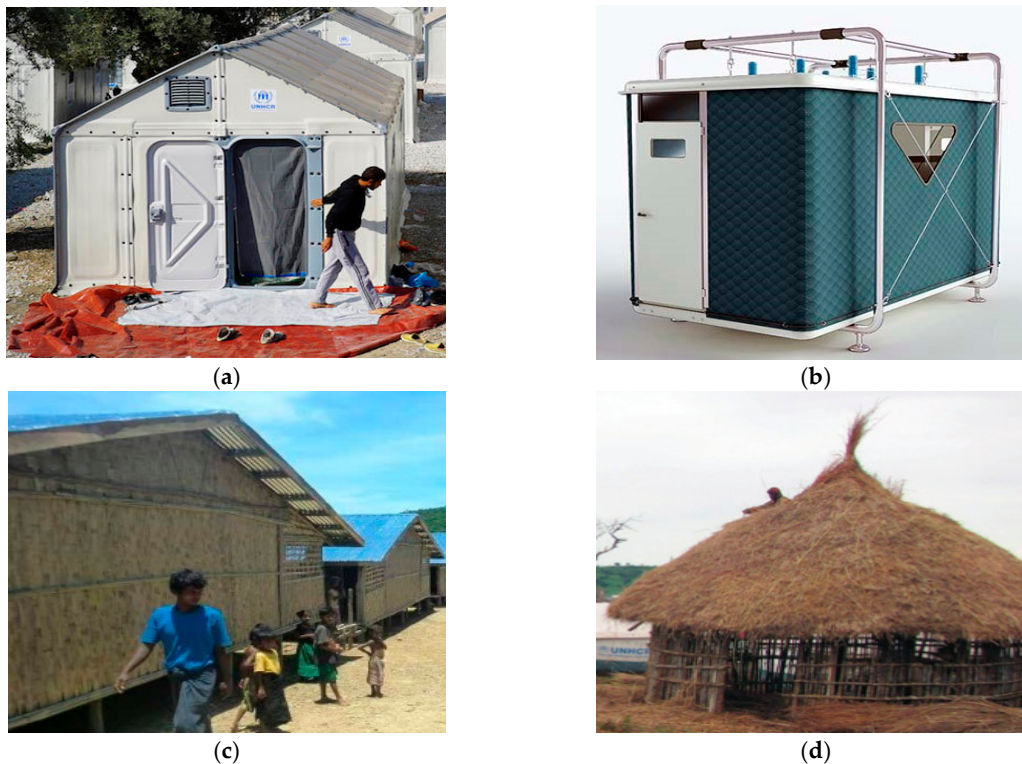
Defining social sustainability is challenging as the field is still emerging [79], while at the same time is vague and impossible to be limited in one definition [80]. However, in this paper, the adopted definition is the preservation of the existing social systems, where the social challenges and concerns are being addressed by considering the history, traditions, dialogue, equity, and participation [79]. The concept of social sustainability sometimes overlaps with the other two dimensions of sustainability, i.e., environmental and economic. However, each dimension tackles the overlapped element in different ways. A clear example is the materials, where the use of local materials fulfils a social need due to its familiarity, besides the fulfillment of the environmental and economic elements. Among the studied cases, the most commonly identified social pros for shelters that belong to both types (novel designs and existing solutions) were: the short time needed to assemble the shelters by a minimum number of workers, the ease of deployment that allows unskilled beneficiaries to take part in the construction, the use of local and locally available materials, the flexibility and expansion possibilities, having various shelter sizes to meet the needs of different household compositions, and having an interior layout that is divided into needed functions. In addition, some of the ‘existing solutions’ were more respectful by adopting local building techniques, having outdoor private areas, or using shelter types that are acceptable to users (i.e., familiar and used within their culture), such as Haiti 2010 [20] and Philippines 2012 [81].

