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A partially pre-fabricated transitional shelter framework: analysis & design

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Abstract

Displacement caused by political and environmental crises is intensifying. With the rise better adapted and better scalable shelter responses are needed. Existing transitional shelter responses for displaced and disaster affected populations have issues with construction, durability and climate adaptation. Remote production puts a strain on transportation capacity and does not benefit local economies. This thesis analyses existing shelter responses according to defined criteria. Based on the found strengths and shortcomings a manifest for an improved transitional shelter is created. A novel transitional shelter design based on the manifest is presented. The main feature is the combination of a climate neutral, pre-fabricated structural timber frame covered with a corrugated galvanised iron roof and climate adapted walls created on-site using local materials. Pre-fabrication steps and low machinery requirements allow a local preproduction of the frame resulting in a shelter kit which is transported to the site. This design incorporates existing emergency shelters like tents allowing for a gradual upgrade process. The walls are constructed over time by the inhabitants according to the climate using local materials. This design is tested by adapting it to the displacement situations in Jordan, Bangladesh and Ukraine, all in different climatic zones. Adapting the shelter design to different climates proved the idea that the main structure should be separated from the hull. The resulting price per square meter was comparable to existing shelter responses. An extension concept allows the shelter to grow and shrink according to changed requirements. It is fully disassembleable to allow a repatriation and increase the acceptance of the local population. The proposed shelter design can make future shelter responses more climate adapted, include the local community and inhabitants better and provide structurally safer shelters for the crisis affected.

Zusammenfassung

Vertreibungen ausgelöst durch politische und ökologische Krisen nehmen kontinuierlich zu. Bedingt durch diese Zunahme sind besser angepasste und skalierbare Unterkünfte notwendig. Bestehende Übergangsunterkünfte für Vertriebene weisen Defizite in den Bereichen Konstruktion, Statik, Lebensdauer und Klima Anpassungsfähigkeit auf. Vorfertigung im Ausland blockiert Transportkapizäten und bringt keinen Mehrwert für die lokale Wirtschaft. Diese Arbeit analysiert bestehende Unterkunft-Designs basierend auf einem Kriterienkatalog. Basierend auf den gefunden Stärken und Schwächen wird ein Manifest für eine verbesserte Übergangsunterkunft erstellt. Aufbauend auf diesem Manifest wird ein neues Design bestehend aus einem klimaneutralen, vorgefertigtem Holzskelett mit einem Wellblechdach vorgestellt. Die Wände werden angepasst an das Klima aus lokalem Material direkt vor Ort von den Bewohnern hergestellt. Mit einfachen Vorfertigungstechniken kann das Holzskelett im Land produziert werden und als Kit auf den Bauplatz transportiert werden. Das Design verwendet Materialien bestehender Notunterkünfte weiter und integriert sich dadurch in den Lebenszyklus. Zur Validierung wird das generische Design für drei konkrete Krisen in unterschiedlichen Klimazonen in Jordanien, Bangladesch und der Ukraine angepasst. Ein Erweiterungskonzept erlaubt es, die Unterkunft basierend auf den Anforderungen zu vergrößern und zu verkleinern. Durch die komplette Zerlegbarkeit kann die Unterkunft nach Krisenende durch die Bewohner rückgeführt werden was die Temporalität unterstreicht und die Akzeptanz durch die lokale Bevölkerung erhöht. Mit dem vorgestellten Design können zukünftige Übergangsunterkünfte besser an das lokale Klima angepasst, die lokale Gemeinschaft besser eingebunden und die Statik verbessert werden.

Acknowledgement

For this master thesis I was given the chance to work on the very relevant topic of transitional housing for displaced persons. During the research phase for this thesis I was able to greatly deepen my knowledge about the institutions working day-by-day to improve the life of people in need.

This work would not have been possible without the inspiration I got from the team around the Vivihouse project. Without the technical and moral support from my friends Nerea and Ines the structure of this design would still be way undersized. I also want to thank all my other friends who provided valuable feedback and input throughout the extended period or writing this thesis. For the thorough support helping to improving the structure of this work and also helping to build a 1:1 prototype detail I want to express my great gratitude to my family and especially to my brother and my grandfather. I want to especially thank my supervisor Andrea Rieger-Jandl for her patience and well founded feedback and input throughout the process of creating this work.

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Contents

Chapter 1

Introduction

The refugee crisis topic is continuously present in the media landscape for the last decade. With more than 100 millions forced to flee in 2022 the number doubled in the last 10 years.[1] Most prominently in the media coverage are the white UNHCR tents commonly associated with displacement and war. The pictures of the tents well beyond their lifespan, deployed in harsh climates rose the question why the most visible shelter response is still tent based. Other visible shelter responses commonly include non-local materials like plastic and aluminium imported prefabricated from abroad.

First the question is asked what criteria are sufficient to analyse existing shelter responses. Then based on the defined criteria the strength and shortcomings of existing shelter responses are analyzed. Finally the research question of how a novel transitional partly prefabricated shelter design with profound structural stability and climate adaptiveness can improve current disaster responses is tackled. The hypothesis is that a new transitional design can improve structural stability and be more climate adaptive with a compareable price.

This work is structured as follows:

Part I gives an overview of the used terminology with chapter 2 starting with the relevant definitions. Also the different phases of disasters and their timing are discussed. Each phase triggers different disaster responses based on the different settlement options. The institutions in the shelter sector, their standards and key publications are introduced to create the basis for the analysis. Basics about camp planning and the common camp infrastructure are given to sum up the existing standards. To understand the different requirements of different climates and earthquake risks a short excursus on both topics is taken.

After the theoretic foundation existing shelter projects responding to various disasters are analyzed in chapter 3. Because the field is very broad the projects were filtered according to defined criteria. Also the key characterizations for a shelter are defined to further analyse the projects accordingly. The projects were not limited to transitional designs because commonly the shelter needs to transform from an emergency to transitional state.

[1] United Nations High Commissioner for Refugees. *Global Trends*. UNHCR. URL: `https://www.unhcr.org/globaltrends.html` (visited on 01/02/2023).

Also incorporating and reusing existing structures from previous phases is a key aspect. The designs are grouped according to their response phase for better overview.

After analysing the projects the commonly identified issues are grouped into a manifest in chapter 4. This manifest tries to create rules for each identified problem category to reduce the negative effects of them.

Part II shows the implementation of the defined manifest into a design. Chapter 5 shows the key aspects for a novel transitional shelter design introduced in this thesis. Especially points like life-cycle and integration into preexisting emergency architecture are discussed in chapter 6. Also details on the construction, sanitary infrastructure, possible layouts, configurations, production and logistics including a price estimate are given in chapter 7.

After detailing the generic concept it is applied to specific refugee situations in Part III. The first showcase in chapter 8 is about the refugee situation in Jordan hosting Syrian refugees. The current refugee situation and local building techniques are analyzed. Also the climate at the chosen location in the refugee camp Za'atari in Jordan is described. Lastly the local design is visualized and key aspects specific to the local climate and building techniques are described.

Chapter 9 chooses the Rohingya refugee crisis in Myanmar to show the adapted design for this all year hot and humid climate and cultural sphere. As location the Kutupalong Camp in Bangladesh is used as it is one of the major places housing refugees from Myanmar. The state of infrastructure and lack of governmental intervention makes the situation different to the camp in Jordan. Local adaptations to the design and considerations for ventilation are given.

To cover another climate, different situation and because of the topicality as of this writing the conflict in Ukraine is described in chapter 10. The situation is different because it is mostly about internally displaced persons and damaged structures in a climate which has harsh winters. Infrastructure and supplies are still mainly available but the scale of the destruction strains the local construction resources.

At the end in chapter 11 the novel design of this work is summarized and evaluated according to the aspects used for the references in chapter 3. Also weaknesses identified on the way, possible solutions and possible future work are given.

Part I

Theory

Chapter 2

Definitions

2.1 Displacement

Displacement is described according to the Cambridge Dictionary as *"the situation in which people are forced to leave the place where they normally live"*.[1]

2.1.1 Causes

Displacement can be caused by various reasons. For this work two main groups of displacement causes can be distinguished:

- Natural disasters like earthquakes, storms or floods. The affected populations in this group are referred to as survivors. Natural disasters more commonly lead to displacement within a country referred to as internal displacement.[2]
- Political or military conflicts resulting in forced displacement can either lead to internally displaced persons if the affected persons stay within their state territory or to refugees when people leave their home country.

Both types can be related or can lead to each other. Distinguishing between those two groups is necessary because organisations dealing with the affected populations and related challenges are different.

The third cause for displacement is economical or climate change threatening the livelihood of the affected groups. This form of displacement is a strategic problem and is beyond the scope of this work.

2.1.2 Refugees

Refugees are people displaced outside their country of origin after crossing an international border.

[1] *Displacement*. Cambridge. URL: `https://dictionary.cambridge.org/dictionary/english/displacement` (visited on 06/11/2021).

[2] Tom Corsellis and Antonella Vitale. *Transitional Settlement and Reconstruction after Natural Disasters*. Oxford: Oxfam GB In association with University of Cambridge shelterproject, 2005. 464 pp. ISBN: 978-0-85598-534-9, p.68.

More precisely the term refugee was regulated in the UN Convention 1951 defining it as: *"As a result of events occurring before 1 January 1951 and owing to well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion, is outside the country of his nationality and is unable or, owing to such fear, is unwilling to avail himself of the protection of that country; or who, not having a nationality and being outside the country of his former habitual residence as a result of such events, is unable or, owing to such fear, is unwilling to return to it"*.[3]

The original UN convention limited the scope to events occurring in Europe targeting the massive refugee crisis in Europe after World War 2.[4] The later UN Convention 1967 removed the time and geographical limitation creating a universal binding definition.[5]

Aside from the definition the other articles of the UN Convention cover important duties and rights of refugees. There is a general obligation to conform to the law and regulations of the country of presence.[6] The discrimination of refugees based on race, religion or country of origin is forbidden.[7] Article 4 handles the freedom of religion. The right for housing stays very broad *"... as favourable as possible and, in any event, not less favourable than that accorded to aliens generally in the same circumstances."*[8] The UN Convention recommends to grant *"... the right to choose their place of residence (and) to move freely within its territory"*.[9] It forbids the expulsion or refoulement to territories where their life or freedom is in danger.[10]

The UNHCR Global Report states the number of refugees in 2020 with 20 millions.[11] The conflict in Ukraine has since added almost 5 million refugees according to UNHCR.[12]

2.1.3 Internally Displaced People (IDP)

The UN defines internally displaced people as *"persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized state border."*[13]

The UNHCR does not have a general or exclusive mandate for internally displaced, in comparison to refugees, returnees, asylum seekers and stateless persons. But UNHCR is authorized by the UN General Assembly to assist in specific projects.[14]

The major difference to the above mentioned refugees is staying inside of the state border. IDP are not entitled to any special rights based on their status.

[3] UNHCR. *Convention Relating to the Status of Refugees.* 1950, Article 1. A (2).
[4] Ibid., Article 1. B (1).
[5] UNHCR. *Convention and Protocol Relating to the Status of Refugees.* 1967.
[6] UNHCR, *Convention Relating to the Status of Refugees*, Article 2.
[7] Ibid., Article 3.
[8] Ibid., Article 21.
[9] Ibid., Article 26.
[10] Ibid., Article 32, 33.
[11] *UNHCR Global Report 2020.* 2020, p.10.
[12] *Ukraine Refugee Situation.* 3rd Jan. 2023. URL: https://data.unhcr.org/en/situations/ukraine (visited on 07/01/2023).
[13] *UN Guiding Principles on Internal Displacement.* 1998.
[14] *UNHCR Emergency Handbook.* 2020, p.656.

The UNHCR Global Report states the number of internally displaced people in 2020 with 48 millions.[15]

2.1.4 Returnees

Returnees are people who are returning voluntarily to their original country or area after a displacement situation. This can happen after days, months or years, depending on the cause and the current situation. According to the UN the return has to be *"voluntary, and in safety and dignity."*[16]

UNHCR was requested by the UN General Assembly 1984 for the first time to handle a returnee situation. The particular resolution was concerning the large number of returnees returning back to Chad after a war caused displacement.[17]

The UNHCR Global Report states the number of returnees (both IDP and refugees) in 2020 with 3.4 millions. An outstanding majority of those 3.4 millions were internally displaced returning.[18]

2.1.5 Non Displaced People / Survivors

If people affected by disaster can stay in the proximity of their houses they are considered non displaced. Non displaced people are commonly affected by natural disasters leaving them with damaged or destroyed houses. According to the International Red Cross non displaced people affected by natural disasters should be called survivors or disaster affected rather than victim because the later has a rather passive connotation.[19] Often social group based coping mechanisms are still working, resulting in more support opportunities for survivors in comparison to refugees. As they have not crossed any international borders they don't have any specific rights from UN refugee conventions.

As natural disasters often do not trigger international responses accurate numbers are hard to find. The International Federation of Red Cross and Red Crescent Societies (IFRC) assisted 12 million people affected by disasters in 2020. Actual numbers are expected to be much higher.[20]

2.1.6 Onset

Displacement can happen at various speeds from fast, sudden displacement (fast onset) to slow, steady displacement (slow onset).

This work will focus on fast, sudden displacement because the other topics would go beyond the scope. Fast onsets commonly overwhelm the local government requiring a support from international organisations. To handle fast onset situations additional tools

[15] *UNHCR Global Report 2020*, p.10.
[16] Ibid., p.14.
[17] *General Assembly Resolution 39/106*. UN, 1984.
[18] *UNHCR Global Report 2020*, p.8.
[19] Ian Davis, Frederick Krimgold and Paul Thompson. *Shelter After Disaster*. 2nd ed. Genève (Suisse): International federation of red cross and red crescent societies, 2015, p.12.
[20] *IFRC Annual Report 2020*. 2021, p.10.

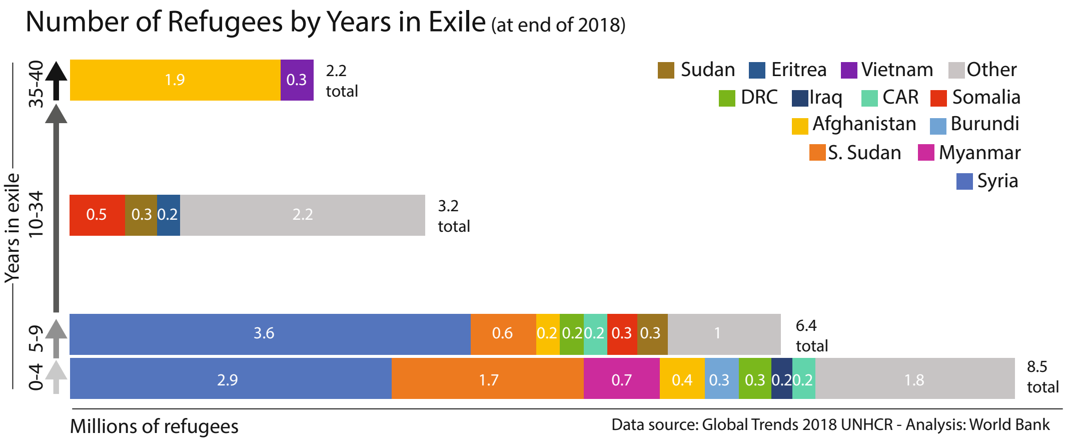

Figure 2.1: This graphic shows that the average displacement duration for refugees can vary quite a lot depending on the area and conflict. Many displacements only last a short time, while others last for many years. Figure by Devictor based on Global Trends 2018, UNHCR

like transit centers are used in conjunction with camp based responses.[21]

Transit centres are *"used as temporary shelters for new arrivals and to provide short-term temporary accommodation for displaced populations pending transfer to a more suitable, safe and longer term settlement."*[22]

Natural disasters and political conflicts usually trigger fast and sudden displacements whereas global climate change leads to steady and slow displacement. It must be noted that climate change favours natural disasters also driving displacement.

2.1.7 Duration

The displacement duration refers to the timespan from the initial displacement event until the affected persons reach a safe place, where they can stay permanently. This duration can vary from days to many years depending on the cause, severity and political situation.

While some publications quote an average of 17 years of displacement the situation is more versatile and heavily depends on the region and conflict. Displacement times range from 35 to 50 years for many Afghan refugees to zero to four years for refugees from South Sudan. Figure 2.1 analyses the different durations based on country of origin. An analysis of the World Bank states that *"the median has fluctuated widely since the end of the Cold War, in 1991, between 4 and 14 years. By contrast, the mean duration stands at 10.3 years, and has been relatively stable since the late 1990s, between 10 and 15 years."*[23]

[21] Tom Corsellis and Antonella Vitale. *Transitional Settlement Displaced Populations.* Oxfam - shelterproject, 2014. 240 pp., p.44.

[22] *UNHCR Emergency Handbook*, p.533.

[23] Xavier Devictor. *2019 Update: How Long Do Refugees Stay in Exile? To Find out, Beware of Averages.* Development for Peace. 9th Dec. 2019. URL: https://blogs.worldbank.org/dev4peace/2019-update-how-long-do-refugees-stay-exile-find-out-beware-averages (visited on 19/01/2022).

As example for a refugee camp which existed for many years the refugee camps of Western Sahara created in 1975 can be mentioned. The initial camp Rabouni in Algeria was created in response to the military invasion of Marocco in Western Sahara and exists since then. The camp transited to a semi permanent space over the years but still kept its status as refugee camp.[24]

The possibly oldest record for a still existing refugee camp which is still in a limbo state is Camp Cooper in West Bengal, India. The camp was created in 1947 after the separation of India and Pakistan and filled with Hindu migrants from Pakistan. Citizenship of the inhabitants stayed an open issue for decades.[25]

Natural disasters like earthquakes can trigger considerably shorter displacement durations. After the 6.6 magnitude earthquake in Amatrice, Italy on 24th August, 2016 more than 15 000 people were housed in temporal shelters provided by the government for the first night. Around 1000 of them stayed in temporal shelters at least till the second big earthquake in October of the same year resulting in a displacement period of more than two months.[26]

2.2 Disaster phases

The displacement starts with the disaster event which requires imminent relocation for the affected persons. The specific displacement phases are named differently in literature mostly depending on its focus on natural disasters or political causes.[27]

The seven phases of operations for displaced groups according to Corsellis and Vitale are:[28]

1. Preparedness phase happens before an emergency is foreseen. It involves establishing early warning systems, consolidating international law, creating stockpiles of shelter material and awareness campaigns.

2. Contingency phase is still before the emergency occurs, but when a future emergency can be foreseen with high probability. In this phase site planning and assessment of existing infrastructure happens.

3. Transit is the main phase after the emergency occurred, where the displaced people are on the move to a safe location. This phase allows organisations to identify and control the scale, speed and location of the influx using transition centers on the way.

4. Emergency is the phase in which a large number of people are displaced and move to a transit center in another country or region. See section 2.2.1 for details.

[24] Manuel Herz. *From Camp to City: Refugee Camps of the Western Sahara*. 1st ed. Zürich: Lars Müller, 30th Sept. 2012. 512 pp. ISBN: 978-3-03778-291-0, p. 89.

[25] Tim Finch. *"In Limbo in World's Oldest Refugee Camps: Where 10 Million People Can Spend Years, or Even Decades"*. In: *Index on Censorship* 44.1 (1st Mar. 2015), pp. 53–56. ISSN: 0306-4220.

[26] Angela Dewan and Lorenzo D'Agostino. *"Italy Earthquake: More than 15,000 People in Shelters"*. In: *CNN* (31st Oct. 2016). URL: `https://edition.cnn.com/2016/10/31/europe/italy-earthquake/index.html` (visited on 20/01/2022).

[27] Tom Corsellis. *Transitional Shelter Guidelines*. Shelter Center, 2012. 242 pp., p.3; Corsellis and Vitale, *Transitional Settlement Displaced Populations*, p. 40.

[28] Corsellis and Vitale, *Transitional Settlement Displaced Populations*, p.40.

5. Care and maintenance is the timespan until all affected have reached a transitional or even durable settlement solution. See section 2.2.2 for details.

6. Durable solution is when the displacement has ended and a permanent settlement option has been achieved. See section 2.2.3 for details.

7. Exit strategy is about to transfer skills, recover equipment and returning used facilities after a durable solution has been reached for all affected.

For non displaced groups, for example after natural disasters like earthquakes, the transit phase does not exist or is very limited. Close proximity to the existing but maybe damaged structures is an important requirement for survivors.

2.2.1 Emergency phase

The emergency phase is defined as the period where *"significant numbers of people are being displaced, with the result that a country or region is receiving a significant influx of displaced people"*. The end of the emergency phase marks the point where most basic accommodation, water supply and sanitation are available.[29]

For survivors of natural disasters the response during these first weeks focuses mainly on non-food items (plastic sheeting, basic building materials, tools).[30]

For displaced people the focus is on food and basic needs.[31] Highest on the list of priorities for non-food items during the emergency phase is personal protection equipment like clothes and blankets. Then the priority shifts to basic shelters and further to mattresses for improved insulation and comfort during the night. Only after this wind proving and stoves get important.[32]

From a governing perspective hazard-mapping, micro-planning and a census should be undertaken within the first three months. Land acquisition for infrastructure and resettlement from the host country or from private owners should happen in this phase between 3 and 12 months after the disasters.[33]

Emergency phase architecture is mostly tents as existing stockpiles of international, national or governmental agencies make them rapidly available. Also the logistics for tents is easier to handle compared to more sophisticated structures. The common lifespan of tents is less than two years, making it infeasible for even midterm solutions.[34] See chapter 3 for details on existing emergency and transitional shelter responses.

2.2.2 Temporary shelter phase

The phase following the emergency phase is the temporary shelter phase. Commonly also referred to as the care and maintenance phase or recovery phase.[35] This phase contains the upgrading of existing low quality basic accommodations to more durable solutions.

[29] Corsellis and Vitale, *Transitional Settlement Displaced Populations*, p.44.
[30] Ibid., p.44.
[31] Ibid., p.44.
[32] Joseph Ashmore and Tom Corsellis. *Selecting NFIs for Shelter.* 2008, p.16.
[33] Corsellis and Vitale, *Transitional Settlement*, p.228.
[34] Corsellis, *Transitional Shelter Guidelines*, p.xvii.
[35] Corsellis and Vitale, *Transitional Settlement*, p.228.

From a government perspective land acquisition should be completed in the second year after the disaster. Land rights of illegal residents should be established alongside with land use and spatial plans.

In the temporary shelter phase emergency structures are often replaced or upgraded to transitional shelters. Transitional shelter is described as an *"incremental process which supports the shelter of families affected by conflicts and disasters, as they seek to maintain alternative options for their recovery"*.[36] Corsellis argues that the basics for transitional shelters can be distributed starting with the first response, thus not making it a separate phase. Five characteristics according to him are:[37]

1. Upgradeable into part of a permanent house. As reconstruction takes years, structures should not be simply replaced during the phases but improved over time to finally reach a permanent shelter solution.

2. Reuseable for a different purpose. The transitional shelter could get an alternative function after reconstruction is finished, like a barn or outdoor kitchen.

3. Relocateable from a temporal site to a permanent site. This allows to reduce tensions with the host community as there is a possible exit plan moving the structures to a more permanent place. Relocateable structures are seen much more temporal for the host country and are politically easier to implement.

4. Resaleable for generating income to aid recovery. Structures should be reuseable to allow the sale of unneeded materials after the reconstruction.

5. Recycleable for reconstruction. While the affected people live in the transitional shelter the reconstruction of a permanent structure is ongoing. Tarpaulin used for emergency tents can be used to cover openings of the upgraded structure.

2.2.3 Permanent phase

The last phase is the permanent phase (or durable solution phase) which, according to the UNHCR 10-Point Plan in Action, consists of the following four possible options:[38]

- Repatriation or return to the country or area of origin if it is possible because of the changed political or military situation. Depending on the time frame a repatriation to the same area offers the possibility to reuse the old structures. There might be external support needed to repair and improve the old dwellings.

- Establishment in a new region in the country of origin. Repatriation to a different area requires a start from scratch as only non permanent belongings can be taken from the transitional home. The process is often monitored and supported by various agencies like UNHCR.

- Local integration in the host country. Usually this involves acquisition of a national passport in the country where the affected people fled to. The legal framework for local integration is given with the 1951 UN declaration mentioned above. The

[36] Corsellis, *Transitional Shelter Guidelines*, p.2.
[37] Ibid., p.15.
[38] UNHCR. *The 10-Point Plan in Action, 2016 Update, Chapter 7: Solutions for Refugees.* 2016, p 183ff.

UNHCR document states that the local integration is a complex and gradual process. Special attention to support building sustainable livelihood options must be given.

- Relocation or resettlement from the current transitional place to a safe permanent location in a third country. This is a considerable option for groups without integration or repatriation chances. It allows for a better distribution of displaced people across countries. Resettlement is especially relevant if the host country can not provide protection for the displaced.

The last and least preferred option is that the affected people stay in the transitional place which becomes their new permanent place. This option comes without getting voting rights or passports. This option is least preferred as it is not considered a permanent comprehensive solution according to the UN document. If unavoidable, at least all affected should have access to land and housing and the spatial plans should reduce the affects of possible future disasters.

2.3 Settlement options

Settlement options can greatly vary in density and the degree of independence of the inhabitants. The options can be primarily grouped into options for displaced populations and for non displaced populations.

Displaced populations don't have access to their previous homes anymore and are in need for new shelters. Providing shelter for a huge amount of people can be challenging. Different classifications with their implications and also the specific options are discussed below.

