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The Use of Non-Conventional Materials in Temporary Shelters: A Case Study of the Kutupalong-Balukhali Camp and the Potential of 3D Printing

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ABSTRACT

This research aimed to identify, through a bibliographic review and comparisons with data available on the Infrashelter Platform, the use of natural materials for structures in Planned Temporary Camps (ATPs), either as complements to buildings or as inputs for 3D printing. The results yielded several solutions in terms of natural materials and composites that can enable the implementation of new approaches to compose ATP structures, considering safety conditions, comfort for refugees, and the reduction of negative environmental impacts. While the use of natural and locally available materials has been common, it may also have negative impacts on sustainability and resilience when construction and design aspects are overlooked.

KEYWORDS

Natural materials. Residues. Planned Temporary Camps (ATPs). Socio-environmental disasters. Refugees. Kutupalong-Balukhali.

INTRODUCTION

Human action inevitably generates impacts. However, the economic, social, and environmental transformations resulting from these impacts can be significant and challenging, caused, for example, by the misuse and occupation of land, such as desertification, reservoir and watercourse siltation, floods, and other 21 emerging problems

(UNEP, 2012). In this context, global warming has increased the risks of wildfires and floods due to excessive humidity and intense and prolonged rainfall, as observed in various parts of the world (ONU, 2023).

In this context, we observe the negative impacts of global warming on populations, especially the most vulnerable. However, humanitarian crises and forced displacements around the world are not solely due to environmental problems but also to conflicts, violence, persecution, and human rights violations. According to UNHCR(2021), approximately 82.4 million people worldwide were forcibly displaced in 2020. Among them, around 48 million were internally displaced persons, and 26.6 million were refugees seeking survival in other countries. Five countries, Myanmar, South Sudan, Afghanistan, Venezuela, and the Arab Republic of Syria, account for the largest number of victims of humanitarian crises, generating approximately 68% of the refugees. One of the camps that receives refugees from Myanmar is Kutupalong-Balukhali in Bangladesh.

One of the effective actions to facilitate the reconstruction and/or recomposition of refugee families affected by socio-environmental disasters has been the humanitarian provision of camps, respecting the time that people need to recover physically, economically, and emotionally. For the United Nations High Commissioner for Refugees (UNHCR), which provides the structures of humanitarian support, shelter is essential to promote the survival and dignity of refugees in situations involving crises or displacements (UNHCR, 2023b). However, many refugee camps are hastily established without prior planning due to urgency, which can negatively impact the residents' stay (CARBONARI, 2021; ARAÚJO et al., 2021). Therefore, it is crucial to plan camps in advance and with organization, which is the purpose of the Infrashelter platform (VIRTUHAB/UFSC, 2023) aiming to contribute.

That being said, the aim of this article was to identify, through a bibliographic review, the use of natural materials that can be utilized for camp structures, either as building complements or as inputs for 3D printing. To achieve this, a case study was conducted in the Kutupalong-Balukhali refugee camp to identify the materials, along with a comparison with other camps already cataloged on the Infrashelter platform.

MATERIALS, METHODS AND PROCESS

This section describes the methods and processes used in the research, which aimed to identify the materials used in the structures or architectures present in refugee camps.

The Infrashelter platform, developed by the VirtuHab Research Group at UFSC, seeks to systematize available information about ATPs around the world and in Brazil, with the goal of supporting the implementation of new structures. In this effort, 20 camps were cataloged, among many others identified worldwide as a result of socio-environmental disasters, and their information was made available following a framework (based on Carbonari's 2021 research) of the spaces needed to attend refugees.

In the study of the Kutupalong-Balukhali camp, located in Cox's Bazar, Bangladesh, the Infrashelter platform's framework served as the basis for researching the existing structures and the materials used in them. A comparative analysis of the structures and the types of materials used in other ATPs available on the platform was then elaborated. This allowed the identification of the main materials used in these structures to facilitate their incorporation in Brazilian camps, which could be used in future 3D printing efforts. The research was divided into three stages: (i) bibliographic review, presented as a preliminary result, (ii) description of the structures and internal spaces of the Kutupalong-Balukhali refugee camp, and compilation of the results.