Conversely, the most common cons under the social dimension are the one-room approach that is more emphasized in the ‘novel designs’ with 58% of the studied cases. In addition, the lack of private toilets and private kitchens is a major drawback, as only 8% of the ‘novel designs’ and 17% of the ‘existing shelters’ are known to have a private toilet, while 17% of the ‘novel designs’ and 8% of the ‘existing shelters’ have a private kitchen. The Refugee Housing Unit designed by IKEA shown in **Error! Reference source not found.1a**, is amongst the many shelter examples of the one-room design that also lacks private facilities [78]. The small or insufficient shelter area (compared to the number of residents and/or their needs) is another common con amongst both clusters. The Tentative

Concept post-disaster shelter which is shown in **Error! Reference source not found.b** is an example with its 8 m<sup>2</sup> overall area [67].

Other common cons were the total dependency on the availability of local materials in the location or total dependency on global materials, and proposing short-term solutions. Building collective shelters instead of private shelters was also apparent in the ‘existing solutions’ such as the Myanmar 2012 shelter that hosts eight families (**Error! Reference source not found.1c**) [81]. Providing a shelter design that is familiar to the host community but not to the users is another issue that was highlighted in the case of Ethiopia 2011. The Tukul shelters that were given to the refugees were familiar in the Ethiopian culture but not for the Sudanese who lived in them (**Error! Reference source not found.1d**). In the same case, another social inadequacy appeared when there was no space to shelter the livestock brought by the Sudanese refugees from their homeland [76]. Recent evidence has also shown that elements of social sustainability should go beyond the human sphere and take into account livestock and domestic animals because of their important role in certain cultures [82].

Identifying the best practices amongst the existing shelter projects and understanding the cultural influence on the spatial needs, would shorten the distance between the decision makers and the shelter users. When possible, engaging the users in the early stages of designing the shelter projects would ensure the social suitability of the final output.



**Figure 1.** Shelters with social inadequacy: (a) Refugee Housing Unit [78], (b) Tentative Concept post-disaster shelter [67], (c) Myanmar 2012 temporary collective shelter, photo by UNHCR [81], (d) Ethiopia 2011 semi-permanent shelter, photo by Demissew Bizuwerk/IOM Ethiopia [20].

#### 4.2. Environmental Sustainability

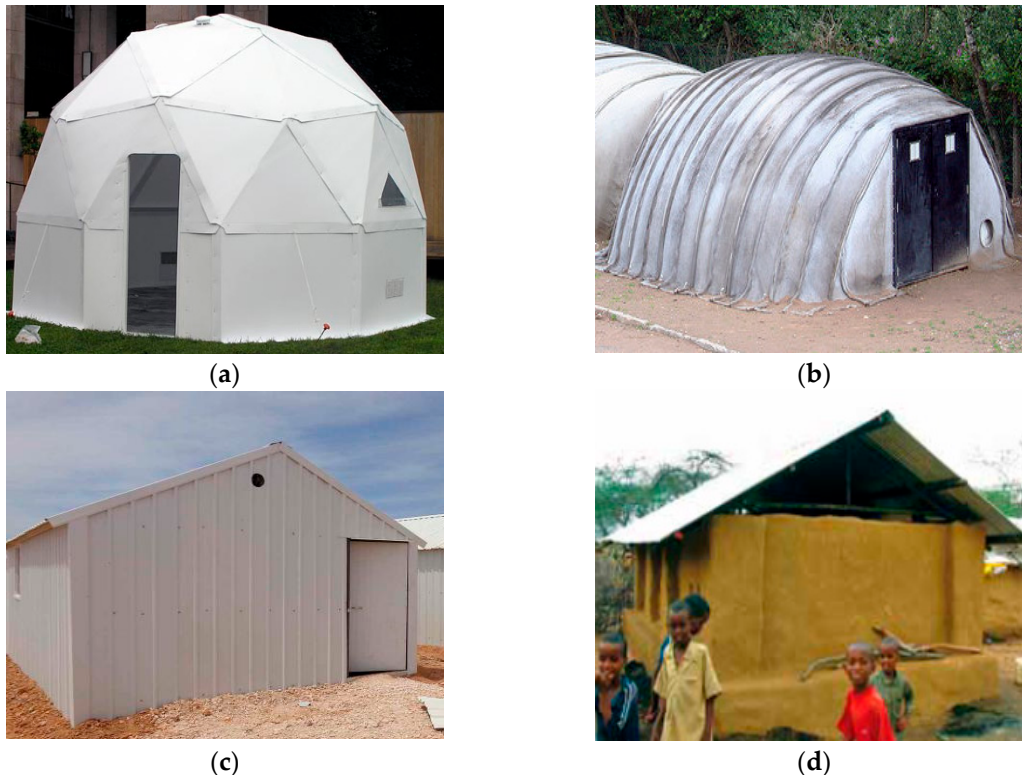
The pros within the environmental dimension are related to the use of local materials such as wood, thatch and earth, the reusability and durability of the shelter, using passive cooling and heating techniques, the ability to collect rainwater and the provision of electricity through solar panels. In qualifying the environmental sustainability, the relative environmental consequences of different elements need to be borne in mind (e.g., the embodied energy in the materials and transport to site, the operational energy demand, the environmental consequences of rainwater harvesting).