Non displaced populations can stay on-site of their previous housing but commonly their homes is damaged and partly or fully inhabitable. Different options like retrofitting, repairing, rebuilding or relocating exist and are discussed.

2.3.1 Displaced settlement classifications

The settlement options can be classifications according to state of organisation:[39]

- Self settled options are created and occupied by the affected population on their own without much apriori intervention from organisations. Self settlement can pose challenges to security, to the relation with the local community and to the local resources. Usually moving the residents to planned settlements is preferred by the institutions because of better control of the above mentioned issues. Moving the self settled population to a planned settlement can be unbeneficial if the affected persons already invested time and resources into building shelters or to farm the land.

  Most common problems of self settlement are the lack of resources, the proximity to the conflict area, density problems in comparison to the local structures and ethnic or political problems with the host community. Especially infrastructure poses a huge problem because it needs to be sized appropriately to be useful to the local population after the crisis. This infrastructure also has different requirements than for the local population and needs to be built timely.

[39] Corsellis and Vitale, *Transitional Settlement Displaced Populations*, p.72.

- Planned settlements are created by (international) organisations in close cooperation with the hosting country. Planned settlements are commonly the only supported response by international institutions. The main issues with planned settlements are that livelihood options are very limited. Area for farming and livestock is rare and needs to be shared. Large planned structures require a substantial investment and still often suffer in terms of scalability when the influx increases. Double infrastructure like hospitals and schools are unsustainable in the long term and can not be used by the local population.

Additionally settlement options can be classified according to their spatial layout:[40]

- Dispersed settlements are settlements where affected populations live scattered across a wide area without distinct concentrations.

  Issues with security are common because disperse settlements commonly happen to be close to conflict front lines. Also ethical conflicts between the host and displaced community can be an issue. Logistically it is more difficult to identify the number of people in need and coordination is more difficult especially during the early emergency phase. Infrastructure like streets and water supply are also harder to provide if a much bigger area needs to be covered.

  Advantages are that it is easier to move to safety if hazardous situations persist over a longer timespan. For self sufficiency, access to environmental resources like clean water and cooking fuel is easier because of the reduced number of people. Often close proximity to the old homes is preferred by affected populations because it makes it easier to monitor the situation and property. Smaller structures like dispersed settlements can adapt faster to changing needs and conditions. Dispersed settlements can also be cheaper to accomplish because of a smaller initial investment.[41]

- In grouped settlements affected populations are spatially living close to each other. This can happen in a clustered fashion with multiple places or at one distinct place.

  Camps and transit centers are the most prominent example of grouped settlements. If there is a good preparedness plan, camps can be very effective to save lives. Grouped settlements can be managed very efficiently.

  If the grouped settlements are too close to the conflict line they might pose an easy military target. Issues with exhaustive gathering or usage of natural resources like firewood can lead to local deforestation. Segregation of displaced and local communities can create social tensions and poses a problem for integration efforts. Being self sufficient can be much harder because the keep of livestock or agricultural spaces can be impossible because of the concentrated settlement. This creates a greater dependency on the local government and can also affect local job markets with displaced people trying to earn their living outside of the grouped settlements. Further disadvantages are that densely grouped settlements like transit or collective centres lead to psychosocial problems if occupied for more than a few days. With bigger group settlements also the health risks increase because of density related problems like rats and diseases like cholera. Inheritance of skill can not happen because of

[40] Ibid., p.73f.
[41] Corsellis and Vitale, *Transitional Settlement*, p.89.

broken family connections and loss of the original living patterns. There is a tension potential because of different assistance levels between the affected population and the people living outside of the grouped settlement. Initial capital requirements and bigger infrastructure costs might be challenging and are higher in comparison to dispersed settlements. The reason is that often infrastructure has to be created exclusively for the grouped settlement because of the size needed.

Generally it is advised to aim for dispersed settlement except for a list of reasons including insufficient support from the local government, tensions between displaced and locals, fragile local environment, time criticality or when no sites with local communities are available.[42]

2.3.2 Displaced settlement options

The following definitions are based on Corsellis and Vitale.[43] All the options can be classified according to the above described classification system. Figure 2.2 relates the different shelter options for displaced populations with the disaster phases.

It is important to note that during a crisis multiple options are and should be available to the affected population. Also the most suitable option for individuals can change over time.[44]

Host families are *"sheltering the displaced population within (the) households (of local families), or on land or in properties owned by them"*.[45] Commonly this happens if there are close social connections from the affected to the local population during initial displacement phases. Payment can be either free of charge, money, labour or sharing of goods received from organisations. Host families and the displaced people should be supported both in this model.

Advantages are that this option is immediately available after the displacement event. Existing infrastructure can be used immediately but the capacity should be upgraded over time to support the new requirements. Family coping mechanisms could be continued if families can stay together at the host families place. Livelihood situation of the local and the displaced group can be improved at the same time.

Disadvantages are that the local communal services might not be able to cope with the additional people. Food distribute centers might be far away from the host family. Long durations of stay at host families can lead to tensions and conflicts. Special attention needs to be taken to prevent sexual or financial exploitation of vulnerable groups. The available space often does not meet the minimum requirements for the increased number of people using the house.

Urban self-settlements are all settlements in an urban context. This can be parts unaffected by the disaster or by informally occupying (unclaimed) land or properties.[46]

[42]Corsellis and Vitale, *Transitional Settlement Displaced Populations*, p.71.
[43]Corsellis and Vitale, *Transitional Settlement*, p.93ff.
[44]Isabelle de Muyser-Boucher and Carlo Gherardi. *Shelter after Disaster: Strategies for Transitional Settlement and Reconstruction*. 2010, p.105; Corsellis, *Transitional Shelter Guidelines*, p.41.
[45]Corsellis and Vitale, *Transitional Settlement*, p.264.
[46]Ibid., p.272.

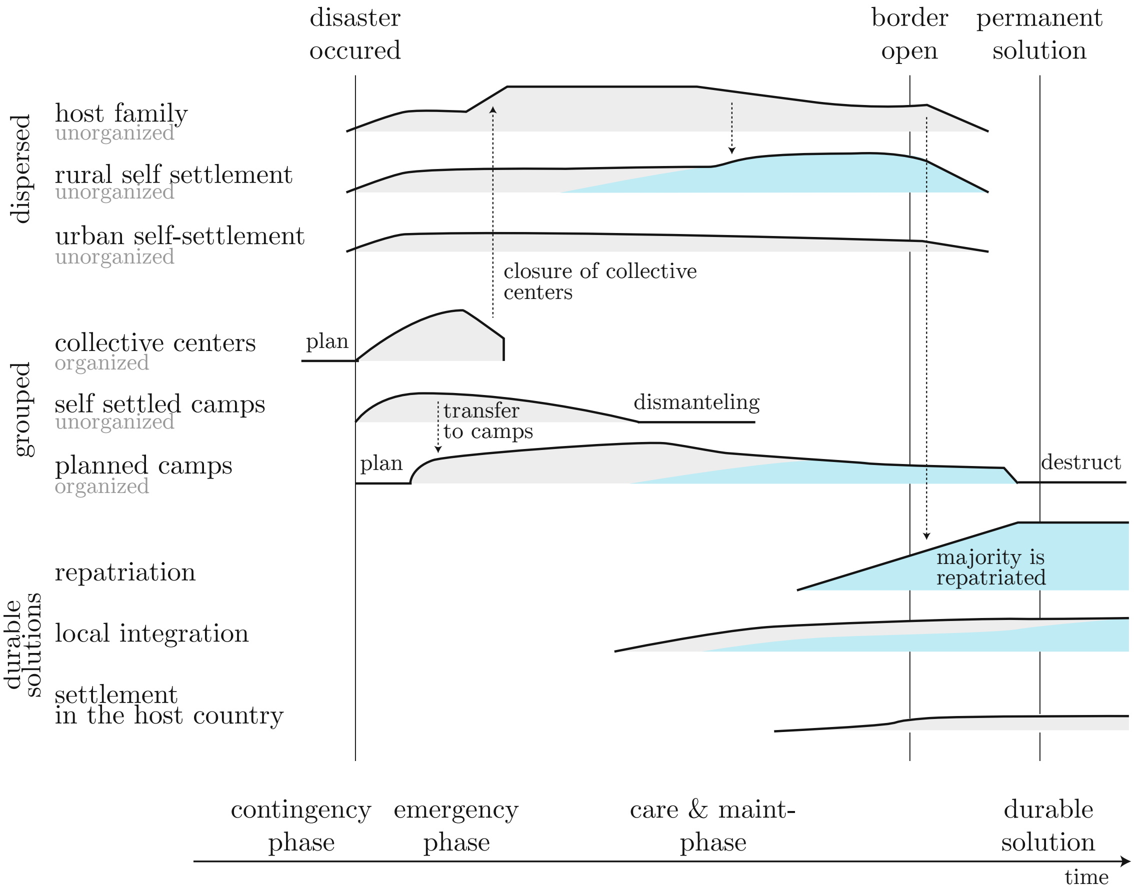

Figure 2.2: This graphic shows settlement options for displaced populations during the different displacement phases. The height indicates the relative number of people choosing the different settlement options. Blue areas are the possible adoption progress of transitional shelters. Adapted from Corsellis and Vitale

The occupation might be tolerated or even legalized by the local government, which in turn takes the property by means of requisition or by providing payment to the owner. Support needs to be given to both the local population and the displaced population.

Advantages are that affected populations previously living in urban areas can continue living in an urban environment. Self-sufficiency and local job opportunities might be better to reach in urban areas. There is a greater integration potential with the local community in urban areas. Usually less effort from organisations is required because displaced persons can be more self sufficient. Upgrades to the local infrastructure can benefit both groups.

Disadvantages include that often informal occupation is not protected by any legal title and thus is not very secure. Competition on the local job market can cause social tension. For organisations it is more challenging to identify the displaced persons in need and to coordinate their response to improve settlements. Often informal settlements are created around the city periphery which could lead to tensions with existing city inhabitants.

Rural self-settlement is *"settle(ment) on rural land that is owned collectively, rather than privately."*[47]

If the property is not owned by the local government it can be made available using nationalization or payments to the owners. It is essential to ensure that the environment can support both the displaced population and the existing local population.

Rural self-settlement can create integration with the local population and usually benefits from a wider family based support network. If farmland is sufficiently available, self sufficiency for the displaced population can be reached. Upgrades of local infrastructure benefits local and displaced population. This form of settlement can also provide a durable solution if the land ownership for the displaced families can be clarified.

Accessing rural settlements is harder for organisations because of longer ways and lower density. Local environmental resources like farmland might degrade with the more intensive use, creating tensions with local populations. For vulnerable groups healthcare is usually not existing or not capable of supporting the increased number of people. A lack of security can lead to sexual or financial exploitation between local and displaced groups in either direction. This can especially happen if the number of displaced people is greater than the local population, commonly leading to issues with local populations and authorities. Another disadvantage is that the displaced beneficiaries might be indistinguishable from combatants or host population when providing relief items.[48]

Collective centers (mass shelters) *"are usually transit facilities located in pre-existing structures."*[49] This existing structures are often buildings providing public services like schools. A plan when and how to return the structure to its original function needs to be developed from the beginning on.

[47] Corsellis and Vitale, *Transitional Settlement*, p.88.
[48] Corsellis, *Transitional Shelter Guidelines*, p.65.
[49] Corsellis and Vitale, *Transitional Settlement*, p.100.

Advantages include easy distribution of food and water. It is also easy to identify vulnerable groups because people are not scattered. Because of the density it is easy to provide services efficiently. Reuse of the structure is guaranteed because there was an original function for it.

Disadvantages are that collective centers create high operational costs. The lack of privacy, sanitation infrastructure and the lack of livelihood options make them only a short term solution. Because of the density it can get into focus of hostile groups. Fire hazards increase with overcrowding and with improper evacuation routes. The original function of the structure needs to be moved to an alternative location for the host population. Degradation can happen quickly if nobody takes responsibility for maintenance. Densely occupied settlements increase the risk for diseases. Often vulnerable groups stay longer than planned in the collective centers because durable solutions for these groups are harder to realize.

Self-settled camps are formed independently from the government or organisations by the displaced population. These grouped settlements often happen before the initial response from organisations or the government. Grouping creates security and increased visibility to receive support from organisations. Commonly communal land close to their original settlement is used for self-settled camps.

Displaced groups can stay close to their original place and social bonds are not broken up. Social cohesion can support hosting of vulnerable groups. Often self-settled camps can be self-sufficient because of the livelihood options available. The infrastructure can be improved to support both displaced and local communities.

If the land is not owned by the state, negotiations about the land-use duration and compensation need to start early. Even if the land is owned by the state, eviction is a constant threat. Livelihoods which depended on the use of the land by the host population can be affected negatively by the new camps. There is no control over environmental damage. If the local infrastructure and services are not capable to support both groups, upgrades are needed, otherwise social tensions are the result.

Organized camps *"are places where displaced populations find accommodation on purpose-built sites, and a full services infrastructure is provided"*.[50] For natural disasters planned camps are hardly necessary and should be considered only as the last option. For refugee situations where affected populations lost all their property they can be a valid option if no other option is available. Social clustering in the camp should be performed according to previous structures (villages).

Like with every dense settlement, advantages are the identification of vulnerable groups and the distribution of goods. Often the land is made available by the government to the aid organisation free of charge. If the needs of the displaced population are identified beforehand, the camps can be planned accordingly. Upgrade of power supply, water and transportation can benefit the local population as well.

A planned camp must replicate the entire support system, resulting in high costs and investments. Because of the density, access to local job markets or other livelihood options is limited. Natural resources need to be shared between many people leading

[50] Ibid., p.105.

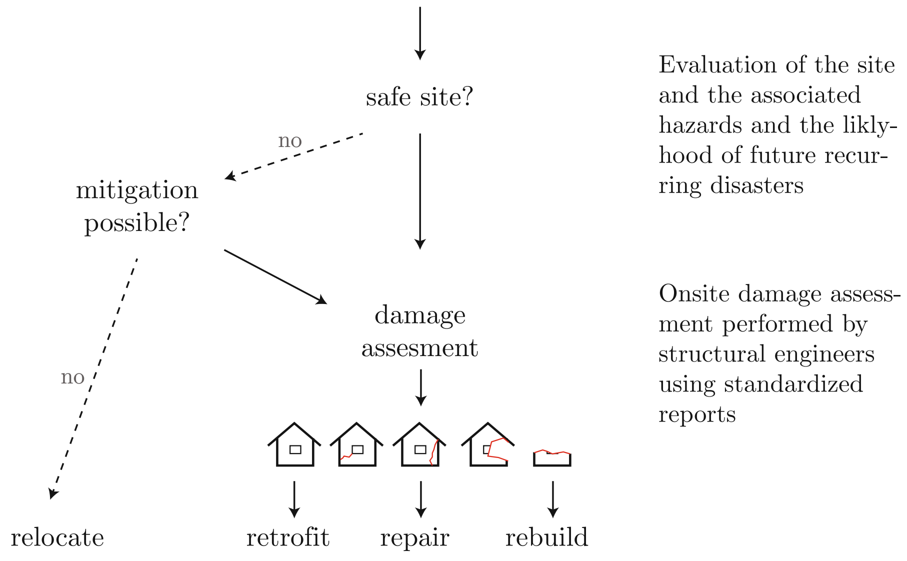

Figure 2.3: This graphic visualizes the different options for non-displaced persons. Graphic adapted from Isabelle de Muyser-Boucher and Gherardi

to a competition over resources. Closing of camps is difficult if there is a shortage of more durable solutions, leading to the risk of permanent camps.

Planned camps and their architectural and infrastructural requirements are further discussed in section 2.5.

2.3.3 Non-displaced settlement options

Non-displaced persons or survivors of natural disasters suffer from partly or fully destroyed houses but are not forced to leave the area directly.

The settlement options for non-displaced, survivors or people returning home can be summarized in tenant based and owner based options. For all tenant based options binding agreements with the landlord about rights and responsibilities after a rebuild should be reached. Informal tenants should be formalized before any rebuild takes place. Depending on the location transitional shelters can be erected next to the damaged buildings allowing to keep social bonds intact.[51]

For all damaged sites it is important to apply the workflow in figure 2.3 of size hazard mapping and evaluation of the structures.

The options for the damaged structures, depending on the category of damage and the safety of the site are:[52]

- Retrofit is applicable for non damaged structures which need enhancements to be able to withstand future hazardous events. Retrofiting might require substantial changes to the current structure and requires engineering input.

[51] Corsellis and Vitale, *Transitional Settlement*, p.110ff.
[52] Ibid., p.142ff.

- Repair indicates *"restoring a building from damage or decay to a sound working condition and meeting the required standards and specifications"*.[53] The effort highly depends on the category of damage and overall quality of the structure.

- Rebuild is necessary for structures which can not be repaired. Commonly the aim is to build back better to avoid similar destruction after the next disaster. Construction failures which lead into the loss of the structure need to be evaluated and addressed in the adapted design.

- Relocate is needed if the site is not considered safe for the future regarding natural hazards and no mitigations are possible. In this case it is not beneficial to invest time and resources in rebuilding the settlement at the same location. Relocation should be considered as the last option because of disruption of social bonds and livelihood options.

2.3.4 Settlement Standards

The chapter Shelter and settlement standard 3: living space in the Sphere handbook[54] mentions important principles what a shelter should provide:

- Living spaces have to support a big variety of activities like sleeping, cooking, eating, washing and storing of food, water and belongings. Flexible openings to the adjacent outdoor spaces ensure that the area can be used during day and night. A minimum living space of $3.5\,m^2$ per person is considered necessary. In cold climates more activities happen indoor thus the recommendation is to provide $4.5\,m^2$ per person. The key principle of providing shelter is to prioritize the roof and the structure. It is easier to start with small initial shelters and scale them up later.

- Cultural practices, safety and privacy should be respected by providing means of space subdivisions like curtains and walls. Space subdivisions might be necessary between genders and age groups. Also space for extended family members has to be considered. Access routes and oversight of the household spaces should be payed attention to.

- In warm, humid climates the design should maximise ventilation, minimise sunlight entrance and have high room heights. Shaded adjacent outdoor space can support livelihood tasks. Sloped roofs with large overhangs protect the walls from rain. Materials with low thermal capacity and raised floors as water protection are considered best practice.

- Hot, dry climates require heavyweight materials to ensure high thermal mass for protection against day to night temperature changes. Earthquake risks are higher for heavier constructions and need to be considered. Ventilated and shaded areas are essential and increase the useable space. Open gaps between floors and walls can lead to sand and dust entering the shelter and should be avoided.

- Cold climates should have a lower room height to reduce the air volume to heat.

[53] Isabelle de Muyser-Boucher and Gherardi, *Shelter after Disaster: Strategies for Transitional Settlement and Reconstruction*, p.112.

[54] *The Sphere Handbook - Humaniterian Charter and Minimum Standards in Humaniterian Response.* 4th ed. Sphere Association, 2018. 458 pp. ISBN: 978-1-908176-70-7, p.254.

Thermal capacity and insulation are beneficial if spaces are used during day and night. Especially the airflow around doors and windows should be minimized for personal comfort. Extra attention needs to be paid to the exhaust fumes of heaters.

- Adequate ventilation reduces health risks. Especially the smoke originating from cooking needs to be ventilated to reduce respiratory diseases. Natural ventilation should always be preferred.

2.4 Organisations and publications

The most important international organisations working with displaced, non-displaced persons and disaster survivors are described in the following sections. Besides advocacy and field work most of the organisations publish extensive guidelines and handbooks on various topics and for different organisational levels.

2.4.1 UNHCR

The United Nations High Commissioner for Refugees is the most well known institution providing responses to political crisis events. Since it was founded in 1950 after World War 2, it is providing support for a growing number of refugees. In 2020 it assisted 91.9 million people in 132 territories with a rough budget of 9 billion dollars.[55]

UNHCR works heavily in the fields of advocacy, refugees, shelter, health and cash-based interventions. With the WASH (Water, Sanitation and Hygiene) program UNHCR tries to improve the sanitation infrastructure in camps by providing technical guidelines and recommendations.

Besides their annual reports they also publish the Emergency Handbook[56] which is a *"guide to agile, effective and community based humanitarian emergency responses"*. The Emergency Handbook is a massive collection of specific handbooks for a broad variety of topics ranging from social media guidelines to food security in rural areas. Most sections provide in-depth links to other publications.

The Shelter Design Catalogue[57] provides many different standard shelter responses performed by UNHCR. Designs are grouped into emergency, transitional and durable shelter solutions with actual case study examples. Details about a selection of designs is given in section 3.1.1.

2.4.2 Shelter Center

The Shelter Center founded 2005 in Cambridge was originally hosted by the IFRC and is based on the work of the University of Cambridge Shelter Center. It mainly focuses *"on learning and knowledge management, through achieving collaboration, consensus and capacity in the humanitarian sector, in partnership with governments, UN bodies, civil society, academia and affected populations."*[58] A wide variety of publications resulted from this united approach.

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[55] *UNHCR Global Report 2020*, p.6.
[56] *UNHCR Emergency Handbook*.
[57] *Shelter Design Catalogue*. UNHCR, 2016.
[58] *Shelter Center*. URL: `http://sheltercentre.org/` (visited on 05/11/2021).

The Humanitarian Library provides access to all of those peer reviewed documents. The most prominent and complete publications with a relevance for this work are discussed below.[59]

Transitional Settlement Displaced Populations provides in-depth guidelines and technical infos about the process and the implementation of creating transitional shelter responses for displaced people, affected by conflicts or disasters. The implementation part of the document is about construction and provides in-depth technical information about the construction of walls, foundations, roofs, tents, materials and climate design basics. The transit and camps chapter of the implementation part focuses on camp site and program planning. This includes transit camps and influx management strategies.[60]

Transitional Shelter Guidelines give definitions for transitional shelters including characteristics. It iterates on how to implement a coordinated response including ways how to involve the displaced community. Site selection and hazard mappings are covered on a high level with additional considerations. An in-depth guide on how to design together with the community to address specific issues, like climate and culture, is provided. Additionally examples of common construction mistakes are given.[61]

Urban Shelter Guidelines is focusing on urban humanitarian responses but is theory and policy heavy. It mainly addresses program managers, governments, decision makers and researchers. Nevertheless it gives important insights and considerations for responses in urban environments. A detailed strength analysis of common assistance methods like contract labour, direct labour and cash support is performed. The section about selected case studies provides timelines and details about implemented shelter projects.[62]

Shelter after disaster: strategies for transitional settlement and reconstruction focuses on the theory but provides good overview diagrams about the whole process and shelter options. One chapter provides ready to use damage assessment forms for post earthquake, flood and storm situations. Evaluation forms for initial rapid assessment of the overall situation on accessibility, water and sanitation are provided.[63]

2.4.3 Catholic Relief Services (CRS)

The CRS, founded in 1943 in the USA, worked in 2020 with 15.8 million participants in 60 countries with a budget of 390 million dollars in the emergency sector.[64]

Learning from the Urban Transitional Shelter Response in Haiti provides experiences of the urban transitional shelter response by CRS to the 2010 earthquake in Haiti. Topics specific to urban areas like crime, gangs and rubble to construction are covered. It is suggested to avoid a two-phase shelter strategy where temporal shelters are created on borrowed land and later a relocation to a permanent location is necessary. After an initial tent based emergency approach the T-shelters program was working on providing transitional

[59] *Humanitarian Library*. URL: `https://www.humanitarianlibrary.org/` (visited on 06/11/2021).
[60] Corsellis and Vitale, *Transitional Settlement Displaced Populations*.
[61] Corsellis, *Transitional Shelter Guidelines*.
[62] Tom Corsellis and Kate Crawford. *Urban Shelter Guidelines*. Norwegian Refugee Council, Shelter Center, 2010. 165 pp.
[63] Isabelle de Muyser-Boucher and Gherardi, *Shelter after Disaster: Strategies for Transitional Settlement and Reconstruction*.
[64] *CRS Annual Report*. 2020.

shelter as an upgrade to the tents. The adapted one-story T-shelter design from a previous response is discussed in detail, including the partial pre-fabrication process. For a detailed analysis see section 3.3.14 on page 96 of this work.[65]

2.4.4 Global Shelter Cluster

The Global Shelter Cluster was established by UNHCR together with IFRC in 2005. While UNHCR focuses on refugees and on internally displaced the IFRC focuses on natural disasters. The shelter cluster coordinates shelter, settlement and non-food items (plastic sheets, tents, shelter kits).[66]

The Shelter Cluster publishes annual case studies of settlement responses like Shelter Projects 2017-2018 - Case Studies Of Humanitarian Shelter And Settlement Responses. The report contains 27 case studies of recovery shelters. Only projects with large scale impact, which were completed or created a solid learning are included. To be included the project must have been implemented within one year after a disaster. Diversity of the setting like rural and urban was favoured in the project selection.[67]

2.4.5 IFRC

The International Federation of the Red Cross is the umbrella organisation of the Red Cross and the Red Crescent Societies.

IFRC founded the Sphere project in 1997 together with other NGOs. It *"is three things: a handbook, a broad process of collaboration and an expression of commitment to quality and accountability."*[68] Sphere is based on the idea that *"all possible steps should be taken to alleviate human suffering arising out of calamity and conflict, and second, that those affected by disaster have a right to life with dignity and therefore a right to assistance"*.[69] The handbook is structured into sections about water supply, sanitation, nutrition, shelter and health services.

