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A Min-Max Protocol for Adaptive Refugee Housing

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ABSTRACT: Within our paper we develop a Min-Max protocol (analogous to the mathematical function) for a Rapid Shelter Kit. The objective is to Minimize dependence on external capital and fabrication, and to Maximize local building practice, supplies and labor. We approach the design by reverse engineering how an initial structure (typically) transforms over a three-phased temporal sequence: 1. rapid response, 2. stabilization and 3. long-term settlement. We minimize the use of imported building elements to the smallest amount required to stabilize a shelter in the first phase of rapid deployment. We maximize the opportunity to transition to local knowledge of construction and building materials in the second and third phase. Field workers observe that a displaced community's participation in the process of transition advocates a sense of ownership and shared identity.
We plan for the three phases by employing adaptive structural engineering principles with respect to connection joints, framing and enclosure components that support improvisation and customization by future residents. For example, for northwest Thailand, we can combine pre-developed connection methods for rapidly deployed housing with locally available linear elements (bamboo) and do structural calculations and testing to provide recommendations to local builders. Our case study simplifies site and as built conditions and geopolitical context in order to focus on the adaptive shelter system. Our paper concludes with guiding principles for systems to support self-building and the need to adapt to local terrain and context.

1 INTRODUCTION

Our objective is to present an approach for flexible rapidly deployable shelter systems that incorporate avenues for community agency in shaping settlement growth and adaptation. The approach supports displaced persons as the lead stakeholders and facilitators in three temporal housing phases.
1.1 Rapid Deployment: instantiate archetypal structural frameworks with local materials when possible.
1.2 Stabilization: create options to customize housing with locally sourced materials.
1.3 Long-term settlement: maximize the potential to extend local efforts and resources with more durable materials, utilities and infrastructure that provide sustainable solutions.

In the first phase, NGO's or government agencies typically organize a rapid settlement. This is often a matrix of tension membrane fabric shelters for protection property, storage, and privacy and Do It Yourself (DIY) assembly, that meets UNHCR standard dimensions. (UNCHR, 2016) In the second stabilization phase, residents often attempt to improve the provisional shelters with available scrap materials, as allowed by local authorities and circumstances. This may include adding spaces and making ad hoc improvements such as insulation, flooring, drainage, water supply, improvement of sanitation and hygiene (WASH) by residents. In the long run, ideally residents are able to move into safer and more comfortable housing by assimilating into a new normative community or by returning to a previous hometown, which may require extensive repair

or reconstruction. But often refugees must remain in segregated settlements, where the long-term third phase may include a standard of hardened enclosure panels and more durable prefabricated shelters (UNHCR, 2021). Imported solutions resurge for this phase, displacing locally sourced solutions due to a reliance on commercial building systems (Weinreich & Montgomery, 2019).

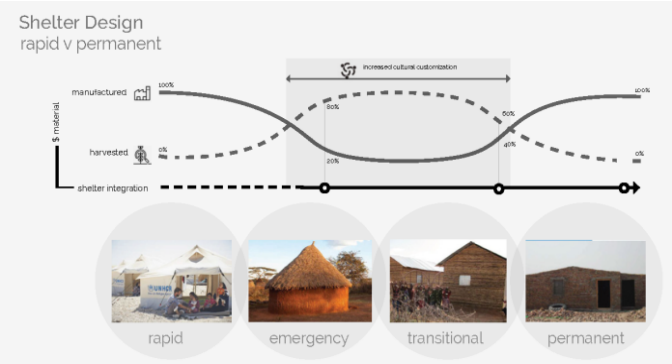

Figure 1 Three growth phases, graph compiled from UNHCR image sources and Ennead Lab's research.

In contrast, the approach we undertake aspires to establish housing "according to the geographical context, the climate, the cultural practice and habits, the local availability of skills as well as accessibility to adequate construction materials in any given country." (UNHCR 2016). Efforts towards stimulating local income and supply production while accommodating cultural patterns of living are rewarding and may reframe the way a society sees itself (Wilcox, 2015).
In this paper we focus on the building system for the shelter itself, and briefly mention related design ideas at the Block scale: 16 communities x 16 household units each for 1,250 persons, of a UNHCR settlement (UNHCR Camp Planning Standard, 2021.).