The bibliographic review involved searching for available references, such as articles, books, theses, dissertations, reports, and news related to the topic. Materials that present, describe, and discuss the refugee camp located in Kutupalong-Balukhali, with a focus on its spatial and constructive evolution, were selected, seeking to highlight sustainable and efficient solutions for emergency situations. The most relevant solutions were categorized and can serve as references for future projects.

Throughout the research, the materials used in the construction of camps and the complementation of structures, such as fabrics, tarps, recycled materials, and some industrialized materials, were analyzed. For these materials, their potentialities and vulnerabilities were pointed out, aiming to assess their suitability for future proposals.
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3. DEVELOPMENT: CONCEPTS AND ANALYSES

3.1 Temporary Camps in Humanitarian Crises

According to UNHCR (2023a), the design and installation of camps should take into account aspects such as the geographical context, climate, culture, local skills, and materials. The Agency also recommends criteria for selecting the site, standards and area per person in the camp, and the sizing of planned settlements, following international references from SPHERE (SPHERE ASSOCIATION, 2018).

With the increasing number of socio-environmental refugees, whether caused by intense climatic phenomena or political crises and conflicts, the existence of Temporary Camps has proliferated worldwide. To gather information about these camps, the Infrashelter platform was created, which has so far registered 52 camps around the world and in Brazil and systematized information from 20 ATPs. One of the recorded occurrences is the Rohingya conflict in Myanmar, where several ATPs were established. Among them, this study focuses on the Kutupalong-Balukhali ATP.

The humanitarian crisis involving the Rohingya Muslim population in Myanmar, formerly known as Burma, is not recent. Since the 1960s, the Rohingya, an ethnic minority, have faced systematic persecution and violence from the predominantly Buddhist population, leading to mass displacements. The consequences of these attacks create severe problems for over a million people who not only live with the trauma of violence but also in the precarious conditions of overcrowded camps. Around Cox's Bazar in Bangladesh, the world's largest refugee camp is located, housing nearly 900,000 people, with approximately 50% being women and children (MÉDICOS SEM FRONTEIRAS, 2022). After recurring cycles of violence and the denial of their rights, a population of nearly one million Rohingya community members lives in the Kutupalong ATP in Bangladesh, bordering their country. The establishment, design, construction, and management of these ATPs present challenges for humanitarian logistics and are gradually becoming the subject of scientific research seeking to provide support for the advance planning of these structures (MÉDICOS SEM FRONTEIRAS, 2022).

3.2 The structures of ATPs (Planned Temporary Camps)

ATPs have an inherently transient nature and aim to provide people in vulnerable situations with dignified and quality living conditions. Initially, the Infrashelter platform presents occurrences related to the level of conflicts and socio-environmental disasters, both nationally and internationally. Secondly, it presents cataloged infrastructures, categorized by: (i) type of emergency; (ii) location; (iii) implementation date; (iv) total number of affected people; (v) administration; (vi) camp structure; (vii) basic camp services and access; (viii) cost; (ix)

structure of individual shelters, among others (VIRTUHAB/UFSC, 2023). The items related to the camp structure, basic services, and access are subdivided into a framework according to the provisions in Table 1.

Camp Structure	Basic Services and Access
area; expansion; layout; reception and screening; administration; storage; goods and merchandise warehouse; reception and stock of food items; psychosocial and health care; educational and recreational space; community areas; kitchen; dining hall; laundry; other areas; humanitarian goods (including furniture present in spaces).	sanitary sewer; energy; solid waste; water; drainage; fire protection; latrines and toilets; washbasins; showers; pedestrian access, vehicular access.

Table 1 - Information about the structure of ATPs and basic services and access, in the cataloging of the Infrashelter Platform.
Source: VIRTUHAB/UFSC (2023)

To support individuals and the camp structures/architectures, a series of humanitarian goods are also required. Humanitarian goods are essential items and tools provided to support ATP structures/architectures and meet the basic needs of the affected individuals. These goods are typically supplied by humanitarian, governmental, and non-governmental organizations and aim to ensure dignified conditions and an improved quality of life for those temporarily sheltered in ATPs. The items include personal hygiene kits, sleeping kits, kitchen items, and shelter kits, such as tarps, tents, canopies, furniture, or other construction materials for weather protection and the provision of private spaces (ROH; LIN; JANG, 2022).