Transitional shelters eight designs[70] is a case study of transitional shelters published by IFRC. The first part analyses the challenges of transitional shelters and in the second part eight real world examples are analyzed by structural engineers with respect to earthquakes, storms and floods. Only projects with a significant built quantity, existing technical information and less than three weeks of build time were analyzed. Each project is classified and structural improvements are suggested.

Shelter After Disaster[71] provides an exhaustive overview on the topic. It includes information about damage assessment, reconstruction, general information about hazards and vulnerabilities and an in depth comparison of shelter strategies including tents and imported designs. Additionally the concept of core housing with a low-cost solid permanent

65 *Learning From The Urban Transitional Shelter Response In Haiti.* Catholic Relief Services, 2012. ISBN: 1-61492-108-3.

66 *UNHCR Emergency Handbook*, p.339.

67 *Shelter Projects 2017-2018.* Global Shelter Cluster, 2019. ISBN: 978-92-9068-782-5. URL: `www.shelterprojects.org`.

68 *The Sphere Handbook - Humaniterian Charter and Minimum Standards in Humaniterian Response.*

69 Ibid.

70 Joseph Ashmore and Corinne Treherne. *Transitional Shelters Eight Designs.* IFRC, 2011. 100 pp.

71 Davis, Krimgold and Thompson, *Shelter After Disaster*.

core, which is filled out by the occupants, is introduced. At the end a list of case studies about responses to natural disasters is given.

2.5 Planned camps

Planned camps were already mentioned in section 2.3.2. This section goes into details about the provided services, organization and requirements.

A camp should be planned with the common urban planning guidelines in mind. Components of camps are access points, intersections and public spaces. The spaces in the camps are hierarchically organized in family plots, communities, blocks, sectors and settlements. This allows for easier access and helps to ensure 30 m wide firebreaks every 300 m. The organisation is visualized on page 30.[72]

Infrastructure which a camp should provide are:

WASH facilities provide sanitary infrastructure. Shared toilets must be within 50 m of the dwelling and used by a maximum of 20 people according to Sphere. Excrement can be stored locally if precaution against pollution of the ground water are taken. Sphere recommends to plan with 40 to 90 L of excrement a year per person.[73] Household toilets are *"considered the ideal in terms of user safety, security, convenience and dignity, and the demonstrated links between ownership and maintenance."*[74]

Water infrastructure provides potable water at collection points or with a piped network. The Sphere guidelines specify the minimal daily water requirements per person for drinking and domestic hygiene with 15 L per person. Also the water stations shall be within 500 m during the emergency phase and within 200 m afterwards.[75]

Lighting solutions provide security especially for marginalized groups. Lighting needs to be provided on a communal and household level. Electric power is often limited and only available during certain hours.

Food storage and process is essential for fulfilling the nutrition requirements. Either stoves and fuel are provided or shared places for cooking are created.

Healthcare facilities need to provide quality health services. This includes the workforce but also the needed medical supplies. A key indicator is that 80 % of the camps population should be able to access basic healthcare service in less than 60 minutes of walking. There should be also more than 18 beds per 10 000 inhabitants.[76]

Solid waste disposal includes organic and inorganic waste. The camp administration needs to apply a waste management system which covers separating, transporting, recycling or final disposal. No waste should accumulate in dwelling areas or the public collection points.[77]

[72] *The Sphere Handbook - Humaniterian Charter and Minimum Standards in Humaniterian Response*, p.250.
[73] Ibid., p.115ff.
[74] Ibid., p.143.
[75] Ibid., p.106.
[76] Ibid., p.299.
[77] Ibid., p.126f.

Schools provide education for children. It must be ensured that all individuals are provided with quality education.[78]

Social spaces include religious worship places, recreational areas but also cemeteries.

Livestock accommodation should be separated from living spaces because of the danger of epidemics. This includes veterinary support, support for feed supplies and providing water supplies like water points.[79]

Sphere recommends a minimum space of $45\,m^2$ per person to account for the household plot, infrastructure and agricultural space. If comunal services can be provided outside of the camp the space requirement can be reduced to $30\,m^2$ per person. When the recommended space is not possible the ratio between covered living space and plot size should be 1:2 or better 1:3. A ratio of 1:5 allows for better self sustainability.[80]

[78] *Minimum Standards for Education: Preparedness, Response, Recovery.* 2nd ed. Inter-agency Network for Education in Emergencies, 2010.

[79] *Livestock Emergency Guidelines and Standards.* 2nd ed. Practical Action Publishing, 2014. ISBN: 978-1-78044-861-9.

[80] *The Sphere Handbook - Humaniterian Charter and Minimum Standards in Humaniterian Response*, p.250.

Fire safety

Fires are one of the biggest risks for dense settlements like camps. This is very relevant as often no water network with fire hoses exists or the next fire brigade is far away. To reduce the chance of fires spreading measures must be already taken on the urban planning level of the camp. The Sphere handbook requires firebreaks at least every 300 m with at least 30 m width and a distance of at least 2 m between houses for organized camps.[81]

For timber buildings fire mitigation techniques need to be applied. Modern constructive fire protecting consisting of plasterboards is not feasible from a budget and availability point of view for this design. As low tech measurement to increase fire resistance of the structural parts chemical impregnation and covering with mud and clay are possible depending on availability and climate.

Timber treatment methods range from soaking to brushing. The preservatives available range from organic linseed oil for inside usages with a lifespan of 5 to 10 years to toxic Pentachlorophenol for outside usages with a lifespan of 25 to 50 years. Some of the toxic treatments might also attack steel nails, bolts and the connectors.[82]

Metal connectors are mostly inside the timber beams to increase their fire resistance. The remaining gaps where they were inserted should be closed with fireproof material to delay the heat-up of the metal connectors. Metal connectors loose their strength after a certain temperature. Specialized paints can be applied to delay this process.

The primary goal of fire safety measures is that the inhabitants have enough time to flee the building before it collapses. The risk is lower for smaller buildings with just two floors.

A major fire risk in dwellings is cooking with open flames. By using a good stove type the risk of fires and smoke can be reduced a lot. Stove types range from low cost mud stoves with a low durability to expensive stoves made from metal and clay.[83] Those design were also incorporated in the kitchen module design in section 7.6.3.

Another fire risk is the heating in cold climates. To reduce the risk closed ovens which are easy to operate alongside with fire safety equipment should be supplied.

[81]Ibid., p.252.

[82]Joseph Ashmore and Jon Fowler. *Timber - A Guide to the Planning, Use, Procurement and Logistics of Timber as a Construction Material in Humanitarian Relief.* UN Office for the Coordination of Humanitarian Affairs, 2009. URL: https://www.humanitarianlibrary.org/resource/timber-guide-planning-use-procurement-and-logistics-timber-construction-material-2 (visited on 09/08/2020), p.34ff.

[83]Matthew Owen. *Cooking Options in Refugee Situations - A Handbook of Experiences in Energy Conservation and Alternative Fuels.* 2002.

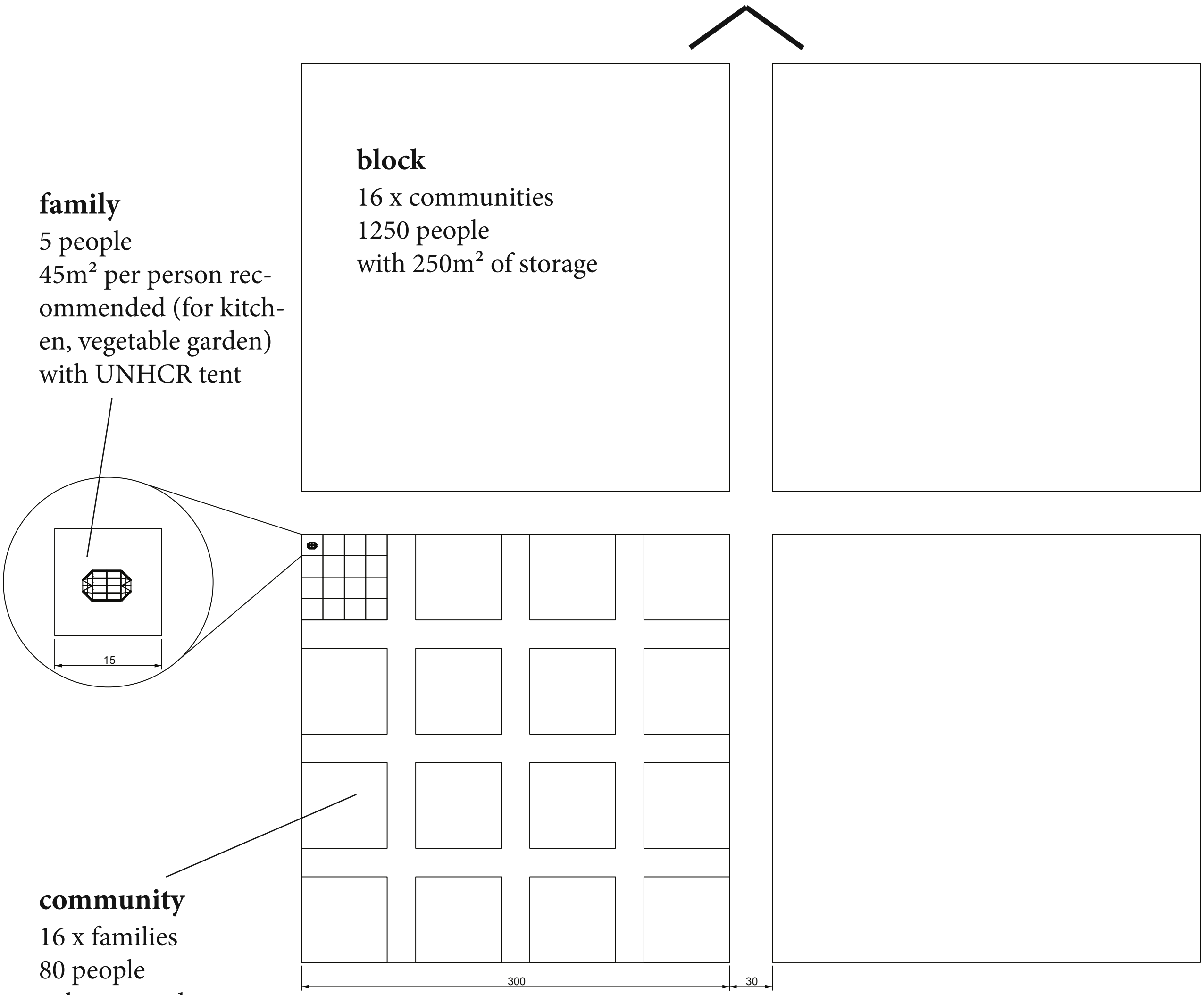
Camp organization

settlement
4 x sectors
20000 people
with one market place
one feeding center

sector
4 x blocks
5000 people
with one school,
one distribution center

block
16 x communities
1250 people
with 250m² of storage

family
5 people
45m² per person recommended (for kitchen, vegetable garden)
with UNHCR tent



community
16 x families
80 people
at least one shower
at least four latrines
one water tap stand

firebreaks
30m firebreaks at least every 300m. 2m minimum distance between two buildings.

2.6 Climate

The climate has major implications on building techniques, building physics, tradition and weather phenomenons.

The most common climate classification system currently in use was introduced by Köppen and Geiger. It divides the world into five major climatic zones denoted with single letters from A to E based on precipitation and temperature. This main zone is further separated by adding a second letter denoting the seasonal precipitation. A third letter adds a distinction about the temperature. The classification is as follows:[84]

Tropical (A) is a zone with an average temperature above 18 °C with significant precipitation. It mostly covers central Africa, the northern part of South America and South East Asia. The zone is further split into rainforest (f), monsoon (m), savanna (w) with dry winter and savanna (s) with dry summers.

Arid (B) are zones with little precipitation and temperatures averaging above 10 °C. This zone mainly covers the northern part of Africa and the Middle East. It is further split into arid desserts (W) and semi-arid (S) zones. The last letter indicates if it is hot (h) or cold (k).

Temperate (C) are zones which have a dedicated cold period averaging between 0 °C and 18 °C and a warm period with at least one month above 10 °C. Mostly Western and Southern Europe and large parts of the United States fall into this category. It is further split into dry winter (w), no dry season (f) and dry summers (s). The summer is additionally separated with the third letter between hot (a), warm (b) and cold (c).

Cold (D) zones have at least one month below 0 °C and a warm month above 10 °C. Mostly Eastern Europe, Russian and Canada are in this zone. The subcategories are the same as for temperate climates. Also the temperature distinction is the same but adds a category for very cold winters (d).

Polar (E) are zones like the Tundra and areas covered in ice with average temperatures below 10 °C.

An up-to-date climate map according to Köppen-Geiger with a resolution of 1 km is available under a CC-By 4.0 license. Vienna is at the border to continental climate but still classified as Cfb.[85]

Also the shelter architecture needs to correspond to the climate.

To adapt the shelters to a cold climate a raised floor should insulate from the ground. One room should be heatable and the structure needs to factor in the weight of snow. The heatable space should be limited as much as possible. Roof insulation has higher priority than wall insulation as more heat is lost through the roof.[86]

[84] Wladimir Köppen and Rudolf Geiger. *Das Geographische System Der Klimate*. Vol. I. 5 vols. Handbuch Der Klimatologie C. München: Gebrüder Borntraeger, 1936.

[85] Hylke E. Beck et al. *"Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution"*. In: (July 2018). URL: `https://figshare.com/articles/dataset/Present_and_future_K_ppen-Geiger_climate_classification_maps_at_1-km_resolution/6396959`.

[86] Ashmore and Corsellis, *Selecting NFIs for Shelter*, p.16ff.

For warm and humid climates plastic sheeting can protect from rain water and sun. Light walls should be applied to prevent the structure from storing solar energy. Surface water should be drained and the shelter raised. Tents as emergency architecture are rarely used in this climate because of the rapid rot. Cyclones often affect these areas and additional bracing measures must be taken. Ideally the roof space is ventilated to improve thermal performance.[87]

In hot and dry climates plastic sheeting is also useful to protect against the sun and possible rain water. Shading is of highest priority but rapid temperature drops during the night also need consideration. In contrast to the humid climates here thick walls with high thermal mass and small openings are key factors. Good ventilated allows to cool down the structure during night time. This can be achieved by creating double layer roofs with plastic sheeting.[88]

2.7 Earthquakes

Besides the climatic influence for shelter structures the earthquake risk also plays a major factor. Earthquakes affect built structures by ground shacking, ground failures and commonly fires in the aftermath. The forces applied to buildings during seismic events are similar to horizontal forces. Additional forces result from vibrations both vertically and horizontally.[89]

The categorization of seismic risk depends on the country with different systems used. Commonly around five to seven classes are distinguished ranging from risks of minor damage till risks of widespread destruction. Also the bearing capacity of the soil plays a major role as weak soils can lead to liquefaction during seismic events. One common denominator is the peak ground acceleration specified in g with $g = 9.81\,\mathrm{m/s^2}$ measured by instruments.[90]

The seismic hazard maps measures the 10 % probability of exceeding the peak ground acceleration within a timespan of 50 years. Data is divided into groups denoted as low $(0 - 0.8)$, moderate $(0.8 - 2.4)$, high $(2.4 - 4.0)$ and very high (≥ 4.0) according to their peak ground acceleration.[91]

Rectangular shapes are generally more earthquake resistant than long or unsymmetrical building shapes. Between separate units small spaces help to avoid cascading collapses. The structural frame should be either braced with diagonal bracings or be filled to create shear resistant walls. An alternative is to create all joints between beams and columns in a very rigid way to resist the forces.[92]

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87 Ashmore and Corsellis, *Selecting NFIs for Shelter*, p.20ff.

88 Ibid., p.22ff.

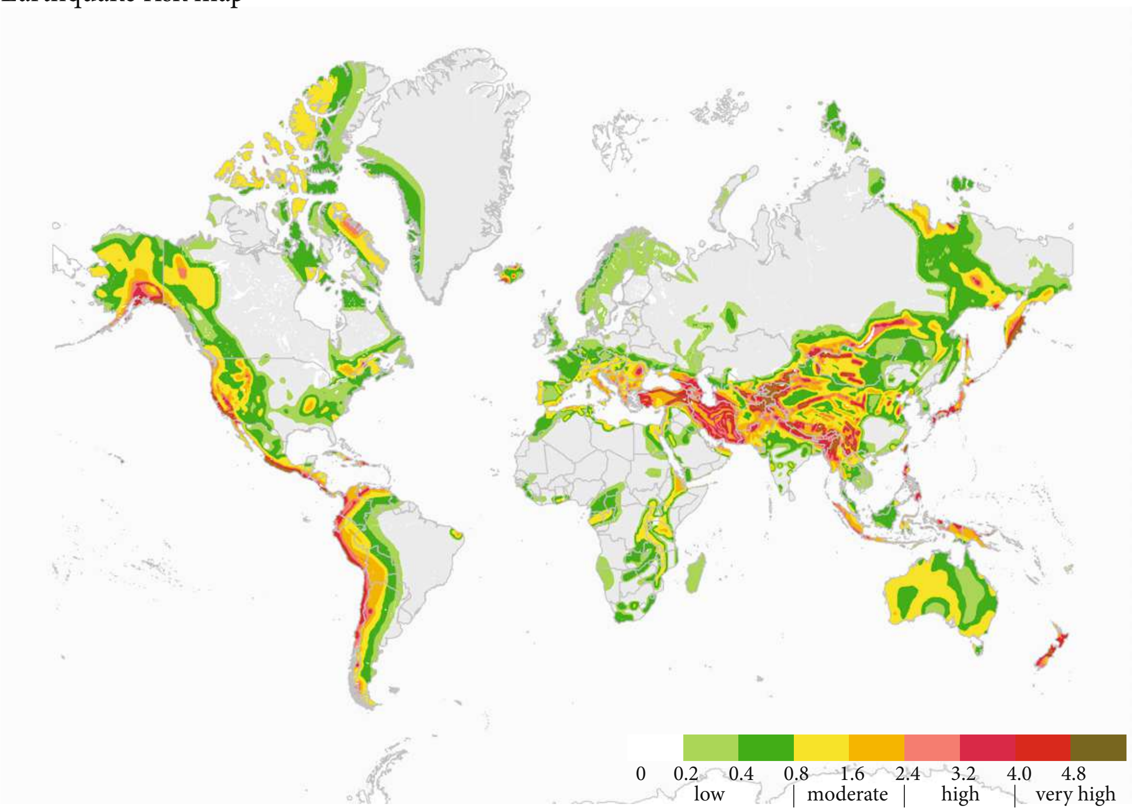
89 Kaikan Kenchiku. *IAEE Guidelines for Earthquake Resistant Non-Engineered Construction.* 2004, p.15.

90 Ibid., p.26f.

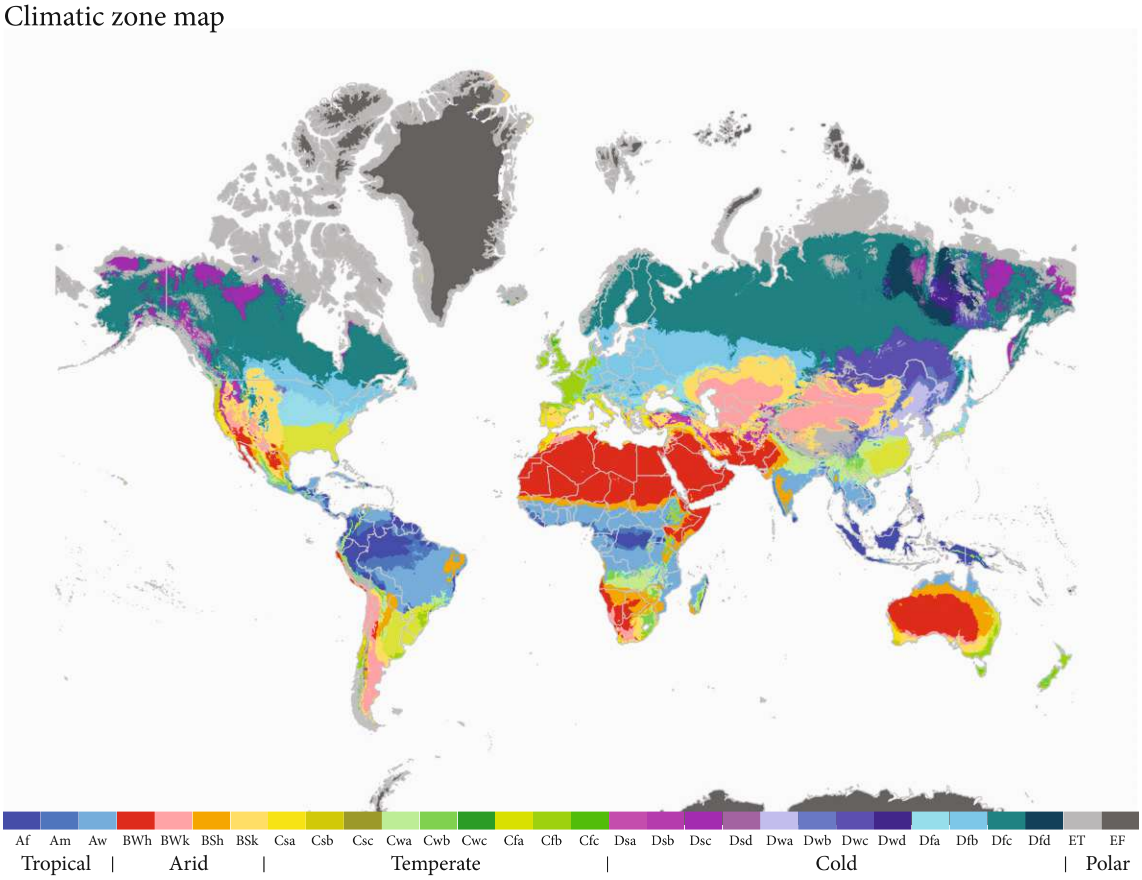
91 Kaye M. Shedlock et al. *"The GSHAP Global Seismic Hazard Map"*. In: *Seismological Research Letters* 71.6 (1st Nov. 2000), pp. 679–686. ISSN: 0895-0695. URL: https://doi.org/10.1785/gssrl.71.6.679 (visited on 26/01/2023).

92 Kenchiku, *IAEE Guidelines for Earthquake Resistant Non-Engineered Construction*, p.28ff.

Earthquake risk map



Climatic zone map



Chapter 3

Displacement responses

In this section different shelter responses are analyzed. As there are numerous examples of shelter architecture available the reference projects were chosen based on the following points. A design is included when it is special in one or more of the following criteria:

Response phase is the target phase of the shelter response. Transitional shelters can be delivered right in the beginning skipping emergency shelters or transform the existing shelters in a meaningful way. Including shelters from the emergency phase allows to analyse concepts about upgrading existing shelters. Durable shelters can offer guidelines of what the inhabitants are aiming for in the long-term.

Archetype diversity is essential as different cultures prefer different building types and styles. Shelters with different archetypes are included to show the variety.

Construction technique diversity can vary greatly from structural metal to bamboo huts hold together with steel wire. References are included when interesting approaches are used which are relevant in the context of transitional shelters.

Materials used in shelter construction depend on the climate and availability. Some responses rely on heavy earth walls while others combine bamboo frames with tarpaulin. This work tries to include a diverse set of building materials to evaluate their respective qualities.

Climate influences the possible building types and techniques. Including shelters from different climatic zones allows to investigate climate appropriate responses.

Upgradeability defines how easy inhabitants can upgrade their shelter during the care and maintenance phase. This can involve combining multiple shelters into one bigger unit or by using local building techniques to allow for local add-ons.

Transportability is about how the material of the shelter is transported on-site. There is a wide range of options where material can be sourced from and if it is preprocessed before delivery to the site. Transport infrastructure is commonly impaired during a crisis and can make up for a large proportion of the total cost, if available at all.

Design process defines how a shelter response is planned and executed. Shelter responses can start by evaluating local traditions and create a specialized local design.

Other shelters are designed generically and apply a global design which can be shipped rapidly. Both approaches result in different shelter architectures.

Attention was paid to give a broad overview of the different approaches and what features were successful.

For each of the selected shelter responses the following key aspects were analyzed. A tabular summary of all the analyzed attributes is given on the following pages. The rest of this section provides the detail analysis for each selected project:

Construction specifies how the structural frame of a shelter is created and how it performs. Special focus was paid on the wind resistance of the structure. Also the bracing and connections to the foundations were analyzed. The construction type and quality are collected from literature or remotely assumed.

Size of the shelter and the plot is a key indicator dictating the number of inhabitants. Too small shelters are not usable by families while too big shelters consume too many resources which could have been used to support more beneficiaries.

Flood safety is an important topic as rain water commonly damages shelters when drainages are not regularly maintained or are not existing. The flood safety using constructive measures was analyzed for all shelters.

Room height and climate adaptability has a huge influence on the thermal comfort and also gives an estimate if the building was constructed with the deployed climate in mind. The climatic zone of each shelter is determined and checked if the used materials are applicable.

Extendability analyses if and how the shelters can be extended or upgraded by the inhabitants when there are increased space requirements.

Material source is all about the origin of the material used for construction. It is investigated if the material is sourced locally or can only be sourced internationally. Material source has a huge impact on local economy, price and delivery times.

Transportation is dependent on the weight of one kit and the number of units fitting in one standard twenty foot shipping container. They play a key factor in shelter responses because of limited transportation capacities and infrastructures.

Price is one of the major factors for successful shelter response. Not only the total price but also the price per m^2 is a relevant performance indicator.