It is self-evident that all types of displaced people and subsistence dwellers all could benefit from more humane and reliable residences. The frequent waves of people fleeing disaster and conflict demand quickly deployed temporary settlements and sensitive support in the transition to safe and stable long-term solutions. Refugees live in provisionary camp settlements built as temporary solutions due to the assumption that they might soon depart, whereas the World Bank (2019) estimated that 5.4 million stay in camps for over 10 years. In the more successful settlements, utilities, commerce, and jobs eventually develop, making them into makeshift village or cities. While each situation has distinct cultural and political conditions, our goal is to stimulate local agency within the three typical phases.

In this paper, we propose to show that the design of a shelter system can support future residents through these phases by being easy to construct and amend. The system comprises a parametric model and connection designs that can adjust to fit available local material, thereby minimizing imported parts and maximizing resident self-build empowerment. We explore how components could be integrated into evolving building systems, beginning with an emergency rapid-response tension membrane fabric shelter and transitioning through the three phases to housing appropriate for a more permanent community. Standardization helps to reduce many uncertainties in quick and mass deployment related to structural stability and reliable enclosures. This ensures basic resident safety which is of primary concern in phase one.

Therefore, phase 1 allows for some manufactured elements with a proven track record of speedy construction of safe minimal dwellings. For example, using imported tarpaulins vetted by NGO's can have a duration ten times longer than using the most inexpensive plastic sheeting at just twice the cost (QSE Working Group, 2015). Where possible local materials and techniques are combined with the manufactured systems to take advantage of existing local area expertise. As the settlement evolves, the goal is to assimilate the structures more completely into the local social and building traditions context.

2 PHASE 1: RAPID DEPLOYED SHELTER WITH TENSILE SADDLE ROOF

We begin with a basic tension membrane fabric unit using a minimal wood, bamboo or paper tube framework with tensile saddle roofing. The parametric model allows substitution of different materials, so that if metal tubing is available the spacing could be much wider. Similarly, member spacing and connectors could be adapted to the size of available PVC pipe or local wood members. Such interchangeable uses of wood and bamboo are already observed in our site study context (Border Consortium 2016). A similar strategy could be applied to integrating structural paper tubes with bamboo in traditional bamboo thatched construction as demonstrated by Shigeru Ban in the Philippines (BURO, 2014). We seek to illustrate how this approach of providing connectors may simplify construction and encourage re-use of shelter elements. While environmental designers have limited control over camp governance, supplying adaptive connectors can make it easier to build and adapt structures using local materials, thus supporting ad hoc improvements.

The bamboo lashing connection techniques are used for our phase one example, a lightweight PVC coated tension membrane fabric structure. The design employs a double saddle-shaped "hypar" tensioned fabric roof for initial weather protection. The independence of the saddle-shaped canopy from the lower walls enables a 2-fly canopy and eases its replacement with a more traditional thatched roof system. The structural members in the wall could be made of available bamboo, wood, metal tubes or PVC pipes. The lower walls are covered with a porous fabric skin forming a membrane-covered frame structure. A second opaque waterproof surface has been added to the walls for privacy, all made from tensioned membrane fabric products (Serge-Ferrari, 2021). Zipper framed door and window openings are added, not atypical to small fabric structures.

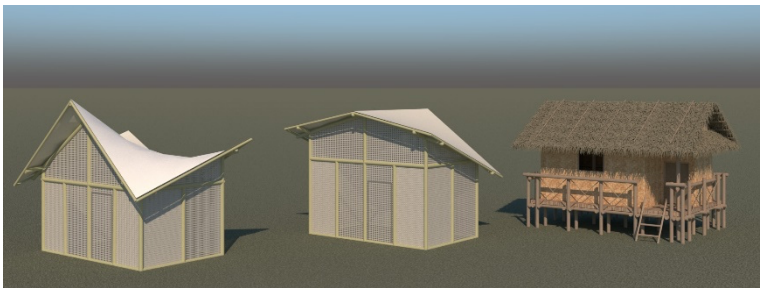

Figure 2 Saddle fabric structures could be built more rapidly than the regional bamboo structure.