The ‘existing solutions’ showed some good practice that was not seen in the ‘novel designs’, such as raising the shelter over a plinth in flood-prone areas, and having construction details that can

withstand severe wind loads in cyclone-prone areas. It can be argued that ‘existing solutions’ have gone through a number of trial and error phases, which led to their better suitability to conditions of and application in the field. ‘Novel designs’ should certainly learn from the iterative experience of ‘existing solutions’. Other positive approaches were the use of salvaged materials, using materials which were produced on-site by the beneficiaries, and adopting some traditional construction techniques, such as Clissage (a mix of lime and earth binding the filling of a wooden structure) and Amakan (woven bamboo wall cladding).

Conversely, the poor practice included using carbon-intensive materials such as concrete, plastic, steel, nylon and aluminium. The U-dome shelter shown in Figure a is an example of a shelter made of such materials. It consists of corrugated polypropylene panels, which are connected by nylon fasteners [52,83]. The Concrete Canvas shelter (Figure 2b) is another example where concrete was used for the outer skin [57]. There are also examples of using carbon-intensive materials amongst the ‘existing solutions’ case studies, such as the T-shelters provided for the Syrian refugees in Jordan. This shelter, which can be seen in Figure 2c [84], is made of an interlocking steel structure and covered with a double layer of Inverted Box Rib (IBR) cladding separated by an aluminium and foam insulation [81].

In some cases, the demand for natural materials exceeded their availability, and this happened in the ‘Kenya-Dadaab 2009’ project (Figure .2d) where the insufficient availability of mud and shortage of water have limited the number of built shelters. Transporting mud from distant locations was proposed for future projects, though it turns the use of mud blocks into a less sustainable option for the rest of the shelters. The unplanned excavation of mud resulted in holes, which in the rainy seasons were transformed into refuse pits or mosquito-breeding sites [75]. In the ‘Ethiopia 2011’ project, a similar challenge occurred when there were difficulties in sourcing the mud and grass used for thatching [76]. In the same way, in the ‘Myanmar 2012’ project, the bamboo was not in season and a lower quality alternative was used [81].