Earthquake risks drive the need for increased bracings and structural stability. Each shelter's site is classified into the four categories described in section 2.7. For shelters in seismic active zones the structural safety is investigated.

Lifespan depends on the climate, used materials and performed maintenance. The lifespan can still give an estimation of how often the shelter needs to be replaced. More durable shelters can easier lead to rejection from the local population.

Build time for one kit and also the number of skilled labourers and untrained supporting labourers is analyzed. This is a key factor for shelter responses as it determines how many people need to be trained and if skilled labour needs to be paid for the construction process.

Each shelter analysis is summarized with this table format:

Climate classification
according to Köppen
BWk = Cold desert climate

Targeted response phase
emerg: emergency phase
tarns: transitional phase
perm: permanent phase

Earthquake risk
from low to very high

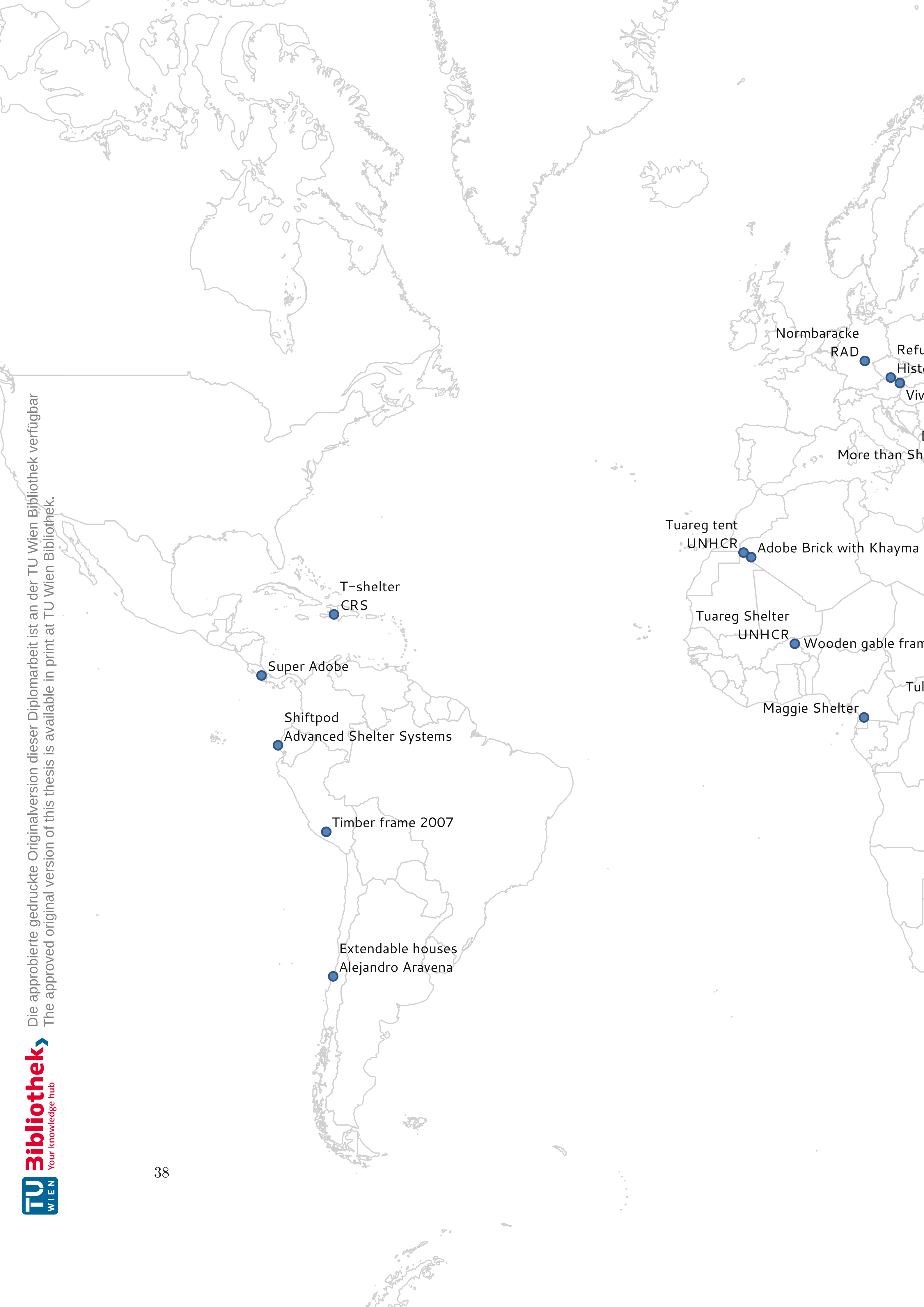
Phase	emerg.	Climate	BWk	Earthquake	medium
Area m²	16/23	Price/m² €	18.26	Lifespan	1 year
Plotsize m²	61	Weight kg	55	Labour	3/0
Room height	125-220	no per TEU	150	Build time	30 min
Local Material	no	Flood safe	no	Extendable	yes

Covered area
main living area / all covered area

Labour
for building up
skilled / unskilled helpers

Transportation
count of units fitting in one twenty-foot equivalent unit (TEU) container

Range of usable room height
minimum / maximum



Normbaracke
RAD
Refu
Hist
Viv
More than Sh
Tuareg tent
UNHCR
Adobe Brick with Khayma
T-shelter
CRS
Tuareg Shelter
UNHCR
Wooden gable fram
Super Adobe
Tu
Maggie Shelter
Shiftpod
Advanced Shelter Systems
Timber frame 2007
Extendable houses
Alejandro Aravena

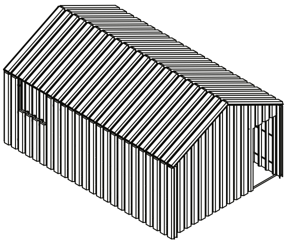

efugee camp Gmünd
istoric
Vivihouse
Domo
Shelters
Container
K-Home
RE:BUILD
Azraq T-Shelter
UNHCR
Tent shelter
UNHCR
Timber frame 2010
Nepal 2015
Architecture for the Mass
Emergency shelter 2015
Shigeru Ban
Twin elevated shelter
UNHCR
Aranya low-cost housing
Balkrishna Doshi
rame shelter
UNHCR
Tukul Shelter
UNHCR
Compact bamboo shelter
UNHCR
Kenya 2019
Shigeru Ban
Steel frame 2005
na

Project	Creator	Size m²	Local Material	Flood safe	Wind safe	Extend-able	Height
Family Tent	UNHCR	23	○	○	●	●	125/220
Self Standing Family Tent	UNHCR	18.5	○	○	●	○	128/183
Domo	More than Shelters	24	○	○	●	●	260
Shiftpod	Advanced Shelter Systems	13	○	○	●	○	210
Tentative	Designnobis	8	○	●	●	○	250
Weaving a home		19.6	●	○	?	○	200
Wooden gable frame shelter	UNHCR	20	●	○	?	?	170/270
Tuareg shelter	UNHCR	21	●	○	?	?	120/170
Tuareg tent	UNHCR	49	●	○	?	○	150/380
Tukul shelter	UNHCR	21.6	●	○	?	○	160/355
Tent shelter	UNHCR	38.7	●	○	?	○	160/315
Refugee camp Gmünd	Historic	420	●	●	●	-	340/460
Normbaracke	RAD	216	●	●	●	-	255/335
Container	K-Home	18	○	-	-	●	280
Refugee Housing Unit	UNHCR	17.5	○	○	●	○	180/260
Hex House	Architects for Society	47	○	●	●	●	300/330
Cortex shelter	Cutwork	24	○	○	●	?	210/296
Azraq T-Shelter	UNHCR	24	○	○	?	○	200/330
compact bamboo shelter	UNHCR	21	●	○	○	?	240/340
Twin elevated shelter	UNHCR	18	●	●	○	?	300/370
Timber frame 2010		24.51	●	○	○	?	90/270
Timber frame 2007		18	●	○	○	?	240
Steel frame 2005		53	◑	●	○	?	280/415
Maggie shelter		100	◑	●	●	●	260/412
T-shelter	CRS	17.8	●	○	●	●	330/360
Nepal 2015	Architecture for the Mass	8	●	●	●	●	90/185
Adobe Brick with Khayma		130	●	○	●	-	200/350
Emergency shelter 2015	Shigeru Ban	29	◑	○	?	-	210/310
Extendable houses	Alejandro Aravena	80	●*	○	○	●	230
Aranya low-cost housing	Balkrishna Doshi		●*	?	?	-	
Super Adobe		16	◑	●	●	●	420
RE:BUILD		256	◑	○	●	●	210

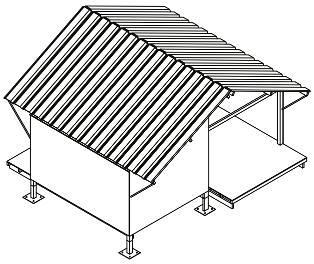
Local material
◑ partly ●* steel and concrete

Price €	Price €/m²	Weight kg	units per TEU	Lifespan years	Skilled / unskilled	Build time	Earthquake risk	Climate
420	18.26	55	150	1	3/0	30m	◕	Csa
420	22.70	52	150	1	3/0	10m	◕	Aw
2850	118.75	140	33	10	2/0	30m		
1700	130.77	29	147	1	1/0	2m		
2500	312.50		8				◔	Bsh
	0.00						◔	Bsh
223	11.15			1-5	1/2	6h	◔	BWh
288	13.71	5000	5	2	1/2	1d	◑	Aw
1190	24.29			2	1/2	1d	◑	Dsb
209	9.68			2-4	1/2	1d		
813	21.01			2	1/3	4h		
37000	88.10						◔	Cfb
	0.00						◔	Cfb
790	43.89	1160	5	10			◕	Csa
1150	65.71	160	17	1.5-5	4/0	5h		
55000	1170.21		0.5	15-20	5/0	6d		
3000	125.00		5	30	0/2	2d		
3442	143.42			2-4	1/3	1d	◑	BWh
708	33.71			2-4	1/2	1d	◔	BWh
329	18.28			2-4	1/2	2d	●	Cwa
500	20.40			1	1/3	1d	◑	Csa
560	31.11			1	1/4	1d	◕	ET
5100	96.23			5	1/4	3d	◕	Af
30000	300.00	1800	6	15	1/5	2d	◔	Am
	0.00			3-5			◑	Aw
500	62.50			1	4/10	2d	●	Cwb
1500	11.54			10	2/2	60d	◔	BWh
	0.00			10			●	Cwa
7500	93.75			20			◕	Csb
	0.00						◔	As
2200	137.50		10	10	1/5	20d	●	Af
30000	117.19				1/5	14d	◑	BSk

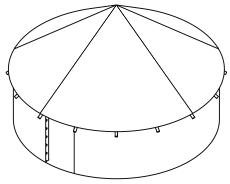
Earthquake risks
◔ low ◑ moderate ◕ high ● very high



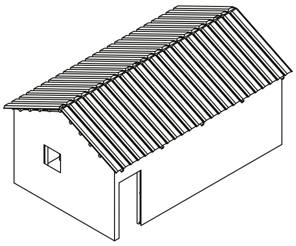
UNHCR Azraq T-Shelter



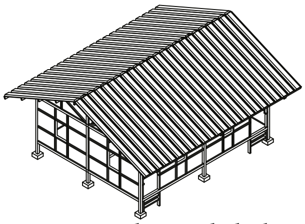
Indonesia - Steel frame 2005



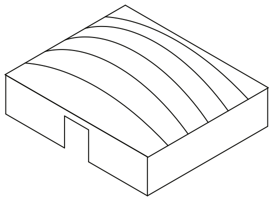
UNHCR Tukul shelter



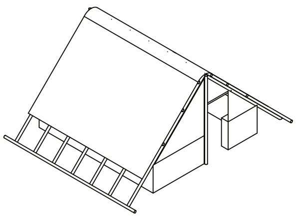
UNHCR compact bamboo shelter



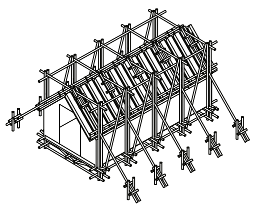
UNHCR Twin elevated shelter



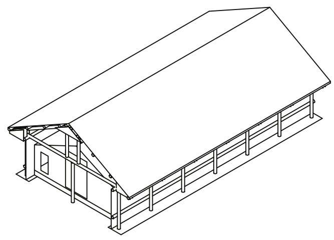
UNHCR Tuareg shelter



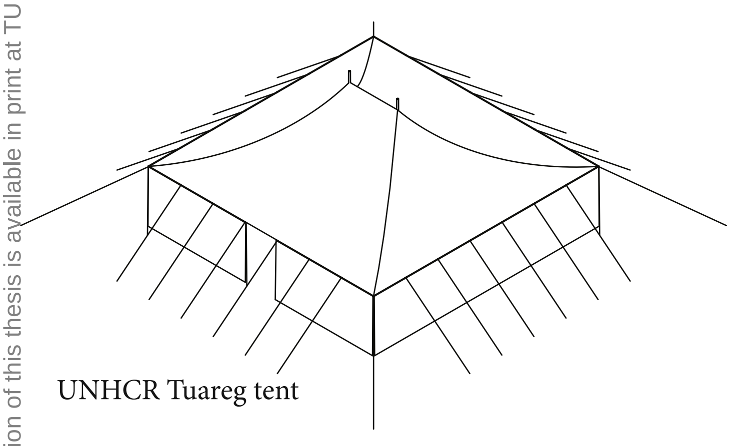
Pakistan - Timber frame 2010



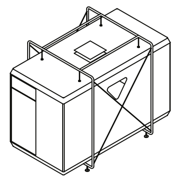
Architecture for the Mass
Nepal 2015



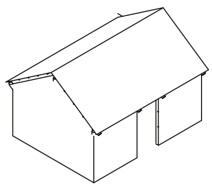
UNHCR Tent shelter



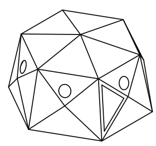
UNHCR Tuareg tent



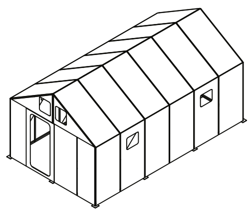
Designnobis – Tentative



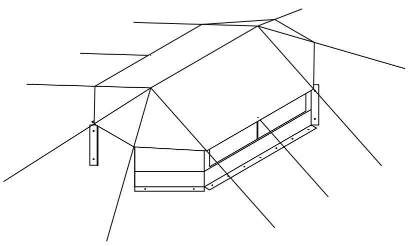
UNHCR Wooden gable frame shelter



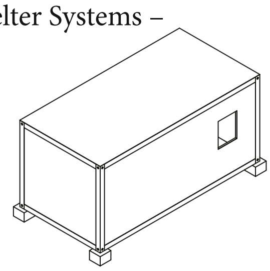
Advanced Shelter Systems – Shiftpod



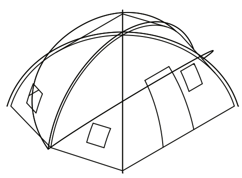
UNHCR Refugee Housing Unit



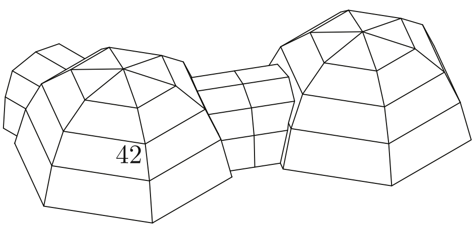
UNHCR Family Tent



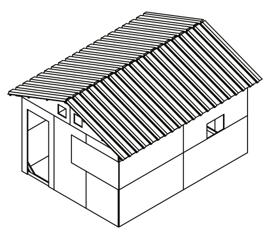
K-Home Container



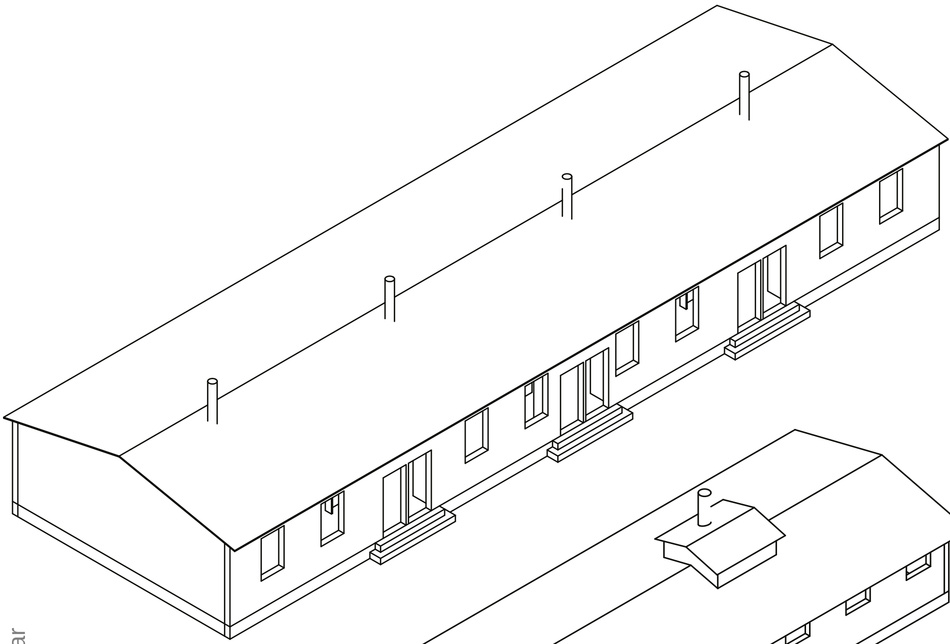
UNHCR Self Standing Family Tent



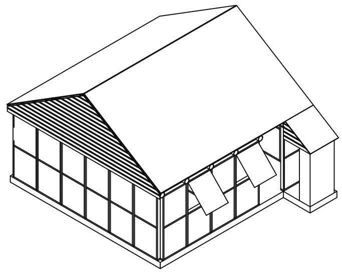
More than Shelters – Domo



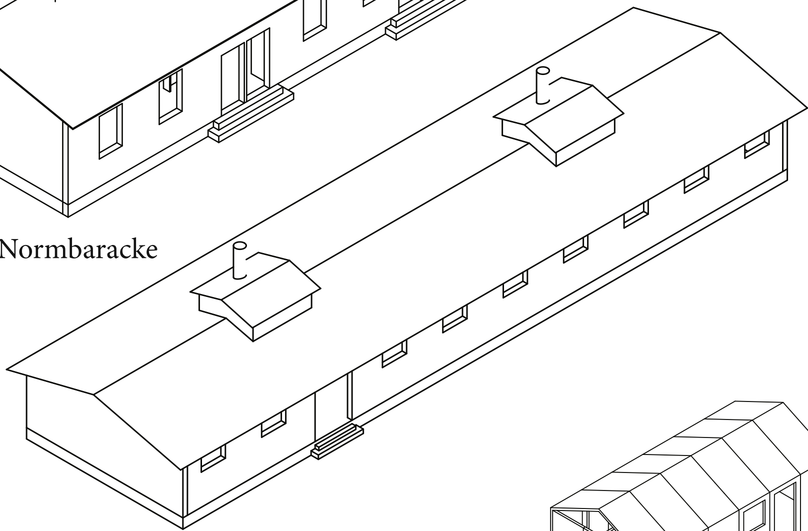
CRS T-Shelter Haiti



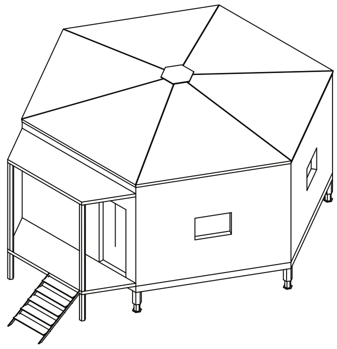
RAD-Normbaracke



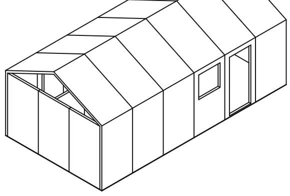
Shigeru Ban
Emergency shelter Nepal 2015



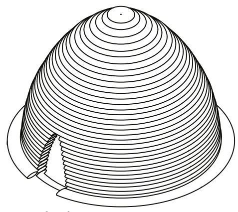
Historic - Refugee camp Gmünd



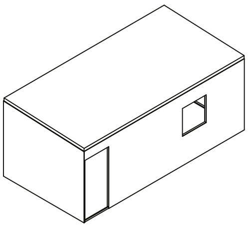
Architects for Society
- Hex House



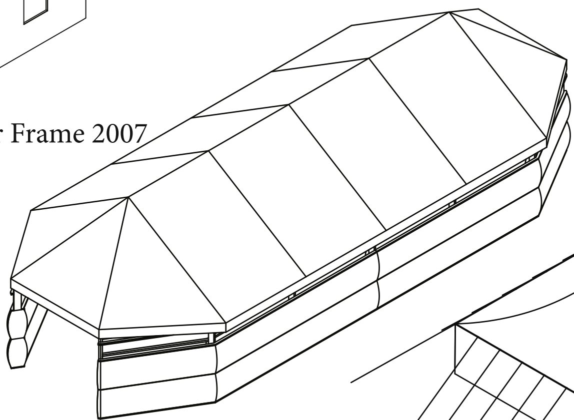
Cutwork - Cortex Shelter



Super Adobe

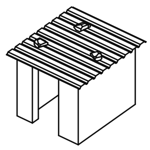


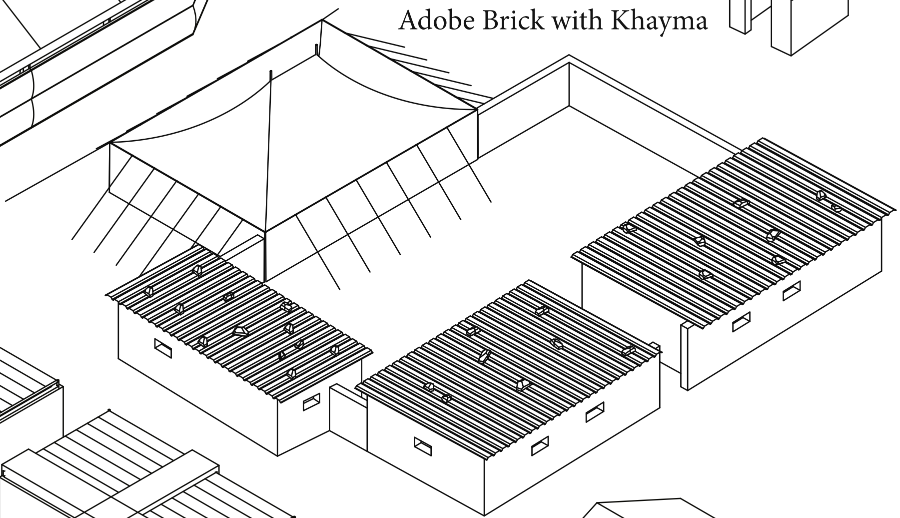
Peru - Timber Frame 2007



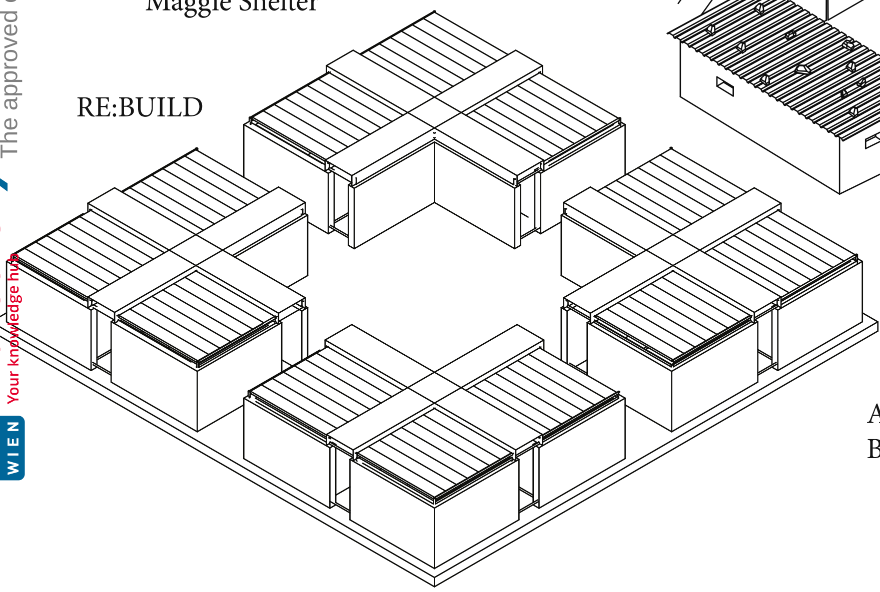
Maggie Shelter

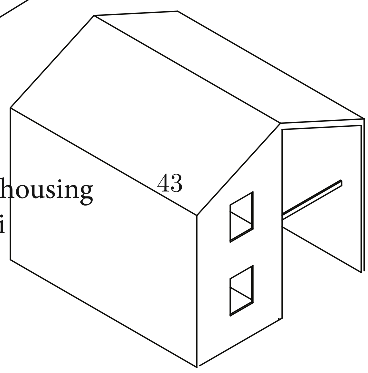
West Sahara
Adobe Brick with Khayma





RE:BUILD





Aranya low-cost housing
Balkrishna Doshi

3.1 Emergency phase

This section focuses on responses during the initial emergency phase.