Regarding furniture, as part of the provided goods, its design is integrated into the activities of so-called Humanitarian Design, and according to Nielsen (2020), it must consider cultural appropriation, the needs of the displaced, as well as the support services required for the production of the object. Furthermore, one of the central challenges facing humanitarian logistics is ensuring that these goods are available on-site, in the required quantity, and at the moment they are needed, based on a demand that is difficult to predict. As innovative materials for the construction of furniture, the use of bamboo and cardboard stands out, demonstrated to have modular characteristics.

According to Nascimento et al. (2022), individual mobile shelters, which are part of the ATPs' structure, are temporary structures assembled to accommodate the population. Depending on the population's profile, the mobile shelters can accommodate an entire family or just one individual. They can be made up of tents that are easy and quick to set up (which generally may not be suitable for cultural and comfort aspects) or even cementitious or polymeric panels, wood, cardboard tubes, tiles, and metal panels. There is a wide range of proposals in the literature, many of which have already been applied in real cases. The authors conducted a comparison between various possibilities of materials usage according to the proposed structures for the emergency phase (days and weeks) or the transitional phase (months and years). Nascimento et al. (2022) highlight the use of some natural materials in ATPs, such as the emergency and transitional shelters of Tukul Houses and the Dolo Addo camp in Ethiopia.

3.3 The case under study: Kutupalong-Balukhali ATP.

Rohingya refugees from Myanmar are being sheltered in various countries such as Bangladesh, India, and Indonesia. In Bangladesh, near the border with Myanmar, there are more than 20 camps listed and grouped by UNHCR to accommodate the refugees. The largest

of these camps is Kutupalong, whose original boundaries and expansions are no longer clear. The original Kutupalong camp, officially managed by the government of Myanmar, has received additions from improvised camps located in the vicinity of the main camp, such as Ghumdum, Balukhali, and Thangkhali camps. The expansions are identified by numbers (1 to 20) and letters (E and W) or names of locations.

The Kutupalong refugee camp, located in the Cox's Bazar district in Bangladesh (Figure 1, (a), (b), (c), and (d)), has informally existed since 1991. It was reestablished in 2017 and currently houses around 957,971 people (estimates vary from 500 to nearly 1 million people sheltered in Kutupalong). It arose from the need to shelter Rohingya refugees, who are a stateless Muslim minority from Myanmar. On August 25, 2017, when violence erupted in the Rakhine state of Myanmar, the humanitarian crisis escalated dramatically, leading to around 1 million people seeking refuge in Bangladesh and neighboring countries. The Kutupalong refugee camp became the largest refugee camp in the world. The majority of refugees arrived in the first three months of the crisis, including many women, children under 12 years old, and elderly individuals who require additional assistance and protection (UNHCR, 2023).

The camp, largely formed spontaneously, includes a hospital, schools, police stations, mosques, community centers, headquarters of humanitarian organizations, shops, shopping centers, sports courts, the actual family housing units, and a road infrastructure.

The shelters in this camp are constructed with basic and locally available materials due to the scarcity of resources and the urgent need to house a large number of people. Depending on the region of expansion, the constituent materials may vary. In the images, one can observe bamboo, tree branches, tarpaulins, fabrics, metal pieces, and a significant amount of waste materials.

The establishment of the camp, using bamboo as the main construction material, raised concerns about environmental devastation, the occurrence of large-scale fires (resulting in fatalities and injuries), and floods caused by hurricanes and monsoons that plague the region. Table 2 presents images illustrating the location and overall view of the camp.

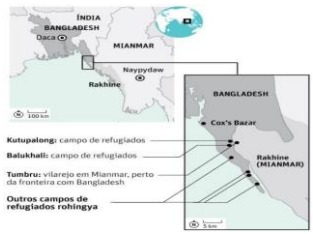 (a)	 (b)

Table 2 - (a) Location of Cox's Bazar; (b) Kutupalong in Bangladesh; Sources: (a) Folha de São Paulo (2018), (b) Médecins Sans Frontières (2022).

The camp occupies a total area of 13 square kilometers. Table 3 below shows images of some structures available in the camp. In the dining areas, bamboo structures can be observed, with wooden tables and benches. There are also images where refugees sit on colorful tapestries or tarps spread on the ground. The use of plates, cups, and food is consumed without the use of cutlery. When food is prepared in individual units, metal pots are used for cooking on ground fires. There are several videos on the internet showing the day-to-day life of the Kutupalong camp (OXFAM, 2020; GUARDIAN NEWS, 2017; AFP News Agency, 2017; ROHINGYA, 2018; BANGLADESH, 2018; TWO YEARS ON, 2019). Cooking food inside the shelters poses a high risk of fires due to the presence of many easily flammable materials. Metal utensils are also used in food preparation (basins and water jars).