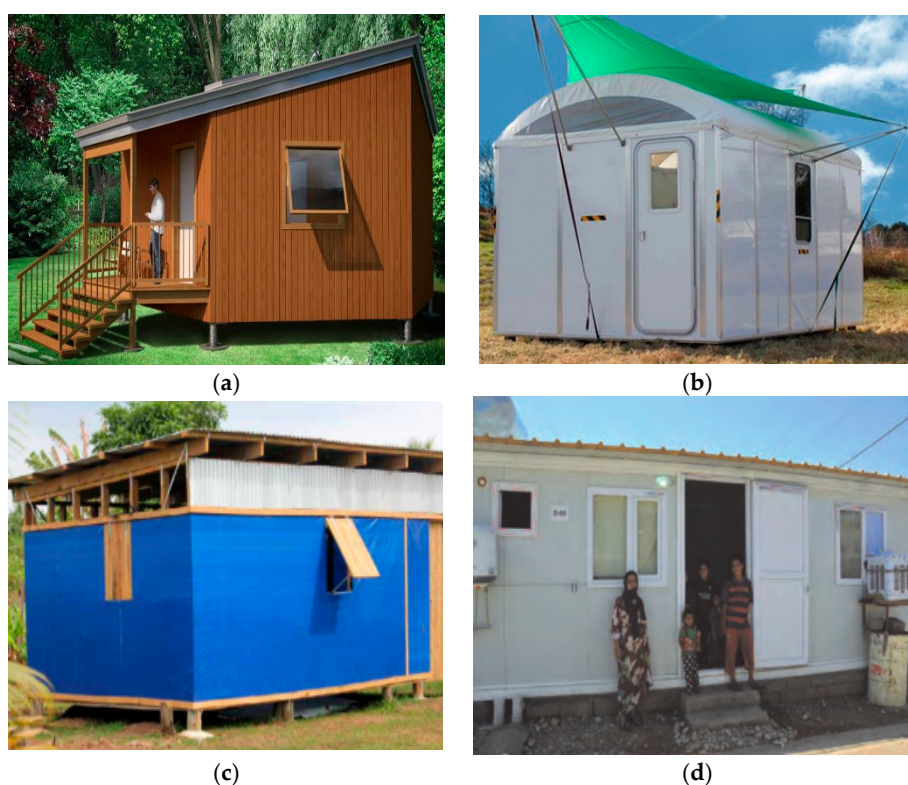


**Figure 2.** Shelters with environmental inadequacy: (a) U-dome transitional shelter (designboom, 2018), (b) Concrete Canvas shelter [57], (c) Jordan 2013 T-shelters, photo by Robert Neufeld (World Vision, 2014), (d) Kenya-Dadaab 2009 core shelter, photo by Jake Zarins [75].



### 4.3. Economic Sustainability

About 83% of the ‘novel designs’ analysed, have costs that are significantly higher than the ‘existing solutions’ or with unknown cost. Fig.3a shows the Hex House, a shelter designed by Architects for Society. In the Dezeen online magazine, the cost per unit was denoted as \$15,000–\$20,000 [70], while in the Hex House website, it is shown as \$55,000–\$60,000 [69]. Another novel shelter design with a high cost is the Rapid Deployment Module (Fig.3b) [65], with unit costs around \$15,000–\$18,000 [64]. On the contrary, 67% of the ‘existing solutions’ had modest costs (equal to or less than \$1300). However, there were cases with costs that are considered high compared to other shelters such as Fiji 2012, which is shown in Fig.3c. Its material costs were \$1800 and the overall project cost per shelter was \$2900. The main reason for its high cost is likely to be Fiji’s remote location, which increased the materials’ transportation cost and therefore the overall cost [81]. Another ‘existing solution’ with a high cost is the Iraq 2015–2016 transitional shelter shown in Fig.3d. The shelter had material costs of \$5500 and a project cost per household of \$9621. The initial costs for establishing the sites were high and the political situation and the higher shelter standards also contributed to the high cost [27].



**Figure 3.** Shelters with economical inadequacy: (a) Hex House shelter [69], (b) Rapid Deployment Module, photo courtesy of RDM and Fast Company [65], (c) Fiji 2012 transitional shelter, photo by Habitat for Humanity Fiji [81], (d) Iraq 2015–2016 transitional shelter, photo by Alan Miran [27].

## 5. Discussion

The review of academic literature around PDPC sheltering and this research on ‘existing solutions’ and ‘novel designs’ allow us to understand best practice and common pitfalls across the three main sustainability dimensions. The main lesson learnt from previous shelter cases in regard to the social dimension is that one room designs do not meet social needs. The possibility of adding an internal fabric division to a single room does not match the performance of a more substantial wall. One of the common challenges in both the ‘novel designs’ and the ‘existing solutions’ is that the toilet/shower and the kitchen are not considered during the design phase. Private facilities are a major need in many cultures and failing to provide them leads to social, health and psychological problems.

Adding those private facilities at a later stage usually results in a waste of time, requires additional resources and incurs higher costs. In addition, the size of the shelter should match the number of space users, their age and gender. Providing one size shelter does not respond to diverse family needs. The Sphere project [4] recommends a minimum covered area of 3.5 m<sup>2</sup> per person, and despite the fact that this number has no scientific basis [85], most designs do not even meet such minimum recommended area. The minimum acceptable covered space per person will differ between contexts and cultures. Using materials that are familiar or accepted within the residents' culture, as well as being maintainable, are important social elements to consider. The shelter should be adequately designed before being distributed as it should not depend on the individual ability to source additional materials. In addition, providing spaces for the residents' animals is an important need in cultures where animals play a significant role. The primary recommendation to fulfil the social sustainability aspect in any shelter design would be to consider the importance of engaging with the residents in the design from early stages. That would help in providing a more satisfactory shelter, which responds to their own cultural needs and at the same time enhances their sense of ownership of their shelters.