3.1.1 UNHCR Family Tent

The UNHCR Family Tent is the old standard tent used by UNHCR, IFRC and ICRC and is designed for families of five people. It is a ridge tent with 4×4 m main area and two additional vestibules with 3.5 m^2 each. To allow many suppliers the design is generic but specific in technical terms. The tent is planned for places with temperatures ranging from 5 to 40 °C. There are strict requirements for transportation size, white color and logo placement.[1]

The structure is hold by a 4 m ridge beam supported by three upright central poles made from ⌀ 30 mm (thickness 1.2 mm) galvanized or painted steel pipes. The door on each side has two supporting poles. The walls are supported by three side poles each. The outer tent wall canvas should be made out of a 200 g/m^2 40 % cotton and 60 % polyester material. The inner tent canvas can be made out of the same material or alternatively out of 100 % cotton.[2]

The family tent is designed as short term shelter solution with only one year of lifespan required. Tents are often stored during preparedness phase and UNHCR requires a shelf-lifespan of five years minimum.[3]

The advantages are that this product is very standardized and established with large existing production capacities. The tent was designed with hot climates in mind and offers an optional shade net to reduce the direct sun exposure. The downsides are the common canvas rot and the limited head room on the sides of the inner tent and entrance. Even with the optional winterization kit supporting heaters, temperatures below 0 °C lead to heavily reduced comfort.[4]

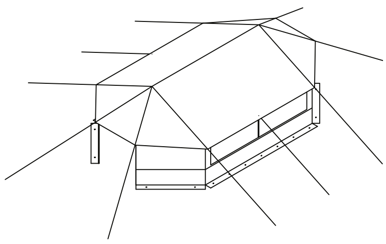
The UNHCR Family Tent was so widely used that it got indissociable with refugees, crisis responses and UNHCR itself. Although the tents are often used much beyond their expected lifespan, they are still seen as temporal by the inhabitants and the local population. With a design refined over so many iterations it is one of the best tested tent structures available. The design creates a decent height and is adapted to hot climates with a shade net available. It also does not require any form of foundation or infrastructure but still tries to protect as good as possible against flooding water by suggesting trenches and by providing a mudflap. The tents are produced and procured from international vendors without any local business opportunities. The winterization kit just consists of a protection for the tent tarpaulin against the hot chimney temperatures. Heating an uninsulated tent shelter is economically and environmentally not sustainable as it requires a massive amount of fuel. There is also no adaptability regarding the shape or the used materials or colors. The thin tarpaulin layer does not offer much security because it can be cut easily. With the separation of the inside and outside tent no direct views to the inside are possible, creating a level of privacy.

[1] *Shelter Design Catalogue*, p.6ff.

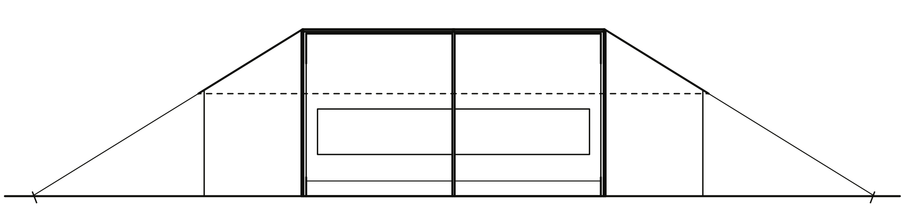
[2] *Core Relief Items Catalogue*. 2012, p.6ff.

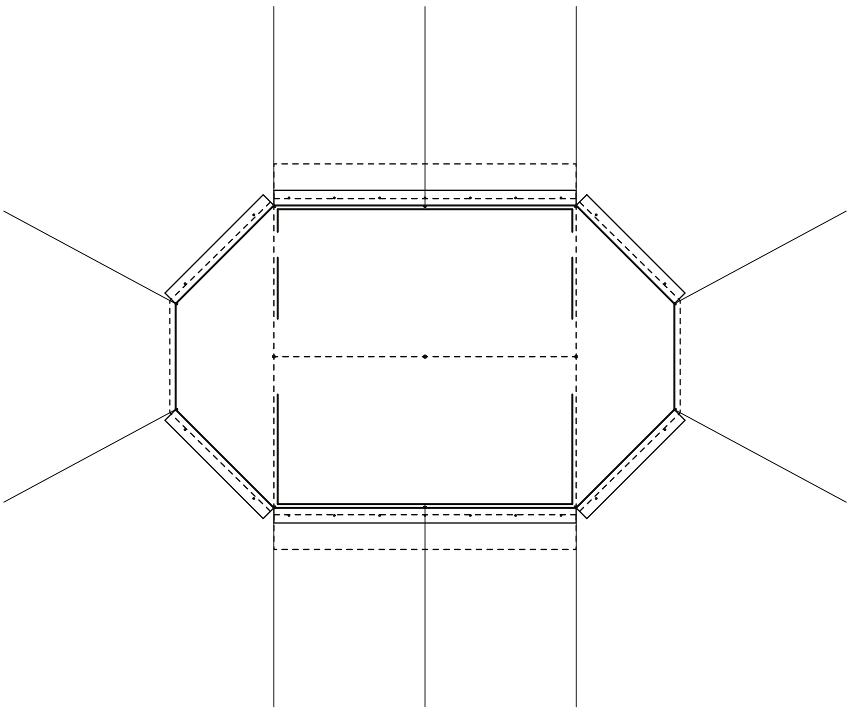
[3] Ibid., p.1ff.

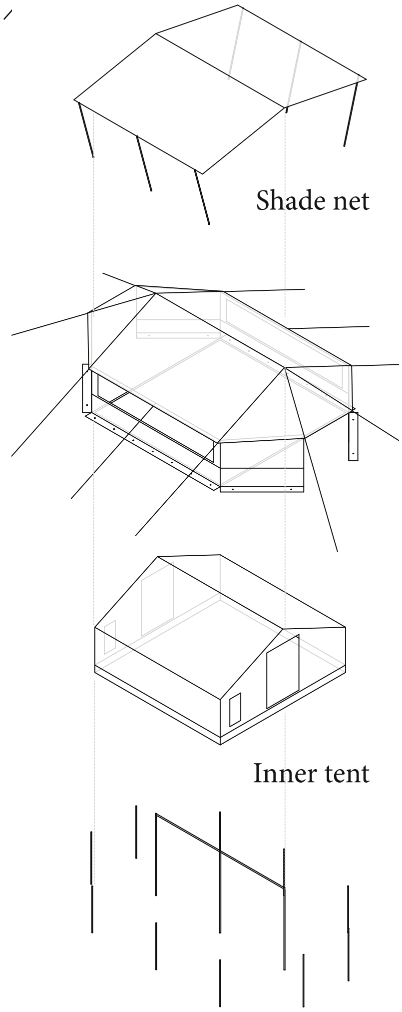
[4] Corsellis and Vitale, *Transitional Settlement Displaced Populations*, p.313ff.

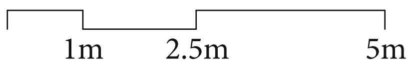


Phase	emerg.	Climate		Earthquake	
Area m²	16/23	Price/m² €	18.26	Lifespan	1 year
Plotsize m²	61	Weight kg	55	Labour	3/0
Room height	125-220	no per TEU	150	Build time	30 min
Local Material	no	Flood safe	no	Extendable	yes









3.1.2 UNHCR Self Standing Family Tent

The Self Standing Family Tent is a dome tent and is the new UNHCR standard tent since 2017. It is the result of the shared research efforts of UNHCR together with IFRC and ICRC. With 4.3× 4.3 m of usable it can host families of up to five people. The inner tent can be optionally partitioned into two same size spaces. For winterization support the tent comes with a chimney reenforcement in one corner made out of heat resistant fabric. The maximum height in the inner tent is 183 cm which is 37 cm less than the UNHCR Family Tent at the highest point.[5]

The tent is fixed with 18 guy ropes and secured with metal pegs which must withstand windspeeds of up to 75 km/h. There is no specific requirement for snowloads in the specification. A 40 cm mudflap allows to further secure the tent against water. The two windows (75 cm × 70 cm) can not be opened but ventilation is possible through eight openings on the sides and on the top of the tent.[6]

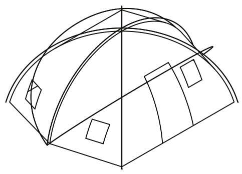
Two doors located on opposite sides allow for independent entrance. In comparison to the previous UNHCR standard tent the inner tent is already pre-installed with a 10 cm airgap to the outer tent. Next to a mosquitonet a shadenet is available to prevent excessive heat up. *"Woven high-density polyethylene ... (or) alternatively plastic tarpaulin"*[7] should be used for the outer tent and the ground sheet. The canvas should have a specific weight of 190 g/m^2. A minimum water penetration resistance of 30 hPa is required. For the inner tent cotton mixes or pure cotton canvas is required. All poles and arch pipes are made of aluminium (⌀19 mm, 1 mm thickness) and are color coded for easier assembly. Pegs are made from galvanised iron.[8]

The lifespan in all climates is required to be at least one year. The assembly instructions fit on one A4 page consisting of just 12 steps which allows a team of two to three people to erect a tent in 10 min. The costs, packages volume and transportation capacity is similar to the UNHCR Family Tent.[9]

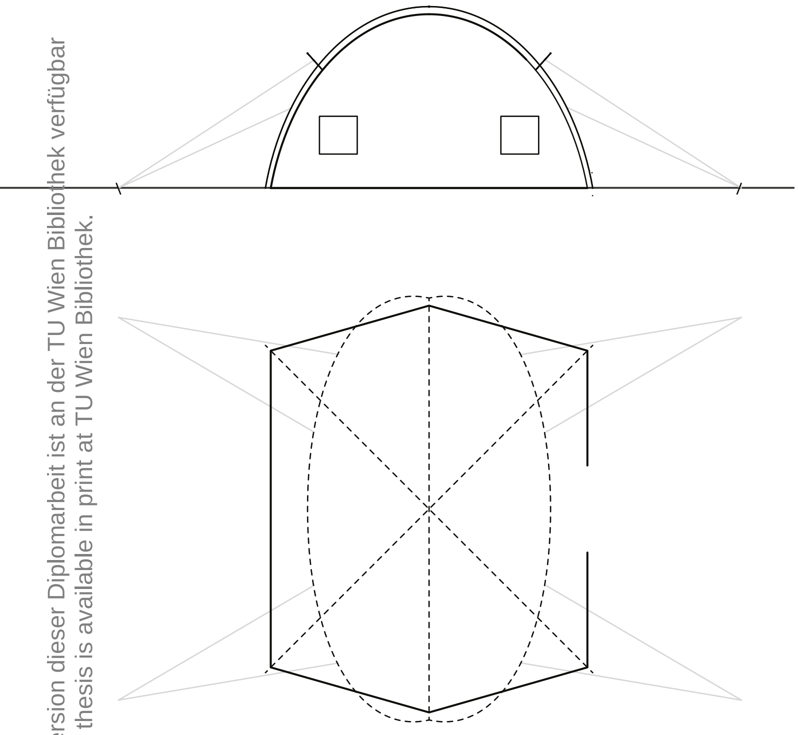
Although the inside area is slightly bigger than the UNHCR Family Tent, the covered area under the outer shell is much smaller. The structure is much easier to erect, especially with unskilled labour. With the high wind resistance it is quite durable against wind from all directions. Besides these points this product shares the advantages and disadvantages of the Family Tent: It is easy and fast to ship and deploy but does not offer any local business opportunities or local design adaptions. The tents also can not be connected to bigger structures.

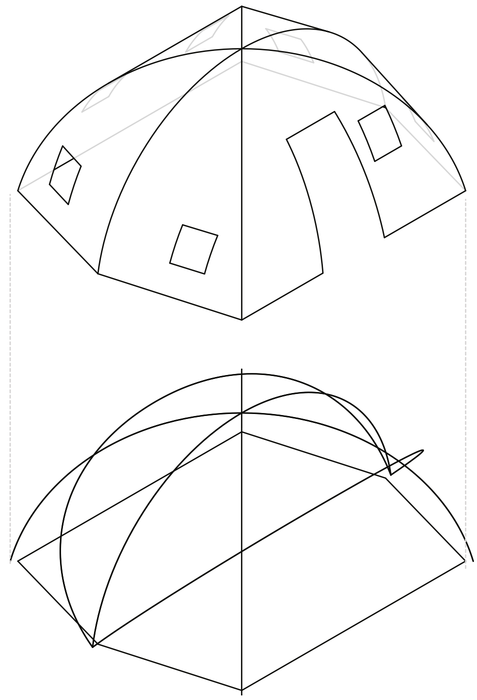
A very similar design is the geodesic ICRC Family tent. While the base shape has the same dimensions it offers 57 cm more headroom with its height of 240 cm. With its weight of 45 kg it weights 7 kg less compared to the UNHCR tent. Packaged volume is around 0.28 m^3 allowing to store around 120 units in one TEU container. A supplier of the tent was contacted for a price quote without success.[10]

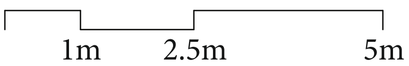
[5] *UNHCR Self Standing Family Tent Specification.* 2017.
[6] Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.
[10] ICRC. *Self-Standing Geodesic Family Tent Basic Unit.* 2019.



Phase	emerg.	Climate		Earthquake	
Area m²	18.5	Price/m² €	23	Lifespan	1 year
Plotsize m²	30	Weight kg	52	Labour	3/0
Room height	125/183	no per TEU	150	Build time	10 min
Local Material	no	Flood safe	no	Extendable	no







3.1.3 UNHCR Reinforced Plastic Tarpaulins in Sheets

Plastic tarpaulins can be used to repair partially damaged buildings or to cover newly built structures. After non displacement situations like natural disasters, often repair material is needed to protect partially destroyed structures from rain and wind and to make them temporally habitable again. Roofs made out of local materials are often damaged and hard to replace quickly. Repair kits usually include nails, washers, ropes and metal straps additionally to the sheets.

During the emergency phase plastic sheeting can be used to covered basic structures made from bush poles. Plastic sheets can also be used to rapidly buildup infrastructure like latrines and fences. During the transitional phase plastic sheets are an important material to upgrade emergency shelters to transitional shelters.[11]

The UNHCR plastic sheet was developed for long lifespan and outdoor use in all climates. It comes in two different sizes: Sheets of 4×5 m and rolls of 4×50 m. One plastic sheet costs 16.50 $. The material is made of woven high-density black polyethylene fibers with a minimum specific weight of $(190 \pm 20)\,\mathrm{g/m^2}$. Even with the strongest weather conditions and UV exposure a lifespan of at least one year is expected. For fixing the sheet to an existing frame reinforced eyelets are placed every 1 m on each reinforced side. The weight of the 4×5 m sheet is 4.27 kg which is packaged in bales of five pieces, resulting in a volume of $0.045\,\mathrm{m^3}$. This packaging allows 2200 to 3500 sheets transported in one TEU container.[12]

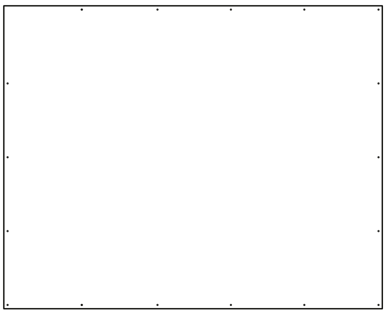
In contrast to erecting tents, covering existing or new structures with plastic sheeting requires construction skills which may not be available on-site. If existing structures are not usable, plastic sheeting alone does not solve any problems of the inhabitants. Plastic sheeting may also not be the only available and useful material so it is always worth to consider local alternatives. Often it can be combined with other locally sourced material like grass to protect the plastic sheet from UV light.[13]

The plastic tarpaulin is of good quality, can be transported easily in large quantities and is usually cheap to buy. Especially for natural disasters with non displaced people it offers a fast and great opportunity for protecting damaged structures from further damage. Reuse ability often happens for annex buildings like staples once the main structure is fully repaired with durable materials. The material is not biodegradable and suffers commonly from decay under direct UV-exposure. Ideally it should be used in conjunction with local materials to use the strength (rain proof) of the material to its full potential.

[11] Joseph Ashmore. *Plastic Sheeting: A Guide to the Specification and Use of Plastic Sheeting in Humanitarian Relief.* 13th July 2007, p.19ff.
[12] *Core Relief Items Catalogue*, p.23.
[13] Ashmore, *Plastic Sheeting*, p.13f.

Tarpaulin
sheet 4 x 5 m

Phase	emerg.	Climate		Earthquake	
Area m²	20	Price/m² €	0.30	Lifespan	1 year
Plotsize m²		Weight kg	3.8	Labour	
Room height		no per TEU	2200	Build time	
Local Material	no	Flood safe		Extendable	yes



alluminium eyelet
every 100 cm for fixation

Images: Shelter Design Catalogue, 2016

1m 2.5m 5m

3.1.4 More Than Shelters - Domo

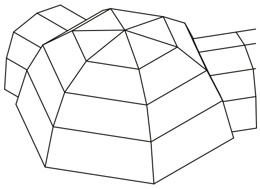
Since 2012 the More Than Shelters project works together with survivors and refugees to redesign traditional emergency tents to overcome existing design limitations. The main characteristic of the Domo system is that it can grow over time by connecting units together. Connectability of different units with each other increases privacy by providing separate rooms, comply with social norms or allows for bigger useable spaces. Upgradeability to a transitional shelter is intentional with an over provisioned aluminium structure. Mass production of the tent is running since 2015 and currently it is used in 30 places around the globe mainly for schools, hospitals and community spaces. A commercial line of the tent is also available for glamping usage at festivals. The hexagonal shape offers $24\,m^2$ of useable space with an edge length of 3 m. Because of the truss like internal structure the room height of 260 cm can be used very efficiently and allows to be standing upright in most places. Similar to the other analyzed tents it sits directly on the ground without elevation. In contrast to the other researched tents there are no guy ropes needed in this design.[14]

The truss-like aluminium pipe structure comes completely pre-assembled in one piece which just needs to be extended during buildup removing most complexity from the assembly process. The floor is made from pure polyester PVC tarpaulin with a specific weight of $540\,g/m^2$ which is roughly three times the density of the floor tarpaulin of the UNHCR tent. Metal pegs are used to secure the floor tarpaulin but not the main structure which just stands inside the tent and does not directly touch the soil. Wind resistance is only specified vaguely to be *"storm-level"*. A snow resistance of 5 kN is specified. Four different wall materials are available depending on the deployed environment and intended usage.[15]

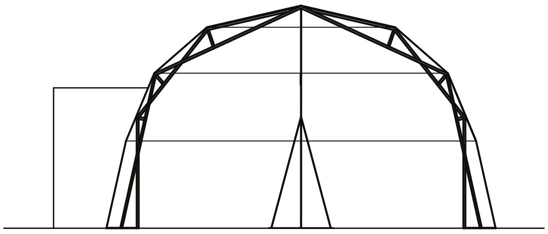
The Domo shell comes in three different soft configurations ranging from pure cotton with $285\,g/m^2$ and a hydrostatic head of 34 hPa to pure Ripstop polyester PU with a hydrostatic head of 294 hPa. A solid configuration with insulating sandwich panels is in prototyping phase. For the interchangeable panels forming the walls, lifespan depends on the material and maintenance. Weight is around 140 kg for the cotton standard configuration. The price is around 2850 € for the standard cotton shell configuration.[16]

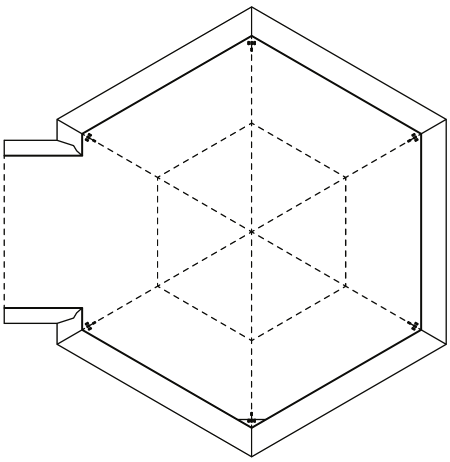
The used materials are durable and of high quality. Multiple structures can be combined creating good possibilities for upgrades or extension. Wall materials can be adapted according to climatic requirements by choosing between three tarpaulin based products from the vendor. In the cotton version the outside tent cotton canvas is connected to the floor tarpaulin using zippers almost directly on the level of the ground. It is unclear how water resistant this design is in comparison to the UNHCR tents which feature a 20 cm high woven and pulled up polyethylene part. Additionally no mud flaps exist in this design in comparison to the UNHCR tents. Because of the complexity of the structure the author of this work doubts that repair or replacement of the aluminium structure is trivial with original parts sourceable only from the supplier.

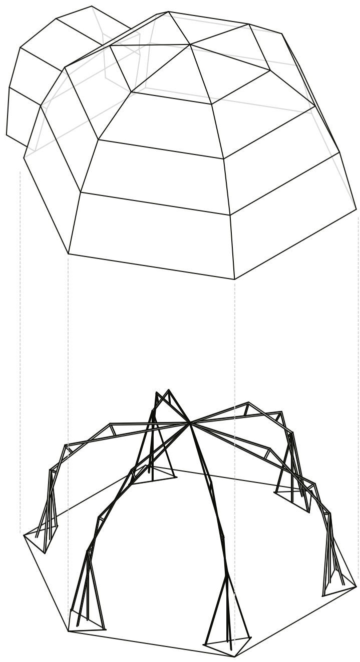
[14] Daniel Kerber. *Domo*. 2016. URL: `https://www.mts-socialdesign.com/_files/ugd/f11c20_ad33c81f929d492a92fc3fea2408e34d.pdf` (visited on 20/01/2022).
[15] Ibid.
[16] Ibid.



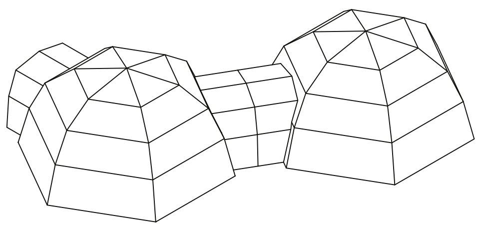
Phase	emerg.	Climate	Csa	Earthquake	high
Area m²	24	Price/m² €	119	Lifespan	10 years
Plotsize m²		Weight kg	140	Labour	2/0
Room height	260	no per TEU	33	Build time	30 min
Local Material	no	Flood safe	no	Extendable	yes







Structure



Extension schema

Frame

Dessert

Tropic

Winter

Solid
(under development)

Images: Daniel Kerber, Domo, 2016

1m 2.5m 5m

3.1.5 Advanced Shelter Systems - Shiftpod

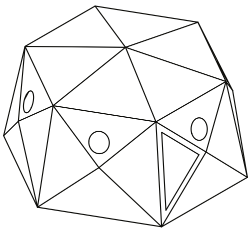
The Shiftpod structure is made from an *"integrated carbon fiber frame for easy set up / strike (and a) hexagon patterned patented multi-layer fabric system (with) dark out(er) layer"*.[17] The hexagon shape has a side length of 193 cm forming 13 m^2 of usable inside space. Two units can be combined together using a vestibule tunnel connector.[18]

The wall material is insulating and reflecting and was designed initially for usage in desertic climates. The floor is waterproof and can be zipped off. Structure and hull material are already pre assembled and just a hammer for inserting optional pegs for guy ropes is required. For additional rainproofness and increased sun reflection an additional shield layer secured with pegs and guy ropes is available. The structure is able to withstand winds of up to 80 km/h.[19]

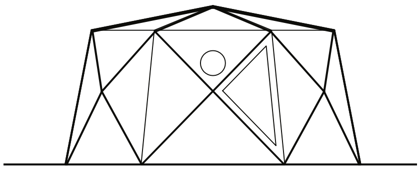
It weights around 29 kg and packaged it measures 195×33×33 cm resulting in 147 units transportable in one TEU container. The Shiftpod is commercially available for campers with a price of 1700 $ in the online shop of the producer `shiftpod.com`.[20]

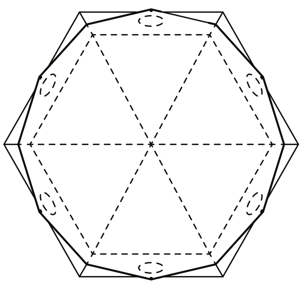
The Shiftpod has an interesting geometry allowing very easy and fast assembly and efficient space usage. The optional guy ropes help to mitigate the wind risk for the heigh structure. As the unit was designed for desertic climates it is insulated and reflects the sunlight without the need of a shade net (although an extra shade net is available for increased rain protection). With the festival design background no heating or cooking possibilities exist inside the structure. The composite material is very special, which makes it unlikely that local repair can be performed.

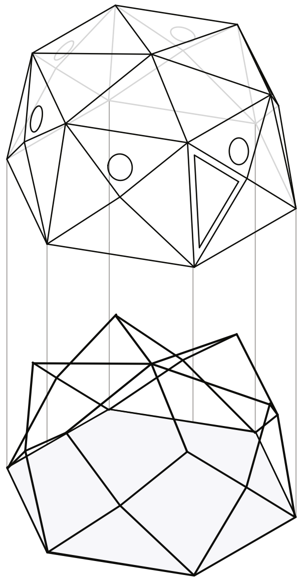
[17] *SHIFTPODIII.* URL: `https://shiftpod.com/shiftpod/shelter/shiftpodiii` (visited on 09/01/2022).
[18] Ibid.
[19] Ibid.
[20] Ibid.