In the present structures/architectures, one can observe the use of natural materials comprising the load-bearing structure (bamboo or tree branches) and lattice made from the same materials sealed with tarps, straw, thatch, or fabrics, forming partitioning elements. Similarly, the roofs are constructed. To prevent the tarp roofs from being carried away by the wind, sandbags and stones are used on top of the roofs.

Table 3: Some of the structures present in the camp.

 (a) Collective dining halls	 (b) Individual kitchens
 (c) Individual Units (source: The Guardian Post)	 (d) Partitioning Elements Structures (source: Financial Times, 2018)
 (e) Living Spaces - Bamboo structures covered with tarps and plastics	 (f) MSF Hospital (Médecins Sans Frontières) Others: 24-hour attention center with 10 beds (around 20 of these centers scattered throughout Kutupalong).

Sources: (a) Action Against Hunger (2018); (b) GUARDIAN NEWS, 2017; (c) INSIDE...2017; ROHINGYA...2018; BANGLADESH...2018; TWO YEARS ON...2019.

In expansion 10 of Kutupalong, several structures are described on the map, namely: CiC Office (Camp in Charge Office); Field Office; Age-Friendly Space; Child Protection Facilities; Women and Girls Friendly Space; Health Center; Nutrition Center; GFD Center (General Food Distribution Center); Community Kitchen; Voucher Outlet; Distribution Center; Storage; Info Hub; Registration Center; Community Center; Fire Points; Learning Centre; Check Post; Mobile Tower; Watch Tower; Religious Facility, and Graveyard. These structures are repeated in all more than 20 expansions of Kutupalong according to maps available on Humanitarian Response (2018).

3.4 Indoor Spaces and Materials.

In the construction of spaces for families (individual shelters), bamboo is used as the main material, as can be observed in the images from Tables 1, 2, and 3, as well as in videos, and in the Community Center and Cultural Center in Bangladesh. The improvised shelters of the early Rohingya refugees were built by the refugees themselves, with the typology of low semi-detached houses made with bamboo, twigs, and low-quality plastic sheets (UNHCR, 2018). Through the distribution of materials such as tarps, ropes for fastening, and instructions for the refugees, the shelters were improved to withstand the frequent rains and strong winds in the area (UNHCR, 2018). Table 6 shows both the external and internal views of the shelters and the civic center.

Table 6 - Bamboo Shelters in Bangladesh, (a) shelter, external view, and (b) shelter, internal view.

 (a)	 (b)

Sources - (a) UNHCR (2019), (b) globalcompactrefugees.org.

Families typically reside in a single room with thin bamboo lattice walls and plastic tarps separating them from the outside or adjacent shelters. In Figure (b), the internal view of the shelter, one can identify some bamboo-made shelves and some hammocks for resting.

In the design of the Integrated Community Center in the Hindu-to-Rohingya Refugee Camp, architect Rizvi Hassan used bamboo as much as possible, but also incorporated structural steel, as can be observed in Table 2 (i), as the material is locally available through Bangladesh's steel industry (RAPONI, 2021). These community structures (such as the Shantikhana space in camp 4, the exhibition center in camp 11, or the women's space in camp 25 - outskirts of Kutupalong) are present in many of the camp extensions within the conglomerate. They used materials from the region, some industrialized materials (such as steel, metal tiles), tree branches, tarps, bamboo lattice, fabrics, thatch, and even mattresses to cover the roofs (AKND, 2019).

In the Rohingya Cultural Memory Center, architect Rizvi Hassan's design sought from the outset to reclaim the community's identity and promote mental well-being through all possible creative means. Artisans and members of the Rohingya community used indigenous knowledge and techniques to support the design and construction (HASSAN, 2019).

3.4 Materials present in the structures.

The main materials identified in the Kutupalong camp are bamboo, straw, palm and coconut leaves, plastics and tarps, compacted or bagged earth, and recycled materials.

Table 7 - Bamboo Shelters in Bangladesh, (a) reinforcements to withstand monsoons, (b) attempts at waterproofing using tarps.