In the environmental dimension, it was noted that all renewable energy applications are positive additions to any shelter design. However, it should be considered that these renewable sources cannot be the only energy source as they generally depend on weather conditions, which are uncertain. In addition, those applications are only cost effective if considered over the long term, and in most cases the duration of the situation is unknown, and budget is limited. Using natural materials like wood, bamboo, thatch, mud and other bio-based or recyclable materials could reduce environmental impacts, but this can only be explicitly analyzed through, for instance, life cycle assessment (LCA) and evidence, rather than the designer's intuition, which frequently drives design choices. Self-made materials such as woven bamboo mats or mud blocks can save money, increase the residents' sense of ownership and be at the same time more sustainable. If seasonal materials are used in the design, then a planned alternative should be identified for cases when the need for shelter falls out of that season. In general, the use of local materials is preferable but prefabrication could in some cases save time, and provide the necessary thermal comfort. Whatever is the selected approach, designing a shelter that can withstand the local weather conditions is a priority, especially in areas prone to severe weather phenomena. Appropriate passive cooling and heating techniques are usually found in a region's vernacular architecture and traditional houses. These techniques are generally more sustainable and familiar to the people. Utilizing them can have positive impacts on both the social and environmental dimensions. There could also be, however, a tension between greater environmental sustainability and greater social sustainability. For instance, in Uganda, as soon as people can afford to, they will get rid of environmentally-friendly thatched roofs as they "harbor pests and disease and are high maintenance, and will upgrade to a metal or tiled roof" [86]. So much so, that the Pulse Lab Kampala is using roof types as an indicator to measure poverty [86].

Materials are also influenced by the temporary nature of most shelters. Permanent shelters are not allowed in most cases, especially after conflicts, where the status of the land is a major concern. The limitations on the approved materials unfortunately direct organizations toward unsustainable materials which do not guarantee adequate levels of protection, such as plastic sheeting and corrugated galvanized sheets. Therefore, a pre-planned sustainable option could be explored and considered for each region, in order to alleviate the time pressure due to the urgency of PDPC situations. The lifespan of shelters and options for their reusability/recyclability should be considered while evaluating alternative designs to have a more realistic understanding of their values.

Most of the 'novel designs' have unrealistically high cost that exceeds that which UNHCR, IFRC and their operational partners usually pay for shelters. This difference is clearly noted by comparing the cost of the 'novel designs' with the cost of the 'existing solutions'. Since some of the 'novel designs' have never been prototyped, not all of them had published cost. On the other hand, the 12 studied 'existing solutions' had published material costs (not the full cost), and they range from \$380 for the Philippines 2012 [81] to \$5500 for the Iraq 2015–2016 [27]. The average material costs for the 12 cases is \$1300. There is no fixed preferred cost for shelters, but the calculated average material cost can give

an indication for what is considered affordable for PDPC shelters. It is vital to understand that the goal of a reduced shelter cost is not only to save money but most importantly to help more people within a fixed budget. Usually the shelter project beneficiaries are much fewer than the affected people who need help. Therefore, the principal purpose is to give the best shelter quality at the lowest possible cost to help the maximum possible number of people in need.

## 6. Conclusions

In the humanitarian sector, there are no agreed terminologies regarding sheltering and the existing terms are usually misused, which can mislead researchers and policy makers. The classification of shelters depending on their historical application values the field implementation, as it differentiates between the shelters that were already used by beneficiaries in real PDPC scenarios (i.e., existing shelters), and the shelters that were designed for PDPC scenarios but were not implemented and used by the affected people (i.e., novel designs).