Phase	emerg.	Climate	Aw	Earthquake	high
Area m²	13	Price/m² €	130	Lifespan	1 year
Plotsize m²		Weight kg	29	Labour	1/0
Room height	210	no per TEU	147	Build time	2 min
Local Material	no	Flood safe	no	Extendable	no







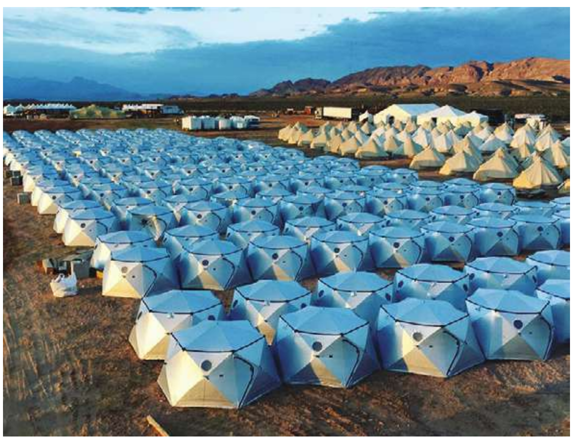


Image: SHIFTPODIIL

1m 2.5m 5m

3.1.6 Designnobis - Tentative

The shelter was designed in 2015 by Designnobis as an easy to transport and quick to assemble housing unit for natural disaster affected. With 4×2 m it creates 8 m^2 of usable space which, according to the designers, can provide shelter for two adults and two children. It must be noted that with the Sphere recommendations of 3.5 m^2 per person, the design only can shelter two people.[21]

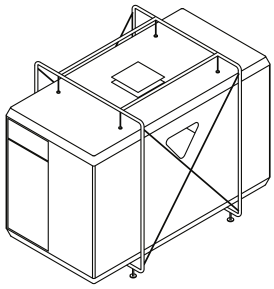
The elevated aluminium frame touches the ground on four metal legs and supports a fibre glass floor and roof panel. The all climate walls are made out of weather-resistant fabric with mineral insulation. With two doors independent entrance is possible, although there is no internal space division in the unit. Above the two entrances on the short side there are two windows.[22]

Packaged size is 4×2×0.3 m resulting in a volume of 2.4 m^3 which allows to transport eight units in one TEU container. In a 40 foot container 24 units could be transported because of a more efficient fitting. The price is estimated to be 2500 $, although no mass production started.[23]

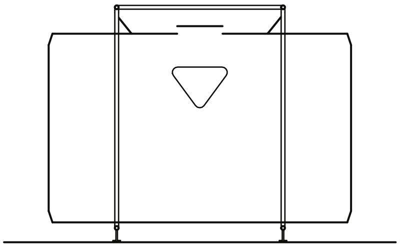
This design was added in this work as a generic reference for many similar *"pod"*-style projects which commonly are slightly compactable, rapidly deployable plastic boxes, but not customizable at all. Another example of such a design is the RD-Shelter by Suisse which never made it into mass production.[24] Also the Humanihut with 1000 kg for 12.8 m^2 of usable space is just a flattened container pod structure. Only six units can be transported per TEU container.[25] Or the 46 m^2 Prefab Modular Pod from Hariri & Hariri architects.[26]

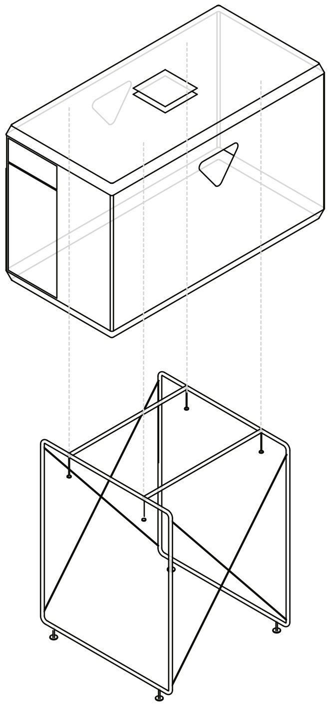
What all of those pod designs share is that they come prefabricated without the need for any local material or skilled labour for erecting them. Some of the pods can be combined to form bigger pod structures with interconnects, greatly increasing flexibility. Their weight to useable space ratio is quite bad but often the material is durable but not very ecological. Commonly hard plastic, steel and aluminium is used. Repairability is very limited because of the prefabrication and the materials. Personalization is often limited but sometimes the outside appearance can be customized with paint. Packaged transportation efficiency is commonly quite bad because of the high level of pre assembly. Often no thoughts on the foundation techniques are put, posing risks of wind uplift. Deviating space usages from the suggested configurations are hard because of the limited size or because of the rigid design.

[21] *This Pop-Up Shelter Brings Smart Design to Disaster Relief.* 31st Aug. 2015. URL: https://www.mentalfloss.com/article/67942/pop-shelter-brings-smart-design-disaster-relief (visited on 09/01/2022).
[22] Ibid.
[23] Eric Oh. *Designnobis' "Tentative" Provides Compact, Individual Living Spaces for Disaster Victims.* 29th Aug. 2015. URL: https://www.archdaily.com/772497/designnobis-tentative-provides-compact-individual-living-spaces-for-disaster-victims (visited on 09/01/2022).
[24] Paul Grey. *RD-shelter.* 2016. URL: https://www.crowdfunder.co.uk/p/rd-shelter (visited on 10/01/2022).
[25] *Humanihut - Rigid Redeployable Infrastructure.* URL: https://www.humanihut.com/emergency-management (visited on 07/02/2022).
[26] Lisa Magloff. *Refugee Shelters That Pop up at the Push of a Button.* 12th July 2021. URL: https://www.springwise.com/innovation/architecture-design/prefab-cabins-emergency-shelters-hariri (visited on 23/01/2022).



Phase	emerg	Climate		Earthquake	
Area m²	8	Price/m² €	312	Lifespan	
Plotsize m²		Weight kg		Labour	
Room height	250	no per TEU	8	Build time	
Local Material	no	Flood safe	yes	Extendable	no





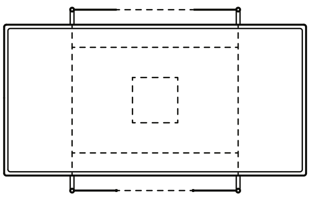


Image: Eric Oh. Designobis

1m 2.5m 5m

3.1.7 Abeer Seikaly - Weaving a home

Weaving a home is a design project creating a portable dome shelter. *"The double layered membrane dome utilises the property of elastic bending in a lightweight pole trusion to induce a stable antiballistic shape into the membrane."*[27] The project tries to bring traditional nomad techniques like weaving into the twenty-first century by creating a visually appealing and performative shelters. There is a very strong community focus in the project by including the future inhabitants in the design and building process. Maximum height of the structure is 240 cm but with a spherical ⌀40 cm water tank mounted at the highest point the useable height is just 200 cm. The diameter of the circular plane is 5 m creating 19.6 m^2 of usable inside floor space.[28]

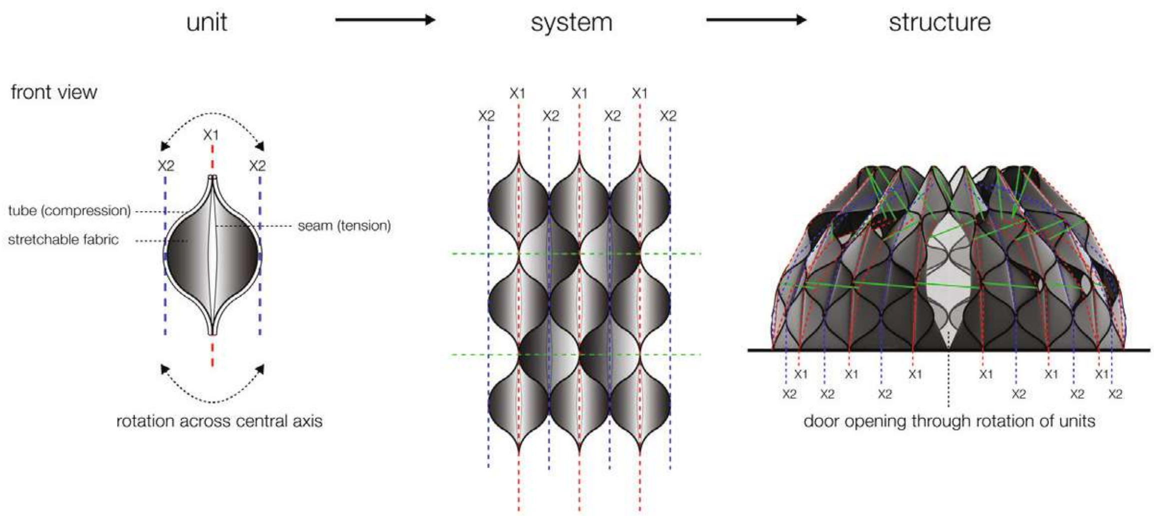
An internal pre-stressed metal frame creates a durable shape for the two membrane layers. The outer membrane allows to collect solar energy with is fed into a battery. This membrane also supports opening or closing pockets for ventilation. Pockets to store belongings are formed by the inner membrane. Rain water is collected in the tank and water from a water source can make its way up to the tank by just relying on heat exchange induced by natural convection.[29]

The membrane can be flat-packed for transportation. The project is still in an early phase with no full size prototype built so far. Packaged size and price are not available yet.[30]

The design is an interesting combination of traditional weaving techniques and modern knowledge about structure and geometry. As the shape is planed to be created by the inhabitants different sizes and materials are possible, which could create diversity. It is unclear how and if the design could be insulated but the two layer membrane system could act as very basic form of insulation. The structure can open up in summer increasing the ventilation while allowing controlled ventilation in winter to retain the heat. As the design is still in an early phase no details on the required structure stretching the membrane layers is available. An interesting design point is the mounted water tank in the middle of the tent providing extra weight potentially compensating wind loads (while weakening seismic resistance). The design has still many problems to solve (protection from rain and surface water etc) but offers an interesting possibility of combining tradition with modern sustainable crisis responses.

[27] *Weaving a Home*. 2013. URL: `https://abeerseikaly.com/weaving-a-home-2013/` (visited on 10/01/2022).
[28] Ibid.
[29] Ibid.
[30] Ibid.

Phase	emerg	Climate		Earthquake	
Area m²	19.6	Price/m² €	?	Lifespan	?
Plotsize m²		Weight kg	?	Labour	?
Room height	200	no per TEU	?	Build time	?
Local Material	yes	Flood safe	no	Extendable	?



Images: Weaving a Home, 2013

1m 2.5m 5m

3.2 Emergency phase - Local design

The local designs were developed for specific situations and places by international institutions. Generally their parts are not available as kits and they try to use local available material as much as possible.

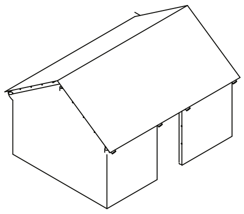
3.2.1 UNHCR Wooden gable frame shelter

This 3×4 m shelter with a gable roof was designed in 2013 specifically for the Ajuong Thok refugee camp, South Sudan which is in a wooded area. The unique aspect of the design is the aim both on the emergency phase and the permanent phase by using different wall materials according to the phase. Different sized versions exist, ranging from 3×4 m to 4×5 m.[31]

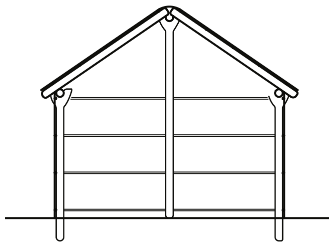
The structural wood construction is made of timber, bush wood or bamboo. The wall poles are covered with different materials according to the required durability or phase. During the emergency phase tarpaulin is sufficient. For a more durable version walls are covered with thatch cladding, adobe plastering or corrugated galvanised iron sheets. The structure sits directly on the ground which can be either plain concrete or compacted earth. Depending on the material the lifespan and estimated price varies from 223 $ to 368 $.[32]

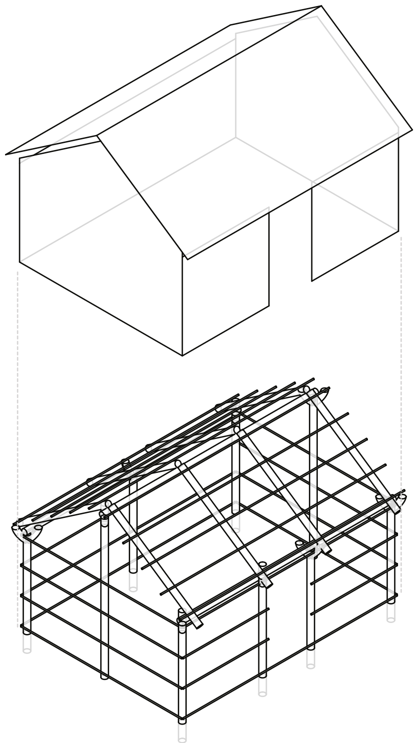
The design is interesting because it allows for different sized shelters and comes with different materials. Initially it can be covered with provided UNHCR plastic tarpaulin and later improved with more local materials. The price is very competitive because mostly local materials are used. Especially lead and transportation times can be reduced effectively by using only local materials. Also technical elements like windows and doors are sourced locally, creating opportunities for local businesses. As the locally sourced materials are not accurately cut and used as a whole (timber poles) technical knowledge is required for building up the structure. Other than the submerged side poles no bracing is added to retain wind loads. This can lead to issues, especially as the shape of the shelter is not very compact. The recommended termite treatment of the buried poles is best effort but a constructive solution would be more sustainable. Because of the lack of bracings, seismic resistance is not expected to be very high, especially as no structural wall panels are used. With the poles just buried the risk of wind uplift is only partly addressed. Also the lack of a raised floor increases the risk of sudden heavy rainfalls severely affecting the living area.

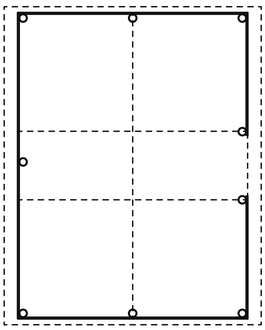
[31] *Shelter Design Catalogue*, p.22f.
[32] Ibid., p.22f.



Phase	emerg.	Climate	Bsh	Earthquake	low
Area m²	20	Price/m² €	11	Lifespan	1-5 years
Plotsize m²		Weight kg		Labour	1/2
Room height	170/270	no per TEU		Build time	6 hours
Local Material	yes	Flood safe	no	Extendable	?







Images: Shelter Design Catalogue, 2016

1m 2.5m 5m

3.2.2 UNHCR Tuareg Shelter

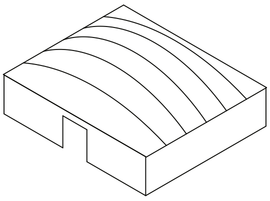
This square shaped shelter with a dome roof realized in 2012 is targeting nomad refugees from Mali, currently living in camps in Burkina Faso. Special attention was put on keeping the traditional Malawi tent architecture. The size of 4.3×5.3 m creates a usable space of 21 m^2.[33]

The main wooden structure forming the frame for walls and the roof consist of of a 4×4 grid of eucalyptus poles (⌀10 cm) which are buried 30 cm in the ground for stability. No wind bracing exist. The roof is covered with plastic tarpaulin to provide water resistance. Walls are covered using straw mats or with plastic sheeting.[34]

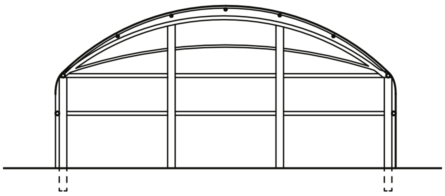
Lifespan is estimated with around two years depending on the used wall and roof materials. In general plastic sheeting is considered more durable. The price varies between 288 $ with just plastic sheeting to 376 $ with straw mats for the wall.[35]

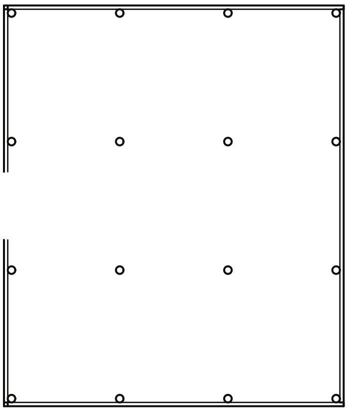
This shelter design tries to continue the local nomadic architecture tradition. This greatly helps to increase the participation of the future inhabitants in the construction. The structure is compact on all sides creating a very good wind resistance. Provided tarpaulin helps to rapidly create shelters while other, local materials are not available. The design offers a decent inhabitable area but the low usable height is not sufficient for the hot climate. The direct poles directly buried in the ground increase the risk of termite damage over time. Also the lack of a raised floor increases the risk of sudden heavy rainfalls severely affecting the living area.

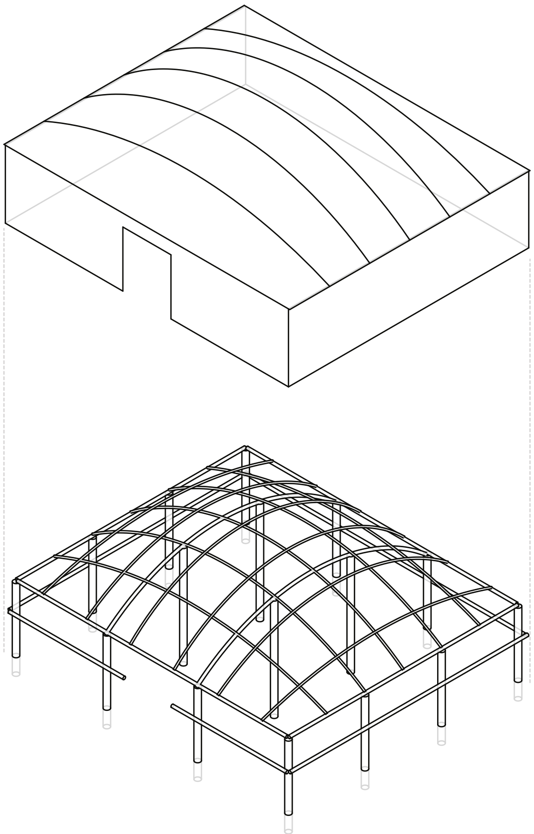
[33] *Shelter Design Catalogue*, p.30f.
[34] Ibid., p.30f.
[35] Ibid., p.30f.



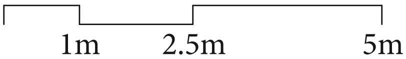
Phase	emerg.	Climate	Bsh	Earthquake	low
Area m²	21	Price/m² €	13	Lifespan	2 years
Plotsize m²		Weight kg	5000	Labour	1/2
Room height	120/170	no per TEU	5	Build time	1 day
Local Material	yes	Flood safe	no	Extendable	?







Images: Shelter Design Catalogue, 2016



3.2.3 UNHCR Tuareg tent

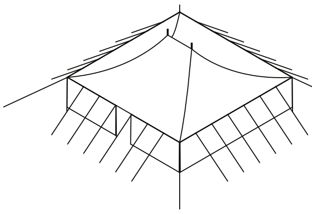
The tent structure was developed in 2012 as a response to the refugees from West Sahara fleeing to Tindouf, Algeria. The double central pole tent offers 49 m^2 of usable space with its 7×7 m layout. Because of guy ropes for wind resistance the foot print is 11×11 m. Smaller sized versions with 5×5 m and 6×6 m are also available.[36]

The floor is covered with tarpaulin or mats. The poles made out of bamboo, timber or metal hold the cotton canvas sheet for the roof. The 28 poles alongside the walls are buried 30 cm deep into the ground for stability. A 30 cm foundation is expected to be made out of plain concrete or compacted earth. Walls and the roof are made out of two layers, with cotton on the outside and colorful blended cloth for the inside. The cotton and blended cloth was delivered in 150 cm rolls and sewed by the inhabitants with traditional nomad techniques.[37]

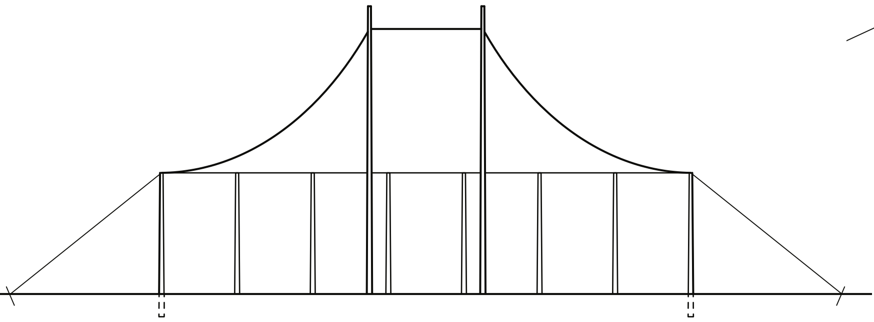
The total price is 1190 $ including the cost of the cotton canvas, blended cloth, transportation and labour. The material cost alone is 821 $.[38]

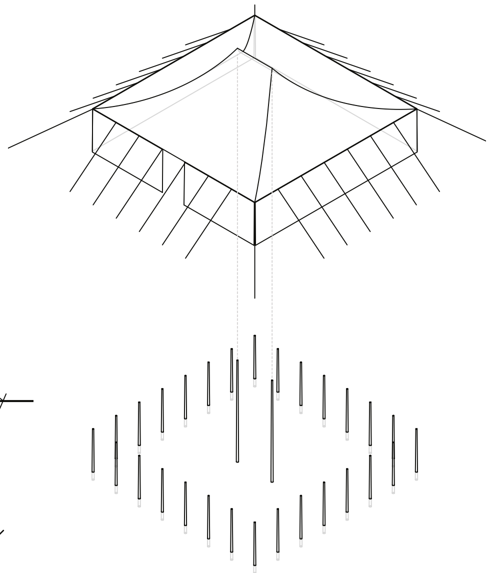
This design uses traditional techniques from local nomadic cultures. Area and maximum height are very good for the desertic climate. The supplied materials are all low tech and repair can be done easily by the inhabitants. The double layered shelter was provided in different colors corresponding to the preferences of the inhabitants allowing for customization of the interior look. Because of the known design the inhabitants can contribute to the construction. The tall shape requires long guy ropes to secure the tent against strong wind. This leads to a very inefficient space usage and a very big footprint. Like all tent structures there is no thermal mass resulting in no buffering between high day and low night temperatures.

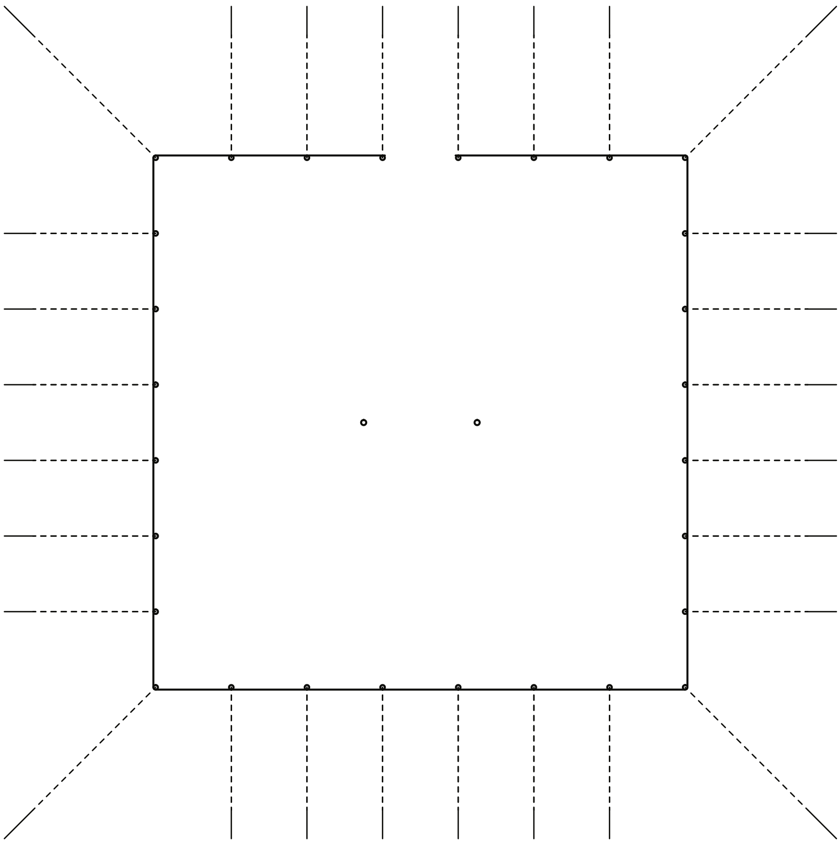
[36] *Shelter Design Catalogue*, p.34f.
[37] Ibid., p.34f.
[38] Ibid., p.34f.