(a)

(b)

Sources - (a) UNHCR (2018); (b) UNHCR (2019).

3.5 Proposals for technological innovations in the construction of shelters in Temporary Planned Camps (ATPs).

Some possible technological innovations for the construction of shelters and structures/architectures in ATPs involve the use of 3D printing (Additive Manufacturing) and new composite materials. Some potential materials include earth (soil) with the incorporation of waste such as sawdust and fibers added in the production of bricks that can be used in extruders (DEMIR, 2008).

In the specific case of reclaimed wood, plastic bottles are an omnipresent example of waste, significantly contributing to waste accumulation and greenhouse gas emissions worldwide (BTI, 2019), including in Bangladesh (Haque, 2019). Studies conducted with samples of plastic bricks and compression strength tests suggest that this recycling method can be used in building shelters in homeless camps (HAQUE; ISLAM, 2021). It is essential to emphasize the importance of conscious and responsible use of these recycled materials, ensuring their safety, durability, and suitability for the intended purpose.

4.Discussion on the potentials and weaknesses of the materials.

In general, the use of natural materials in shelter construction reflects a lower durability and the need for replacement. Increased durability requires a design that considers detailed planning by specialized personnel, which has been implemented in larger community facilities but becomes unfeasible in individual spaces where construction is carried out by families using the basic materials provided. Therefore, while the use of local materials enables accessibility, it hinders durability due to the absence of construction and treatment techniques that can promote longevity.

There is a need for replacement of parts in an already scarce vegetation environment. For instance, in Kutupalong, there are reports of devastation caused by the accelerated influx of people, who used local vegetation for shelter construction and as fuel for heating and cooking. The UN has been providing sawdust for burning, given the current lack of local vegetation, as inadvertently, when wood was extracted in the early uses, the plant roots were removed, hindering their regrowth, and the soil became destabilized, leading to excessive mud and the risk of collapse. (UNHCR, 2018)

The project by architect Rizvi Hassan aimed to reclaim the lost identity of his community and to strive for the mental well-being of all through creative means. The construction process itself sought to ensure this from the outset.

According to Gregory et al (2016), the cost of different types of shelters, from the simplest to the most elaborate, will depend on the structure and materials used. 3D printing is a

technology that can be used in real-time and has the potential to save thousands or millions of lives around the world, and it can be applied in various installations such as houses, clinics, public service centers, and weather stations (GREGORY et al, 2016).

There have been many advances in different technological trends in shelter construction in disaster-affected areas (SUBRAMANYA; KERMANSHACHI, 2022). The construction of prefabricated units (temporary shelters) using 3D printer technology is not widely studied; this technology has been tested and implemented in the construction industry over the last decade in various applications (SAKIN and KIROGLU, 2017 cited in SUBRAMANYA and KERMANSHACHI, 2022).

According to James (2015 cited in GREGORY et al, 2016), 3D printers can replace supply chains that are slow or difficult to manage. He states that they can be installed in affected countries and rapidly produce shelters, prosthetics, water purifiers, and other aids appropriate for each situation. In support of this, Edwards (2015 cited in GREGORY et al, 2016) exemplifies that technology from specific companies can combine "3D printing with low-tech innovation, such as 'hyper-local' manufacturing, to provide humanitarian workers and disaster-affected individuals with tools to overcome weaknesses in the current system." In this context, 3D printing is a solution that can be used for everything from constructing buildings to becoming a life-saving tool before and after natural events or other disasters.

Final considerations (or conclusions)

This article addressed concepts of ATPs, the main present structures, and possibilities of materials that can be used in the composition of these structures. For this purpose, it used the framework of structures cataloged in the Infrashelter platform.

Based on the cataloged structures, a case study of the Kutupalong ATP was conducted, where two main camps were identified, which expanded to more than 20 regions.

In the case study of Kutupalong, the use of materials such as bamboo, branches, soil, steel profiles, and recycled materials was identified. In the comparison, similarities were found between the structures of other ATPs in the Infrashelter Platform, as well as the use of natural materials like bamboo, branches, and soil. The cooking of food is done over open fires, which presents a significant risk of fire.

Modular structures represent a perspective for these shelters, and the use of composite materials, combined with bamboo, is a potential area to be explored in future research.

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