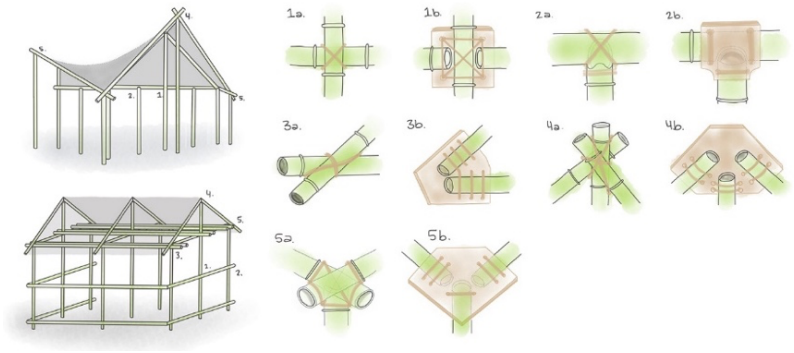

Figure 3 Structural forces and joint conditions were analyzed to determine the best possible choice of the varied options for lashing and bamboo fabricated gusset plates after seminar work by Golczewski and Chen .

Each type of connection joint was further examined for constructability and applicability to each joint configuration, resulting in the following table of connection alternatives.

Table 1. Joint Types for Tension Membrane Fabric Structure and Thatched Roof Structure

Joint	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Type	Lash	Gusset	Lash	Gusset	Lash	Gusset	Lash	Gusset	Lash	Gusset
Members	2	2	2	2	3	3	3	3	3	3

Both lashing and gusset plate connections minimize the number of foreign materials needed and maximize resident control and the opportunity to use local materials. By reducing the number of unique joint configurations during each phase, and by provided two technique alternatives for each configuration, the structure maintains a flexibility and a constructability that limits constraints on structural adaptations and adjustments. Each joint type can be reinforced over time through improved techniques and materials.

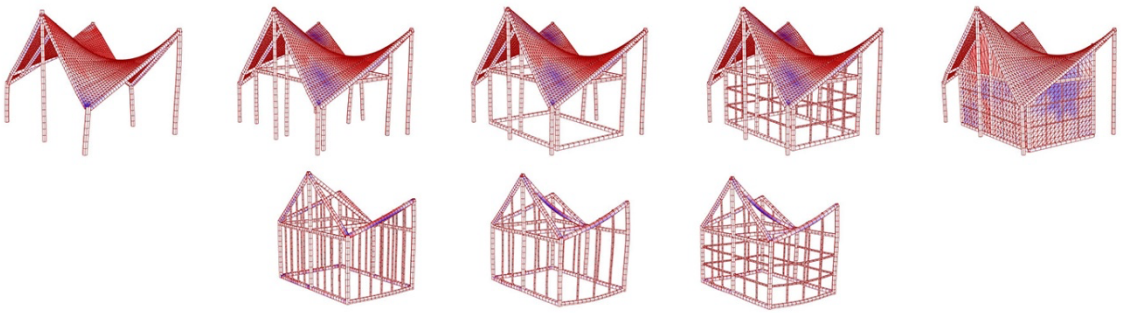

Figure 4 Saddle canopy provides protection for framing shelter enclosures. Karamba3D simulation enabled speculation on secondary framing with available members (below) and types of adaptive joints needed.

For our Thailand refugee camp example, we use locally well-established bamboo lashing techniques to support do-it-yourself building. We have considered how gusset plates, simple jigs and lashing may make it easier for novices to construct the joints to be secure and the structures square. (Chen & Golczewski, 2020). We focused on using low-tech lashing and guiding gusset plates for re-usability at low-cost. These techniques are engaged from the first rapid shelter phase and are adapted for longer term maintenance and small building additions that emerge over the next two phases of stabilization and longer-term settlement.

Thus, in the first phase, our approach aims to minimize the number of foreign materials needed and maximize resident control and the opportunity to use local materials.

3 PHASE 2: AD HOC ADJUSTMENTS AND TRANSITIONAL SYSTEMS

Refugees typically work to make emergency relief tents more habitable through methods such as raising headroom to increase space, adding covered outdoor space, or increasing thermal comfort through draft reduction or insulation (Ashmore 2004). We explored how this tension membrane fabric unit can be aggregated for the development of neighbor clusters with shared outdoor space. We also examined how this basic unit might be expanded with overhangs, water collection points and roomy extensions. When clustered, the saddle consolidates water collection and drainage. We adapted these rapid shelters to use lashing and gusset plates fashioned out of bamboo.