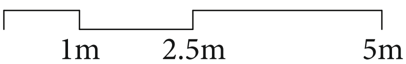


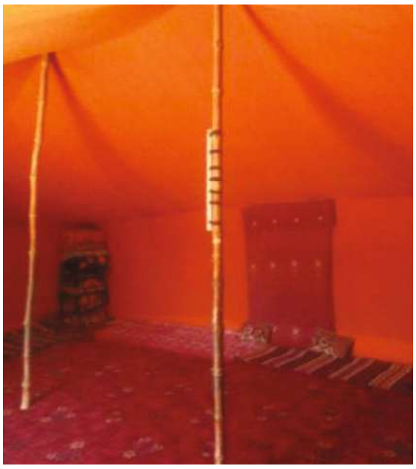
Phase	emerg.	Climate	BWh	Earthquake	low
Area m²	49	Price/m² €	24	Lifespan	2 years
Plotsize m²	121	Weight kg		Labour	1/2
Room height	150/380	no per TEU		Build time	1 day
Local Material	yes	Flood safe	no	Extendable	no











Images: Shelter Design Catalogue, 2016

3.2.4 UNHCR Tukul Shelter

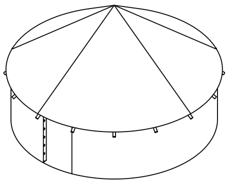
The round shelter inspired by traditional housing forms and made of locally available materials was developed in 2012 in South Sudan. With a diameter of 5.25 m it offers a usable space of 21.6 m^2. Usable height ranges from 160 cm close to the wall to around 355 cm in the center.[39]

A 30 cm foundation is expected to be made out of plain concrete or compacted earth. The wall poles forming the structure are made out of bush wood, timber or bamboo and are buried 30 cm deep in the ground. They are covered with tarpaulin, grass cladding or mud plastering. The conical roof with its timber structure is covered with tarpaulin or thatch. A 15 cm gap between wall and roof provides good ventilation.[40]

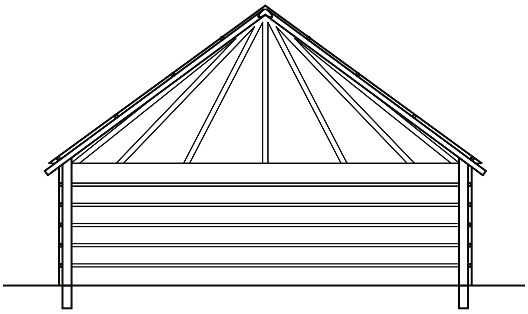
With three people the shelter can be erected in one day and the overall lifespan is around two (with plastic tarpaulin) to four years (with adobe brick). The total cost including transportation, labour and material is 250 $ for the version with tarpaulin covered walls. The version with local adobe plastering is estimated with a total price of 209 $.[41]

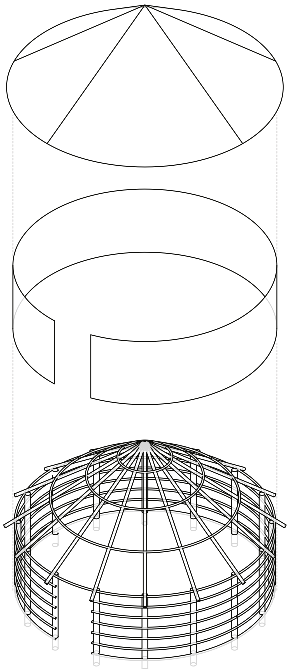
The round shape is adapted from locally known architecture tradition and works in different diameters. As all materials are sourced locally, future repairs can be easily performed while strengthening local supply chains. The design is very flexible and allows to use different materials for structure and for the roof, increasing flexibility for the procurement. Individuality is possible within the range of the available materials. It has very good wind resistance with its round shape and small roof overhang. Without a central pole the whole floor area can be used flexible. The design does not include windows but given the non structural cladded walls adding windows should be not an issue. The round shape does not offer many possibilities for additional bracing which limits the seismic resistance of the shelter. Surface water problems could arise because the construction is directly placed on the ground. The lack of a proper foundation reduced the wind uplift resistance of the shelter.

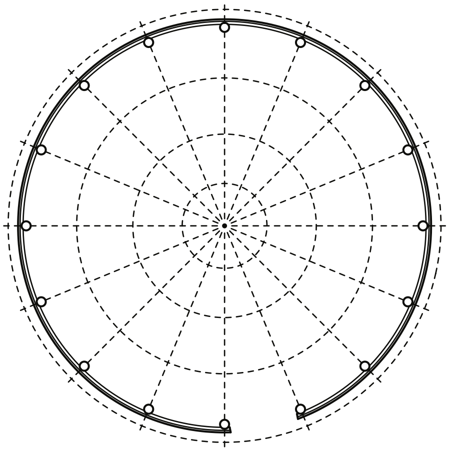
[39] *Shelter Design Catalogue*, p.38f.
[40] Ibid., p.38f.
[41] Ibid., p.38f.



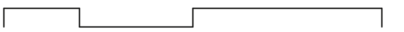
Phase	emerg.	Climate	Aw	Earthquake	moderate
Area m²	21.6	Price/m² €	10	Lifespan	2-4 years
Plotsize m²	64	Weight kg		Labour	1/2
Room height	160/355	no per TEU		Build time	1 day
Local Material	yes	Flood safe	no	Extendable	no







Images: Shelter Design Catalogue, 2016



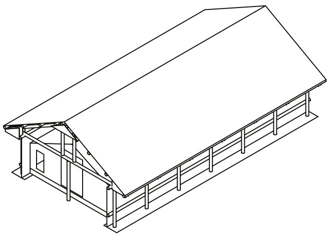
3.2.5 UNHCR Tent shelter

The shelter with pitched roof was developed in 2009 in Afghanistan to withstand the harsh climate. The initial task of the structure is to provide a second layer to a standard UNHCR emergency tent and a covered space for household activities. It is very easy to disassemble and relocate or upgrade the shelter. The shelter covers an area of 4.3×9.4 m.[42]

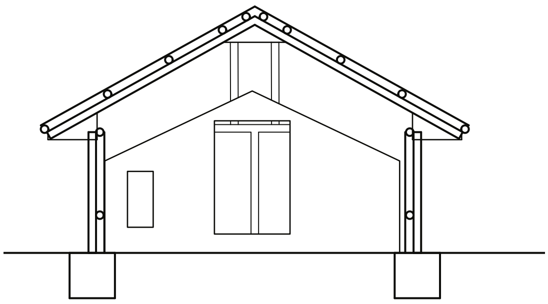
The pre-fabricated (drilled, cut) roof trusses are stabilized with plywood plates. The bamboo structure can be covered with tarpaulin or mud brick for walls and iron sheets or tarpaulin for the roof. The 14 side poles are buried 60 cm deep into the ground for stability. No foundation is mentioned or included in the price but the technical drawings suggest a 60 cm deep concrete strip foundation. The total price of the tarpaulin covered version of 813 $ is mainly driven by the bamboo and labour costs. Material cost alone is 560 $.[43]

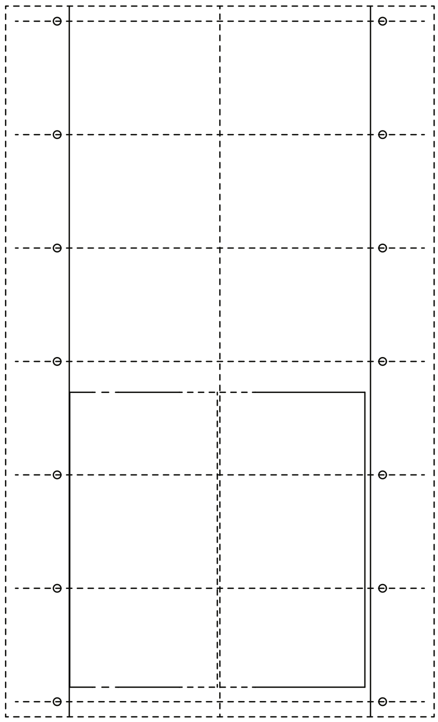
This design fits very well in with the idea of providing quick and rapid emergency shelter and then improving it over time. Because the initial tent shelter is not removed during the upgrade it can be continuously inhabited. The partially prefabricated design can be extended in length over time and allows easy assembly on-site. An interesting point of the design is that one side is left intentionally open to allow light and ventilation. It is very climate appropriate because cold climates require covered outdoor space for daily activities. The bolted structure can be disassembled and relocated when the need arises. The design is very basic and allows the people to upgrade it further with more durable materials. But it is left to the inhabitants to strengthen the structure when upgrading to more heavy materials. As there are no clear recommendations on how to upgrade the missing walls wrong construction techniques and materials can lead to reduced seismic resistance by adding too much weight and not enough bracing. Additional guy ropes could reduce the wind uplift risk. Wind bracing with plywood plates is only added to the axis of the trusses creating a risk for horizontal deformation in the other axis during strong winds.

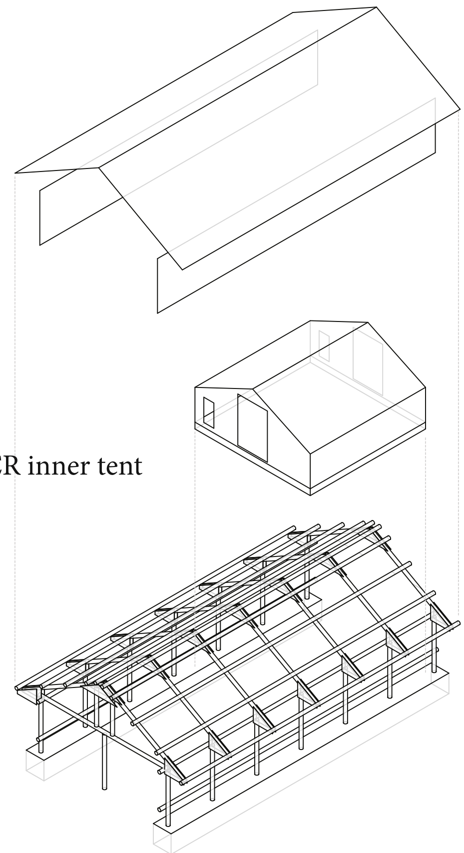
[42] *Shelter Design Catalogue*, p.42.
[43] Ibid., p.42.



Phase	emerg.	Climate	Dsb	Earthquake	moderate
Area m²	38.7	Price/m² €	21	Lifespan	2 years
Plotsize m²		Weight kg		Labour	1/3
Room height	160/315	no per TEU		Build time	4 hours
Local Material	yes	Flood safe	no	Extendable	no







Images: Shelter Design Catalogue, 2016

3.3 Transitional phase

3.3.1 Historic - Refugee camp Gmünd

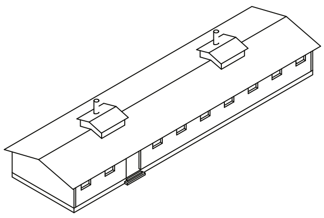
The refugee camp in Gmünd, Austria was a camp for internally displaced people fleeing the eastern parts of the *K&K* empire during World War I and was in operation from December 1914 till August 1918.[44] Maximum occupancy was reached in May 1916 with almost 30 000 people.[45] Leaving and entering the camp required a permit for inhabitants and people visiting. The camp was enclosed by a fence and guarded by military units. Even after the offical closing of the camp it was constantly inhabitated till 1926 when new communal housing buildings on the site were constructed.[46]

The initial design was wooden units with a size of 40.2×10.4 m (420 m^2) designed to host 250 people each, resulting in just 1.6 m^2 per person. Private space per person was just a stacked bed with around 2×0.8 m. Initially no inside communal spaces existed. Room height on the lowest point along the sidewalls was around 300 cm. The whole structure was raised by around 65 cm and based on concrete point foundations.[47]

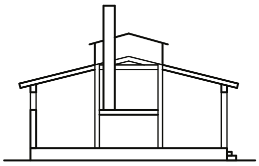
Later upgrades included concrete floors, brick chimneys for improved fire safety and wall cladding for improved visual appearence and windproofness. Price of one unit was around 37 000 €. [48][49] Construction was performed by private contractors from the surrounding areas, but later also by the inhabitants themselfs. The amount of people per unit was reduced to only 160 people in 1915. At this point the camp was hosting 23 000 internally displaced. Also the design with stacked beds was abandoned and increased community spaces were added. Initial construction material was timber, but with later designs starting 1916 a partly solid construction was prefered because of extended lifespan. In 1917 newer types called family baracks changed the size to 45×10 m consisting of four sleeping compartments arranged around the chimney with one shared cooking and sanitation room. Construction quality was low, resulting in deaths because of cold temperatures.[50]

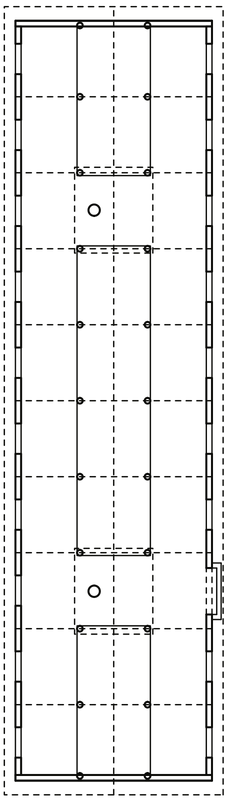
The barack style housing was needed to host the massive number of refugees and internally displaced people during World War I. The design was standardized to lower construction costs and increase build time. It was cheap and easy to construct and needed mostly wood as construction material. Because of the lack of insulation and war related shortages of fuel, harsh inside temperatures were common. The huge amount of people per unit in combination with inadequate ventilation (to preserve the heat) lead to rapid decay of the wood construction. The baracks had an elevated floor as protection against surface water. Private space was almost non existent.

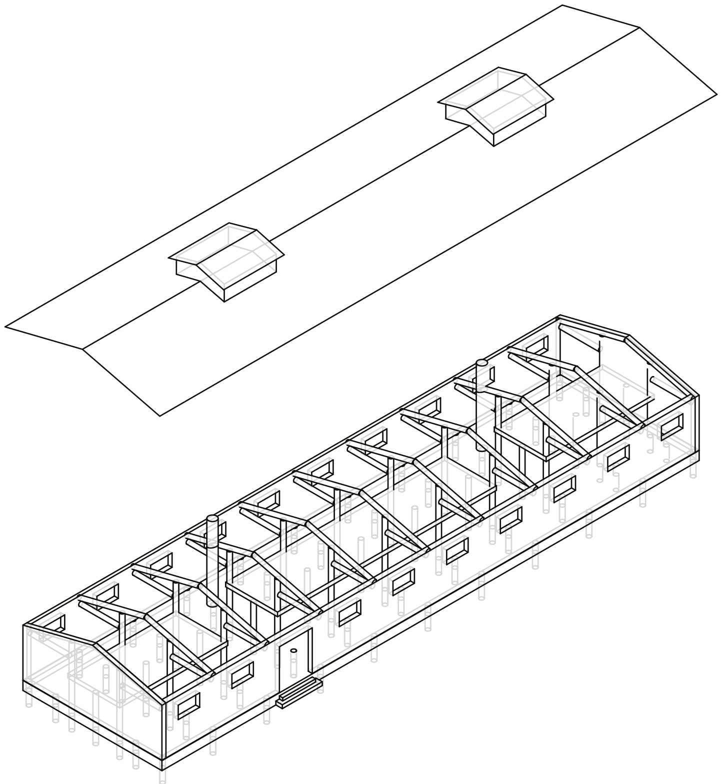
[44] Martina Viktoria Hermann. *"Die Hölzerne Stadt. Das Barackenlager Gmünd 1914 – 1918."* PhD thesis. Graz: Karl-Franzen-Universität Graz, 2017, p.5.
[45] Ibid., p.64.
[46] Ibid., p.148.
[47] Ibid., p.77.
[48] `https://www.eurologisch.at/docroot/waehrungsrechner/` 20000 Kronen in 1916
[49] Martina Viktoria Hermann, *"Die Hölzerne Stadt. Das Barackenlager Gmünd 1914 – 1918."*, p.71ff.
[50] Ibid., p.78ff.



Phase	trans.	Climate	Cfb	Earthquake	low
Area m²	420	Price/m² €	88	Lifespan	
Plotsize m²		Weight kg		Labour	
Room height	340/460	no per TEU		Build time	
Local Material	yes	Flood safe	yes	Extendable	yes







Images: Martina V. Hermann , 2017

1m 5m

3.3.2 RAD-Normbaracke

The development of the RAD-Normbaracke started in 1933 with the foundation of the FOKORAD (*"German: Forschungs- und Konstruktionsgemeinschaft der Reichsleitung des Reichsarbeitsdienstes und der Deutschen Holzbau-Konvention"*[51]) which was part of the Reichsarbeitsdienst (RAD) managing forced labour in Nazi Germany. The baracks were produced in an industrial fashion, with usages in military, forced labour camps and deportation during the Holocaust.[52]

The predecessor of the RAD baracks was the Doecker-Norm-Baracke which was already prefabricated and shipped in boxes in 1910. All elements were marked with numbers and letter codes for easier and faster assembly.[53]

Main advantages of baracks are the transportability, the rapid deployability and the adaptability allowing different functions. Most commonly a panel frame (German: Tafelbauweise) construction method was used. The baracks use a raster of 3.3×8.14 m. Organization of camps and baracks in a raster fashion allows to make objects and people easily addressable.[54]

The RAD-Normbaracke RL IV/4 from 1936 was mainly used for housing. It consisted of four compartments and had an overall size of 26.6×8.14 m ($216\,m^2$). Because of the modular design construction could be shorter or longer by adding or removing a full length unit. Concrete strip foundations on the long side were used and the floor was slightly elevated from the ground. Each room featured one chimney in the center and four windows.[55]

The designs were used long after World War 2 ended. Adapted designs were produced in Eastern Germany till 1980 and used for administration purpose and to host construction worker.[56]

The Normbaracke was designed in a very standardized military way. As material was scarce, material usage was optimized. The systems aims to create general purpose rooms with fixed width and varying length to suite a broad range of usages. Because of the prefabrication and standardization construction an on-site buildup is fast. When only one family is placed per room the design outperforms tents by far. The permanency of the concrete foundations could lead to rejection of the local population. Combining multiple units for families together is more efficient but reduced the flexibility and privacy of the design for each family. The design is very rigid and does not allow any different shape of the overall structure other than adapting the length.

[51] Axel Doßmann, Jan Wenzel and Kai Wenzel. *Barackenlager. Zur Nutzung einer Architektur der Moderne*. transcript-Verlag, 25th Sept. 2015, pp. 220–245. ISBN: 978-3-8394-0550-5, p.6.

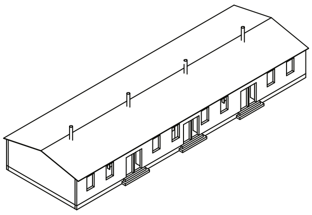
[52] Ibid., p.6.

[53] Ibid., p.16.

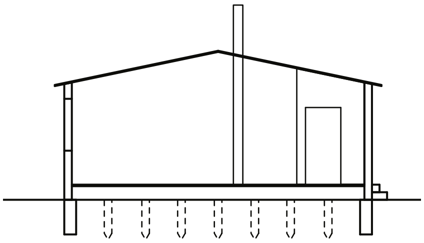
[54] Doßmann, Wenzel and Wenzel, *Barackenlager. Zur Nutzung einer Architektur der Moderne*, p.6; Lore Mühlbauer and Yasser Shretah. *Flüchtlingsbauten: Handbuch und Planungshilfe : Architektur der Zuflucht: von der Notunterkunft zum kostengünstigen Wohnungsbau*. Berlin: DOM publishers, 2017. ISBN: 978-3-86922-532-6, p.68.

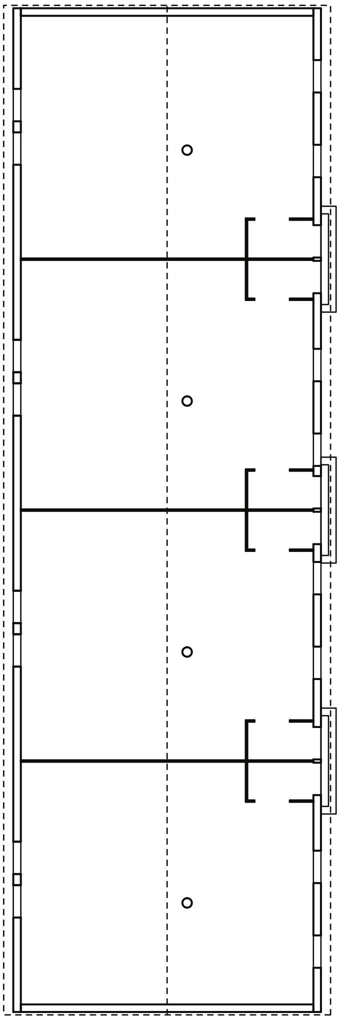
[55] Axel Doßmann, Jan Wenzel and Kai Wenzel. *Architektur auf Zeit: Baracken, Pavillons, Container*. Berlin: B_books, 2006. ISBN: 978-3-933557-66-7, p.124.

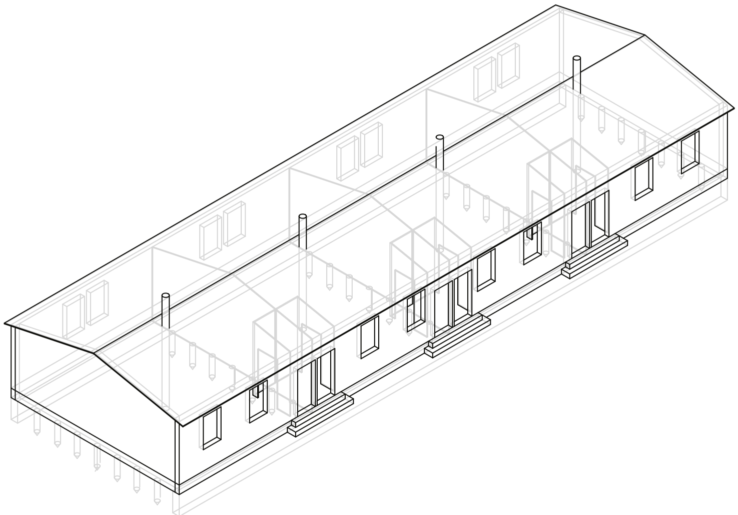
[56] Ibid., p.129.



Phase	trans.	Climate	Cfb	Earthquake	low
Area m²	216	Price/m² €		Lifespan	
Plotsize m²		Weight kg		Labour	
Room height	255/335	no per TEU		Build time	
Local Material	yes	Flood safe	yes	Extendable	yes







1m 5m

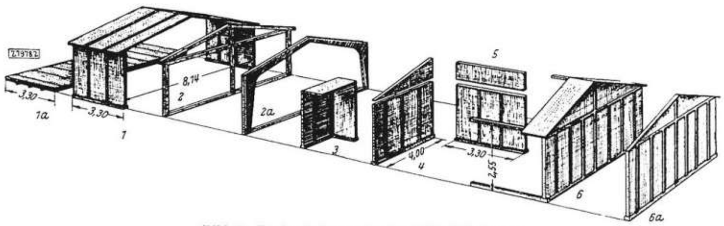


Bild 2. Baukastenbauweise des RAD-Holzhauses.

Hausteil 1 Binderfeld, 3,30 m lang (eine halbe Einheit), ohne Binder, ohne Fußboden
Hausteil 1a doppelter Fußboden für ein 3,30 m langes Binderfeld (= eine halbe Einheit)
Hausteil 2 Binder (mit Mittelstütze)
Hausteil 2a freitragender Binder
Hausteil 3 Windfang 1,80/1,10 m (einschl. Innentür)
Hausteil 4 halbe Querscheidewand
Hausteil 5 Längsscheidewand, 3,30 m lang
Hausteil 6 Giebelwand zur Vervollständigung bestehender Häuser
Hausteil 6a Giebelwand

Images: Normbaracken, 2016

3.3.3 K-Home Container

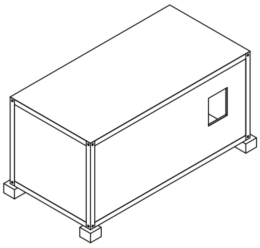
There are many suppliers for containers used to create office space or for refugee shelters. For this work K-Home was picked because it was deployed with 160 units in Athens, Greece for a resettlement camp in 2019. The unit 3×5.96 m with a height of 280 cm is wider than a classic 20 foot container which measure 2.4×6.1 m and has a height of 259 cm. The K-Home units are shipped packaged from China and the frame and the wall panels need to be assembled on-site. Units can be stacked up to three stories, although stacking was not performed in the project in Greece.[57]

The main structure is made out of bent 2.3 mm thick 160×160 mm steel profiles which are assembled on-site without the need for heavy equipment. Both the roof and the floor have a secondary steel structure to support the roof and floor panels which are assembled after the structure is completed. All parts are bolted together during assembly allowing easy disassembly and reuse afterwards. The containers have a flat roof which consists of a 5 cm glass wool insulation and a 0.5 mm thick galvanised steel plate to seal it off against rain. Walls come in panels made out of a sandwich construction with 0.4 mm steel plates inside and outside and a 5 cm rock wool insulation inbetween. The construction is designed to withstand wind loads of 120 km/h and resists a snowload of 0.6 kN/m^2. The price per unit without shipping is around 790 $.[58] Shipping costs from China vary a lot over time. No accurate estimate can be given during the current shipping situation.

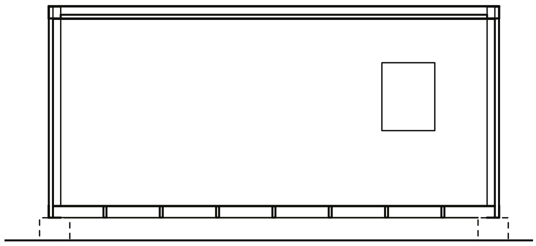
K-Homes are transported packaged and are assembled on-site to improve space efficiency. Also the price and durability of the materials used is very competitive. Because of the flexible design containers can be attached creating bigger units. As the walls comes completely pre-built only cosmetic changes can be done inside and outside. The design does not include a foundation concept, but it seems that containers are commonly put on concrete cubes. Without a proper foundation wind uplift and sinking of the whole container during rainfall poses a threat. The roof is not inclined (stackability) resulting in potential water damage over time. Because of the all metal surfaces the inside can considerable heat up in hot climates.