It is widely understood that a compromise is always necessary in designing shelters, specifically between cost, performance, durability, cultural appropriateness and building technologies [20]. Considering sustainability in this complex scenario, which is often further constrained by resources and time, is inevitably challenging. However, it has a vital role to play in the wider wellbeing of the displaced. Currently, both existing and novel shelter solutions as described in this article fail to adequately meet the users' needs and a rethinking is therefore necessary. Additionally, the global need to address the climate crisis, and the consequential social benefits of more sustainable designs, push for a more holistic view of shelter design, one that addresses all three pillars of sustainability. Table 4 illustrates a summary of considerations when dealing with PDPC shelters in both the design stage and choosing materials, against the three dimensions of sustainability.

**Table 4.** Recommended PDPC shelter considerations.

	<b>Social Sustainability</b>	<b>Environmental Sustainability</b>	<b>Economic Sustainability</b>
<b>DESIGN PHASE</b>	Engage the residents in the designing phase	Use renewable energy applications, when applicable	(No available information on the cost of the design phase)
	Include private facilities whenever required	Appropriate passive cooling and heating techniques could be adopted from the region's vernacular architecture	
	The size must match the number of residents, their age and gender requirements	Consider the life-span of the shelter-	
	Include spaces for the animals when needed	Make it reusable or recyclable	
<b>CHOOSING MATERIALS</b>	Familiar or accepted within the residents' culture	Use natural materials and other bio-based or recyclable materials, when applicable	The material costs for the shelter is preferred to be around \$1300
	Maintainable	Use self-made materials whenever possible	The material costs shall not exceed the maximum amount of \$5500
	Available	The use of seasonal materials shall be accompanied with a planned alternative	
	Temporary whenever the status of the land is a concern	A mix between local materials and prefabrication could be useful depending on the case	

The main limitation in this research paper is the dependence on the available documented information instead of testing the prototypes themselves or conducting field visits and surveys. Moreover, the lack of an agreed documentation form for the shelter projects, resulted in having information which is neither consistent nor harmonized and therefore limited the scope of the compared indicators. The information was cited as found in the references, which means that they are not verified, specifically the 'novel designs'. This limitation forced a degree of qualitative interpretation to classify the indicators into pros and cons. Another limitation is the wide sample of



studied shelters that were not focused on the responses of a certain disaster or a geographic region, which could offer clearer and more specified criteria for designing PDPC shelters. Future research could target a narrower group of shelters based on disaster type, location of shelters, culture, method of building, and/or political situation. Future research could also seek other ways of sourcing information, such as lab tests and field visits, to be able to collect the necessary data to achieve quantitative results.

Acknowledging and identifying compromises is a way to clarify possible future amendments and to achieve more sustainable shelter designs in future. This is what this article has sought to achieve, to comprehensively review the ‘novel designs’ and ‘existing solutions’ for post-disaster and post-conflict sheltering and conclude possible consideration for future shelter designs. The review was based on the available academic literature, organization reports and desk-based research to assess sustainability dimensions of shelter, which proved to be very limited. Both shelter clusters have been evaluated against social, environmental, and economic sustainability, in an attempt to qualify pros and cons along each dimension. Rather than to prescribe future design efforts, the aim of this paper was intended to identify best practices and successful and unsuccessful elements of design. A clearer understanding of successful approaches and areas for improvement represents an important stepping-stone for future work in this area to accelerate the transition to sustainable shelter solutions.

**Supplementary Materials:** The following are available online at [www.mdpi.com/xxx/s1](http://www.mdpi.com/xxx/s1) and [www.mdpi.com/xxx/s2](http://www.mdpi.com/xxx/s2), Table S1: Extended table—Novel designs sustainability comparison, Table S2: Extended table—Existing solutions sustainability comparison.

**Author Contributions:** F.P. had the original idea of investigating the subject within the context of the project above. L.A. carried out the data collection and wrote the first draft of the article. F.P., L.A., B.D.A., S.S., and P.G. all contributed to subsequent drafts which gave the manuscript its final form. All authors have read and agreed to the published version of the manuscript.

**Funding:** The research presented in this article was funded by the Royal Academy of Engineering, under their Frontiers of Engineering for Development Programme, Grant No. FoESFt5\100015.

**Conflicts of Interest:** The authors declare no conflict of interest.

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