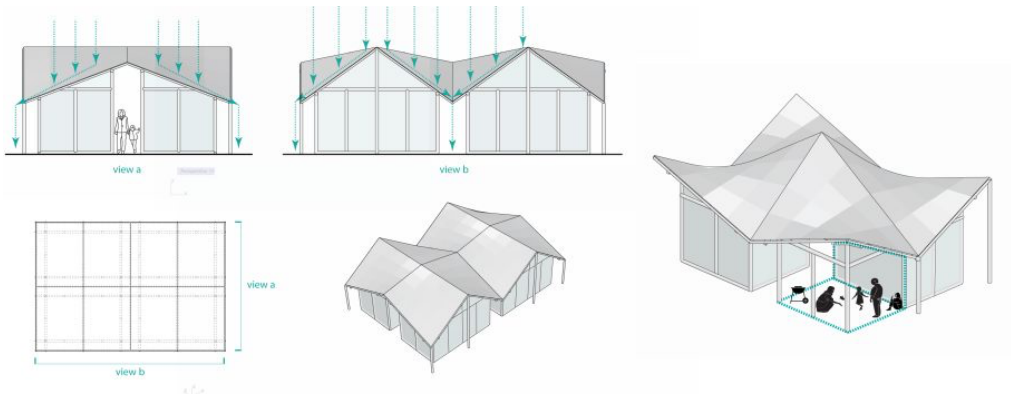

Figure 5 Clusters accommodate water drainage and pedestrian circulation.

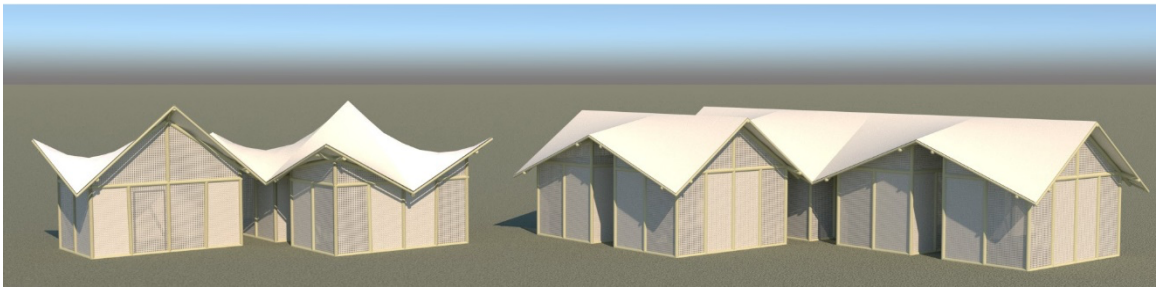

Figure 6 Flexible clustering variations of the units were tested.

In this intermediate phase, the initial fabric structure needs to be prepared in a way that it morphs more coherently to the local building type (thatched roof and bamboo structure) during transition to phase three.



Figure 7 Transitioning Saddle Shaped Roof Structure adjacent to Thatched Roof Bamboo Structure.

We have also considered ways in which the original deployed shelter and emergent locally developed structure may need to exist concurrently. By reviewing building patterns observed at the case study location in Thailand, we have imagined how the second and third phase structures could emerge side by side with the initial rapidly deployed structure.

Our goal is to reinforce how construction guides and connector elements make rapid shelters possible with a maximum use of local materials. Furthermore, we would like to facilitate re-use of these elements to various types of late phase structures – expansions that support more community activities. Ideally at the end of their inhabitation, the rapid shelters could be deconstructed to provide elements and connectors for more permanent housing or community buildings within the same settlement.



Figure 8 Hybrid site scenario, juxtaposition of different phase1, 2 and 3 type units.

In order for the inhabitants to sustain these shelters, they need to mirror local techniques that combine site appropriate architectural & structural practices. The building system also needs to suit the setting and must evolve with the changing social demands of a developing encampment. While recognizing that settlement outcomes are dependent on specific circumstances and actions,

we see value in an approach that could applied in many circumstances by substituting the different materials for building a basic shelter.

4 PHASE 3: PERMANENT OR LONG-TERM PHASE

Because most refugee settlements are used for many years beyond their planned life, residents begin to make them more livable. When the need to personalize a home expands into the public realm, this can conflict with settlement rules setup to maintain order (Albadra 2017). A strategy to encourage resident agency is to include open space both for sharing uses and shelter unit expansion. Rather than filling every space in a grid with a domicile, settlements could be planned so that units expand reasonably, incorporating potential elements which contribute to community cohesion, such as overhangs and use of interstitial spaces. Periodic spaces that are open or sheltered from rain and sun can encourage group interaction, and later be filled with shared amenities.

Adaptable joints (lashing, clamps, gussets) can be re-fashioned with minimal loss of strength as a structure changes & adapts to community development. Such hybridization allows for the Phase 1 structure to act as a temporary framework/shoring within which a later structure is built. Since Phase 1 is an imported, safe solution, it provides an initial protected space. As Phase 2-3 construction components are added they may replace the Phase 1 construction components that could be reused elsewhere. For example, as a thatched roof system is put into place, the original tension membrane fabric roof could be reassembled for a new temporary structure.

The phase 3 structural analysis assumes that this structure will contain the fewest imported elements and will house the community for the longest period of time. Basic wind and seismic calculations are performed as a proof of concept for the minimum Phase 3 scenario. The structural reinforcement techniques which are illustrated (joint upgrades over traditional structures, cross-bracing, doubling up members) can be combined to create a structure with a higher safety rating.

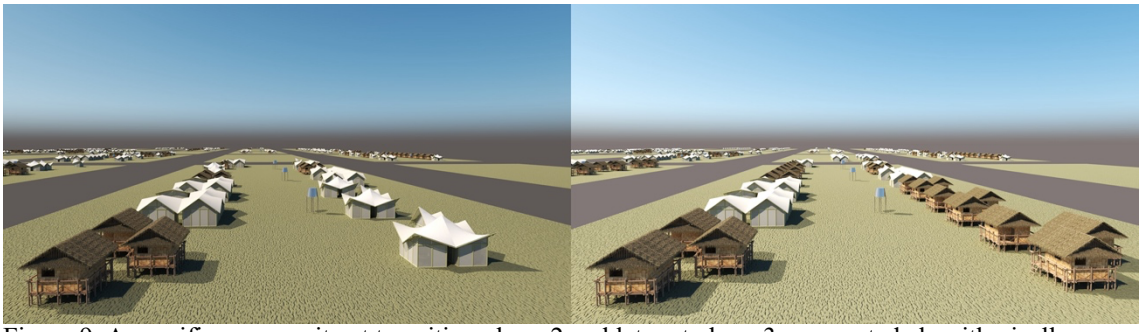

Figure 9 A specific community at transition phase 2 and later at phase 3, generated algorithmically.

5 SETTLEMENT BLOCK AND SITE PATTERNS

Structural techniques (joint & bracing techniques) can be shared throughout the community as refugees use their own agency to make improvements. To support residents' ad hoc home improvement and community activity, space must be planned from the start of the settlement site design, along with consideration of access, privacy, and safety. For example, Ennead Lab suggests initially building shelter only on three-quarters of a site so that the remaining quarter can be developed with a higher housing standard (Weinreich and Montgomery 2019). Within UNHCR layouts, a similar strategy of leaving an occasional site empty allows residents allocate the space as they wish, such as for WASH (water, sanitation, and hygiene), food, power, and medical clinics.

For example, figure 10 shows void spaces left open to serve to accommodate larger settlement level services and green community spaces for a UNCHR Block of 16 Communities of 16 family units each. Rather than a standard densely packed UNHCR 4 x 4 grid of 16 communities, we instead place our units within a 5 x 5 grid that incorporates 9 large scale open spaces. We use a random number algorithm to generate three different scenarios over time. In our mockups, we

have explored aggregates of original phase 1 rapid shelters that later become mixed with phase 2 transitional structures and that in turn are mixed with phase 3 more permanent structures.

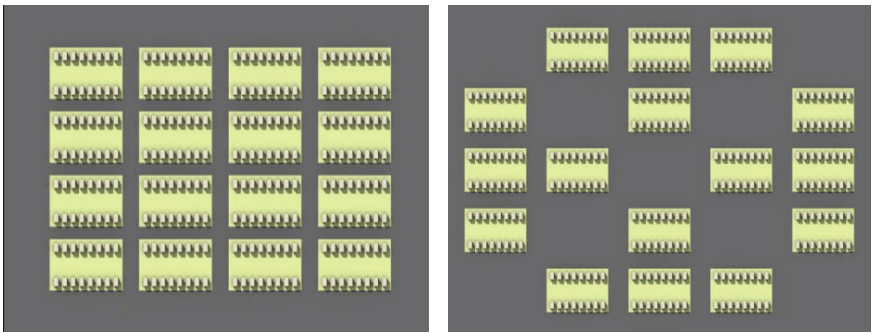

Figure 10 Changing a typical 4 x 4 settlement layout grid to a 5 x 5 grid creates voids for future community development space.

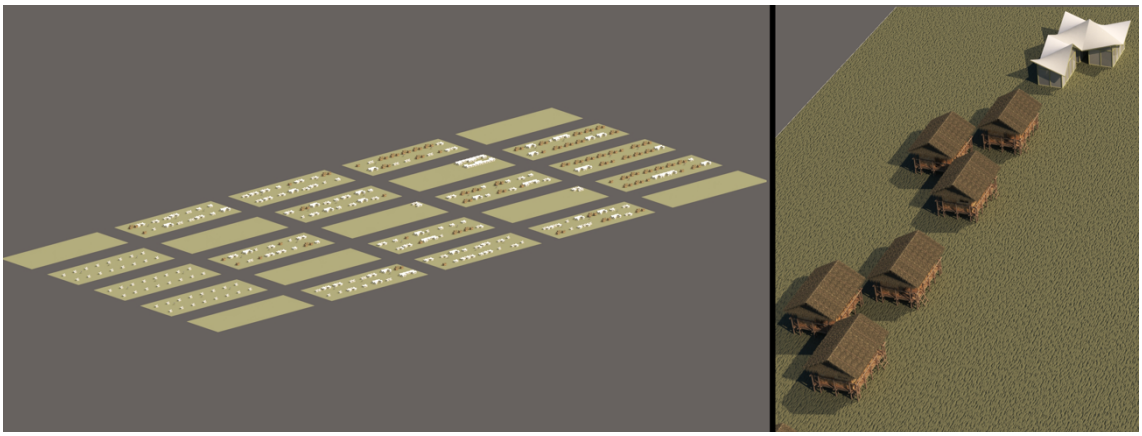

Figure 11 A 3D view shows transitional development left to right from basic fabric shelters to permanent shelters (as visualized on right).

Settlement hygiene options illustrate how adaptive systems are appropriate for refugee settlements. The initial layout anticipates future WASH stations along safe circulation and shelters that relocate for drainage. (Apart from adding open areas for green spaces or rainwater absorption, these are not shown figures 10 and 11.) Emergency WASH solutions typically employ containers of water and latrines or chemical toilets due to cost and urgency. While piped infrastructure might seem preferable for long term situations, a container-based WASH system with remote or proximate composting can be safer, flexible, and thus more durable (Russel 2021). The Container Sanitation Alliance publishes a removable container composting system with a global track record (Russel and Montgomery 2020). It avoids exposed untreated sludge that is subject to contamination in an incomplete built-in system and reduces the risk of local host country opposition to a permanent infrastructure. In locations where flush toilets and water infrastructure are less common, container systems are more readily accepted (Comazzi 2021). Due to many location-dependent uncertainties, new settlements are best served by systems that adapt to new constraints.

6. CONCLUSIONS

This design exercise for Thailand sheds light on building systems principles that support residents:

6.1. Incorporate local building skills and materials: By integrating lashing of bamboo, our system utilizes regional expertise and allows use of bamboo of different dimensions. While political, economic, climatic and social circumstances determine how much local or imported materials are used, location specific approaches have more cultural acceptance and be more easily sustained.

6.2.Provide guides and training to proliferate and sustain the system: Gusset plates simplify creating a strong joint with members at the preferred angles. Visual guides quickly convey

emergency shelter construction concepts across cultural barriers (Ashmore 2004). Polak (2008) describes how marketing was the big challenge in distributing a low-cost irrigation. He used a mom-and-pop shop network to sell irrigation devices, training a platoon of installers, making a movie to spread the word, bringing the movie to small villages.)

6.3.Design interchangeable or substitutable parts to facilitate on-going maintenance: Imported designs become unusable since they often require specialized components or technology to repair.

6.4.Plan with water in mind: At both the shelter and site design scale, the settlement must be designed with attention to water flow to maximize water collection, reduce problematic waste streams and reduce chance of flooding.

6.5.Plan space for expansion and community development: Shelter spacing reduces fire spread (Ashmore 2004). Open space provides opportunities for better resident interaction and cohesion.

6.6.Use a waste-as-resource approach: Refugee camp closures provide an opportunity for recycling and reuse of construction materials, as shown in a study funded by the Border Consortium (2016). Dismantling and waste management pose their own distinct strategies and probabilistic risks. Considering the elements as part of an on-going circular economy provides forces a long-term perspective for design.

We offer these adaptive strategies as a way to address uncertainty and scarcity of resources with the recognition that emergency settlements emerge within quickly evolving circumstances, where choices are contingent on the situation. More investment in permanent building materials may be preferred, but imperfect best-case scenarios can provide the basis for design decision-making using supplies that range from simple rope and tarp to highly manufactured products.

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