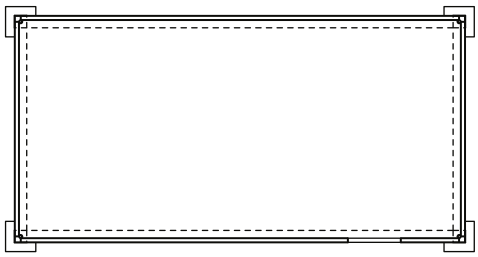
[57] *Prefabricated Container Camps.* 2021. URL: `https://khomechina.com/container-camp` (visited on 21/01/2022).

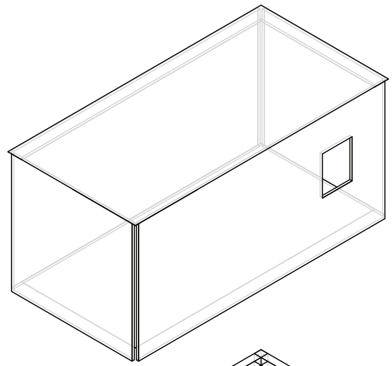
[58] Ibid.

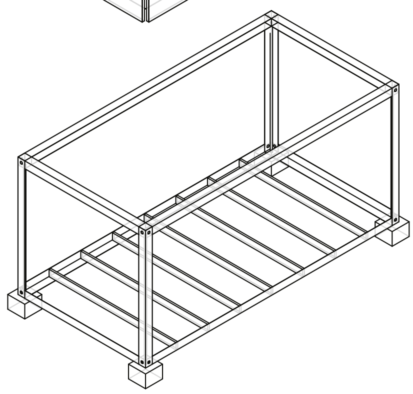


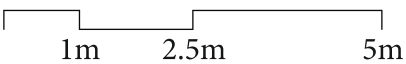
Phase	trans.	Climate	Csa	Earthquake	high
Area m²	18	Price/m² €	44	Lifespan	10 years
Plotsize m²		Weight kg	1160	Labour	
Room height	280	no per TEU	5	Build time	
Local Material	no	Flood safe	yes	Extendable	yes











Images: Prefabricated Container Camps, 2021

3.3.4 UNHCR Refugee Housing Unit (RHU)

This steel framed, panel covered shelter was developed in 2015 together with Better Shelter and IKEA. It is also refered to as flat-pack refugee shelter. It comes with all needed parts and tools packaged, including a solar energy system. The 5.7×3.3 m span 17.5 m^2 of useable space.[59]

The structure is made out of a galvanized steel frame which is assembled on-site. Walls and the roof are covered with semi-hard plastic panels made from 5 mm thick plastic sheets. Plastic connectors connect the panels and the metal structure. A ground anchor system consisting of ten ground connection points prevents drag and uplift using a combination of a ground plate, a pipe and an anchor. The design was tested to withstand a snow load of 0.1 kN/m^2 and a maximum wind speed of 100 km/h. An overall thermal resistance of 0.08 $m^2\,K/W$ was measured which leads to a recommended minimum temperatur of 5 °C.[60]

The lifespan is expected to be between 1.5 to 5 years depending on the maintenance, although the metal structure itself has an expected lifespan of more than ten years. The production happens currently almost entirely in Northern Europe. Pure construction price without transportation or labour is 1150 $. With the package volume of 1.14 m^3 weighting 160 kg 17 units can be transported in one TEU container.[61]

An interesting project from Better Shelter is investigating a version of the design where only the structural frame of the RHU is used in combination with local materials. This reduced the transportation costs and supports the local economy. The projects fits very well with the idea of upgrading existing transitional shelters to more permanent shelters.[62]

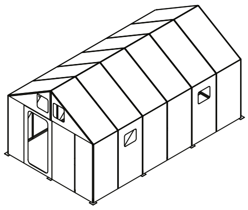
The original RHU was developed and evaluated very carefully by UNHCR creating a good fitting design. It can be erected fast and features a good transportation ratio. Additional attention was put into a good foundation design which works well on different surfaces. The internal bracing and light materials should prevent deformations from wind loads and seismic events. Downsides are clearly that the shelter is produced completely outside of the affected country not yielding any benefit for local economies. Walls are fully pre built and do not offer customization options. Units can not be combined and windows and doors can not be moved or adapted. All surface materials are made out of plastic, reducing the ability for the inhabitants to repair the shelter. There is no insulation available creating a shelter which is hard to heat in cold climates. Participation of the future inhabitants in the construction is low as only trained workers are tasked with the buildup.

[59] *Shelter Design Catalogue*, p.19.

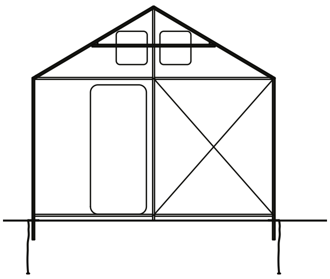
[60] *Better Shelter 1.2 Product Information*. 2018. URL: `https://bettershelter.org/wp-content/uploads/2018/09/Better-Shelter-1.2-Product-Specification.pdf` (visited on 17/12/2021), p.9ff.

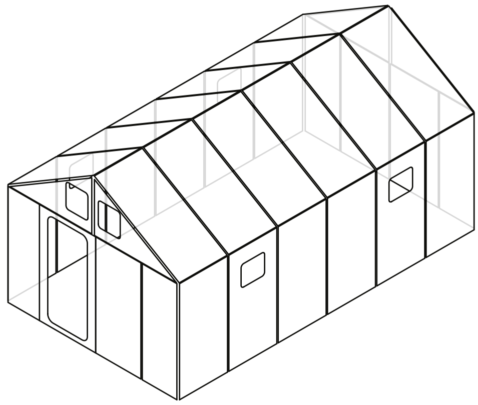
[61] *Shelter Design Catalogue*, p.19.

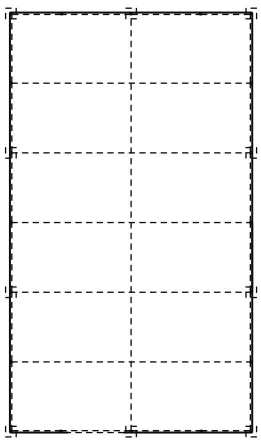
[62] *Preliminary Assessment of the Pilot Structure Approach to Humanitarian Sheltering*. June 2021.

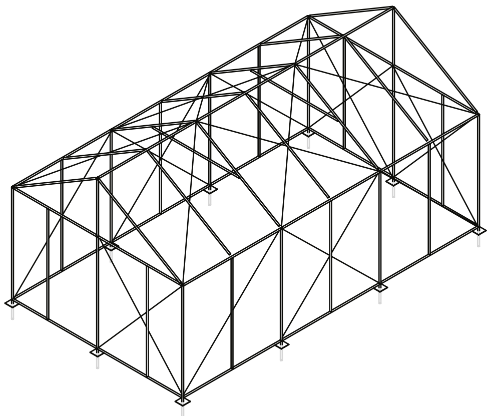


Phase	trans.	Climate		Earthquake	
Area m²	17.5	Price/m² €	66	Lifespan	1.5-5 years
Plotsize m²		Weight kg	160	Labour	4/0
Room height	180/260	no per TEU	17	Build time	5 hours
Local Material	no	Flood safe	no	Extendable	no









Images: Better Shelter 1.2, 2018

1m 2.5m 5m

3.3.5 Architects for Society - Hex House

The Hex House is described as a *"sustainable, rapidly deployable structure based on Structural Insulated Panel technology which can be shipped flat-pack and (be) easily assembled. It has the flexibility to be both a permanent or temporary structure."*[63] The geometry of the house is a hexagon with a side length of 4.25 m. The design can be expanded by adding units over time when demand for more space arises. Sanitary facilities, mentionable a composting biogas toilet, are included in the design. Usable space of a single unit is around 47 m^2. While on the side the room height is 300 cm the maximum height in the center is 330 cm to allow hot air to escape the shelter. Inside space is divided into five rooms. A porch can be added to the Hex House as attachment to create elevated and optionally covered outside space. The design mentions a potable water tank and a rain water tank under the structure, partly submerged in the ground.[64]

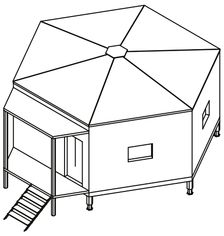
The main load bearing structure is made out of hollow structural galvanized steel tubes creating a hexagonal platform connecting in the middle in a star shape. Steel connection elements secure the load bearing structure together using bolts. The whole structure is elevated using six adjustable metal legs on each corner and one central leg. Legs are mounted on concrete point or metal screw foundations.[65]

Exterior structural wall panels (4×3 m) are 15 cm thick and consist of an interior and exterior metal shell with rigid insulation between. The insulation is adapted according to the deployment climate. The U-value of the exterior wall panel is 0.054 $W/(m^2 K)$. The outside can be covered with cement or wood cladding. Inside walls are 10.2 cm thick. Thickest element with 25 cm is the roof and the elevated floor with 22 cm. Different finish materials for the inside walls like OSB or plywood are available.[66]

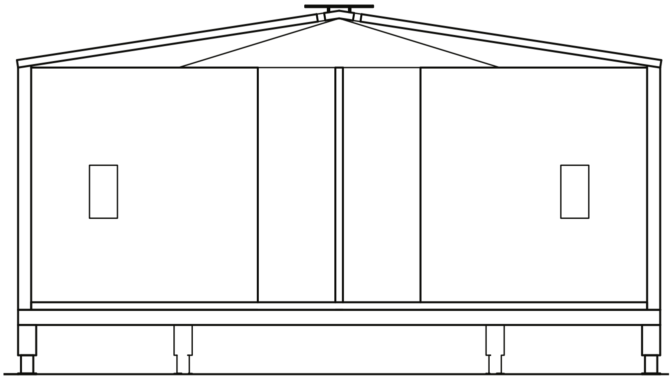
Lifespan of the design is not specified but the author of this work expects it to be at least 15-20 years given the fact that all important parts are made out of metal or covered with metal. Packaged units have a volume of around 56 m^3 which does not fit in one TEU container which only has a volume of 38 m^3. Assembly takes five people five to eight days to complete. A single unit costs between 55 000 € and 60 000 €.[67]

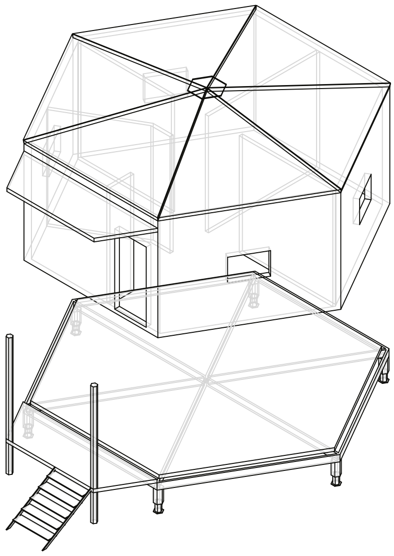
The design is sophisticated, allows to be extended by adding modules, allows flexibility of window placement and is elevated to protect against floods. For the construction no additional tools are required. But drilling the screw foundations can require heavy equipment depending on the soil type. The wall modules can be adapted to the deployed climate. Sanitary installations are designed to support off-grid operations. While the structure can last over a decade it is still disassemble-able. A major downside of the design is the transportation space requirement and the high price. The big initial unit size requires an high initial investment.

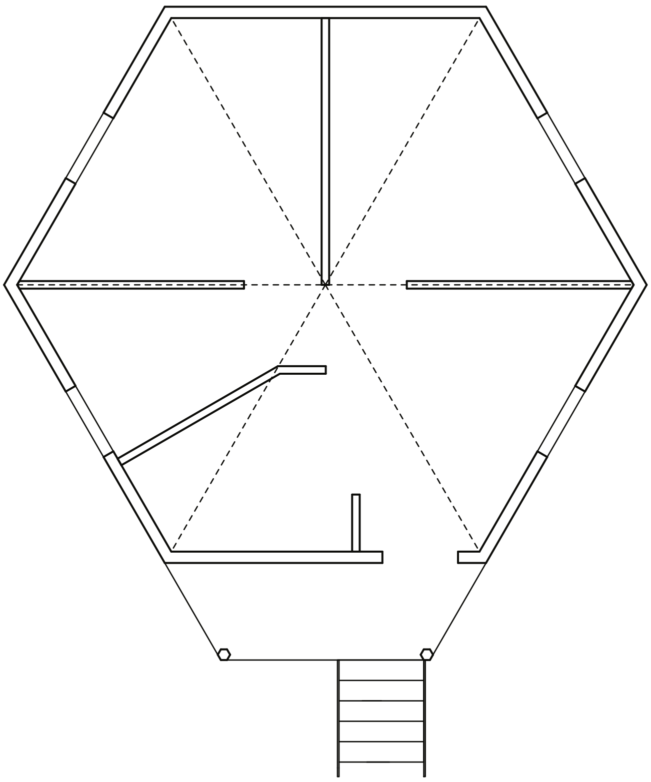
[63] *Hex House*. URL: `https://hex-house.com` (visited on 08/01/2022).
[64] Ibid.
[65] Ibid.
[66] Ibid.
[67] Ibid.



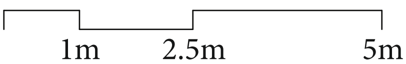
Phase	trans.	Climate		Earthquake	
Area m²	47	Price/m² €	1170	Lifespan	15-20 years
Plotsize m²		Weight kg		Labour	5/0
Room height	300/330	no per TEU	0.5	Build time	6 days
Local Material	no	Flood safe	yes	Extendable	yes







Images: Hex House



3.3.6 Cutwork - Cortex Shelter

The Cortex Shelter is *"a flat-pack, "just-add-water" housing solution that can be built in a single day and last up to 30 years."*[68] It creates a sheltered space of 24 m^2 on an area of 6.9×3.6 m allowing to host families of up to six people. The idea with this permanent design is that most, initially temporally planned, refugee camps exist longer and could be transformed into new cities as visualized on the right page. Replacing tents in refugee camps in regular intervals can be more expensive than building more durable structures in the first place.[69]

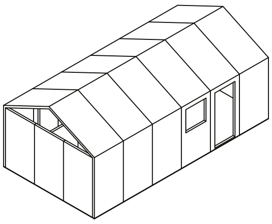
It combines two technologies. The Cortex technology consists of concrete in rolls which just needs water to create a solid concrete surface. It comes in rolls 2.4 m wide, 30 m long with a thickness of 1.25 cm. The surface is waterproof under all climatic conditions. This claim could not be verified as no detailed material specification is publicly available from the vendor. Because of the concrete it is fireproof. The other technology is the Cutwork technology which *"allows metallic tubes to be easily bent by hand and then lock into architectural structures."*[70] This is achieved with laser pre-cuts where bending could happen.

Each wall panel consists of two layers of Cortex concrete with a Cutwork metal structure inside.[71] The inbetween space can be used for insulation although the design has not been tested yet.[72] The floor is also created with Cortex rolls. Sanitary facilities with a separated dry toilet and off-grid shower are included in the design.[73]

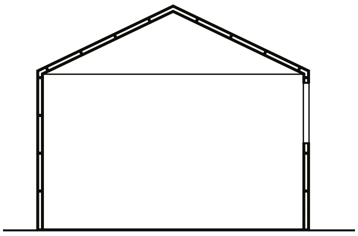
Assembly takes one day with two people and does not require heavy machinery or technical construction skills. Hardening of the concrete takes another 24 h. The weight of the concrete rolls is limiting the maximum amount of units per TEU container to around 5. [74] The supplier was contacted for a price estimate and responded that *"the price estimate is not precisely available, however our target is under* 3000 € *per unit."*[75]

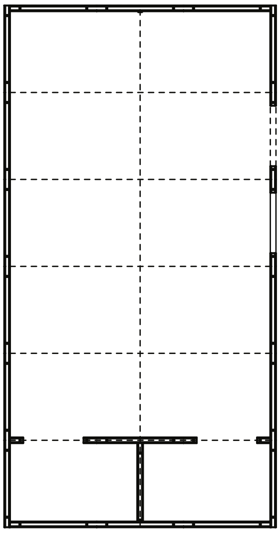
The idea of creating permanent concrete structures on-site without the need to setup a concrete supply chain is interesting. This allows fast transitional shelters with very little effort with a long lifespan. The cortex rolls create very durable surfaces but are very heavy. An internal, separated and ventilated sanitary installation gives independence from public sanitary spaces. The foundation is not specified but wind uplift is not expected to be a major issue because of the weight of the concrete. Without a proper raised foundation or plinth surface flooding water could enter the shelter. It is unclear how long the concrete roof surface will stay water proof. Also the internal room climate does not benefit from the all concrete surfaces.

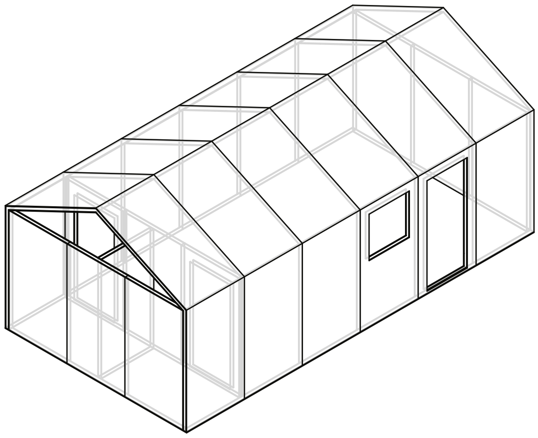
[68] Cutwork. *Cortex Shelter.* URL: `https://cortexshelter.com/` (visited on 09/01/2022).
[69] Ibid.
[70] Ibid.
[71] Ibid.
[72] Kelsea Crawford. *CortexShelter Information for Arch Master Thesis.* E-mail. 17th Jan. 2022.
[73] Cutwork, *Cortex Shelter*.
[74] under the estimate of around 2 m^3 of concrete and a maximum weight for a TEU container of 21 t.
[75] Crawford, *CortexShelter Information for Arch Master Thesis*.

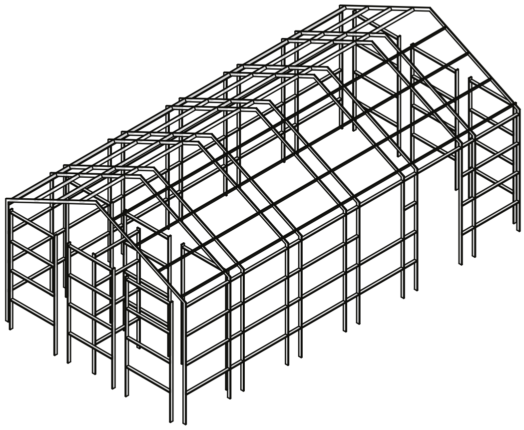


Phase	trans.	Climate		Earthquake	
Area m²	24	Price/m² €	125	Lifespan	30 years
Plotsize m²		Weight kg		Labour	0/2
Room height	210/296	no per TEU	5	Build time	2 days
Local Material	no	Flood safe	no	Extendable	yes

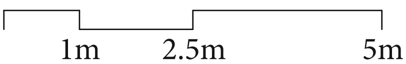








Images: Cutwork. Cortex Shelter



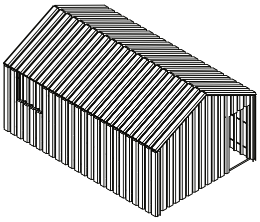
3.3.7 UNHCR Azraq T-Shelter

This metal frame, aluminium panel covered, gable roof T-Shelter was designed and built for the Azraq refugee camp in Jordan in 2014. A total of 13 500 T-Shelters were constructed in the camp for 67 000 Syrian refugees. The shelter is 6.1×4.3 m resulting in 24 m^2 of usable space. An average of five people were living per shelter which is within the range of the Sphere recommendation. For privacy reasons a version of the design with an attached side entrance was developed after feedback from the refugees. This prevents direct glances inside the shelter when the door is opened.[76]

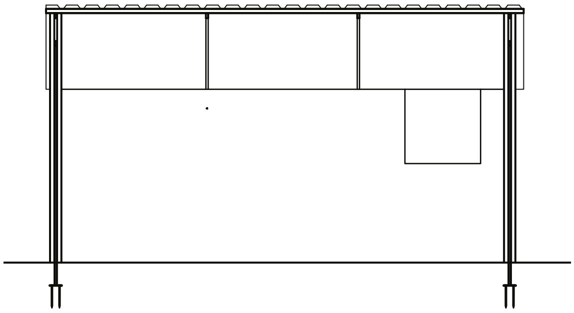
Overall structure consists of steel tubes with a size of 60×30 mm and a thickness of 1.2 mm. The metal tubes are anchored to the floor with base plates which are secured with steel pegs. Base plates are additionally secured with material from the 15 cm to 30 cm deep trench. With the adjustable size of this ground connection the shelter can be erected on small slopes as well. Walls consist of two layers of inverted box rib panels with 1.5 cm insulation made out of aluminium foam in-between. A 5 cm thick reinforced concrete floor is put into place after the shelter is erected. The total costs of the shelter was 3442 $ which consists of a 2374 $ materials bill, 356 $ for transportation and 712 $ for labour.[77]

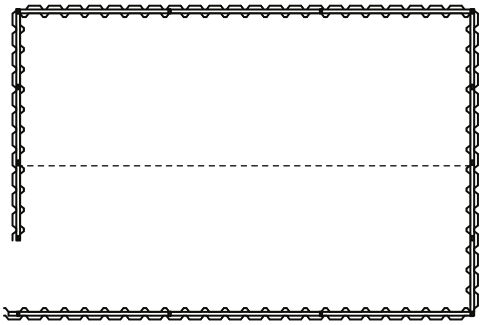
The center of the structure is quite high allowing for good air circulation while the small openings do not provide good ventilation. The walls and the roof are insulated with a thin layer of expanded polyethylene avoiding heat loss during the night. The structure is well connected with the ground but does not have any diagonal bracing in the walls or roof. Because of the internal steel structure the inside is unobstructed and creates one big space. The shelter is made entirely from premade elements, not creating opportunities for local businesses. Also the design does not have thermal mass and can not use the temperature change during day and night. For the given price the lifespan of just two to four years seems not to be appropriate. It is unclear why the aluminium surfaces and the steel structure only have this limited lifespan. No thoughts were paid on protection from surface floods other than creating a trench. The only customization possible is the addition of an attached entrance improving the privacy.

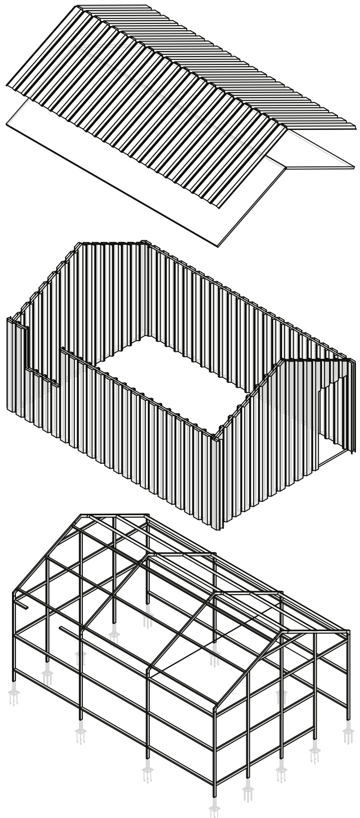
[76] *Shelter Design Catalogue*, p.46.
[77] Ibid., p.46.



Phase	trans.	Climate	BWh	Earthquake	moderate
Area m²	24	Price/m² €	143	Lifespan	2-4 years
Plotsize m²		Weight kg		Labour	1/3
Room height	200/330	no per TEU		Build time	1 day
Local Material	no	Flood safe	no	Extendable	no







Images: Shelter Design Catalogue

1m 2.5m 5m

3.3.8 UNHCR compact bamboo shelter

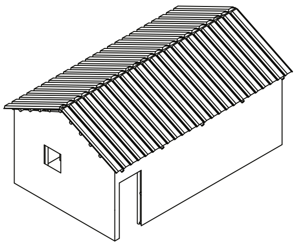
This shelter with structural eucalyptus beams and a corrugated galvanised iron sheet gable roof was built in the Dollo-Ado refugee camps, Ethiopia in 2013. There is an internal room division with two rooms. The size of 6×3.5 m creates a useable space of 21 m^2. With this project many host community members benefited by working for the local prefabrication. Mostly local material was used in the design.[78]

Structural eucalyptus poles (⌀8 cm) are buried 60 cm into the ground which requires termite treatment depending on the local situation. Bracing for increased wind resistance is also made out of eucalyptus.[79]

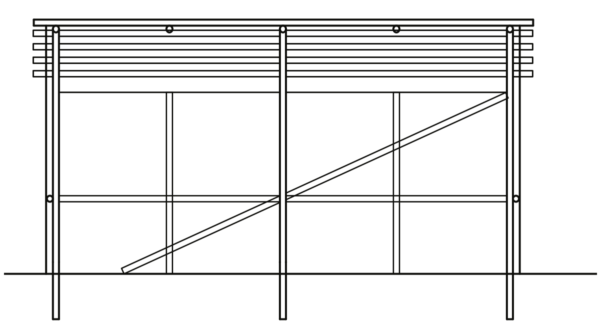
The design offers different materials to be used for the wall cladding. Inhabitants can use plastic sheeting, clothes or bamboo mats to cover the post-and-beam eucalyptus structure. Clothes and bamboo mats provide good ventilation for the hot climate. The total costs of the shelter was 708 $ which consist of a 488 $ materials bill, 73 $ for transportation and 146 $ for labour.[80]

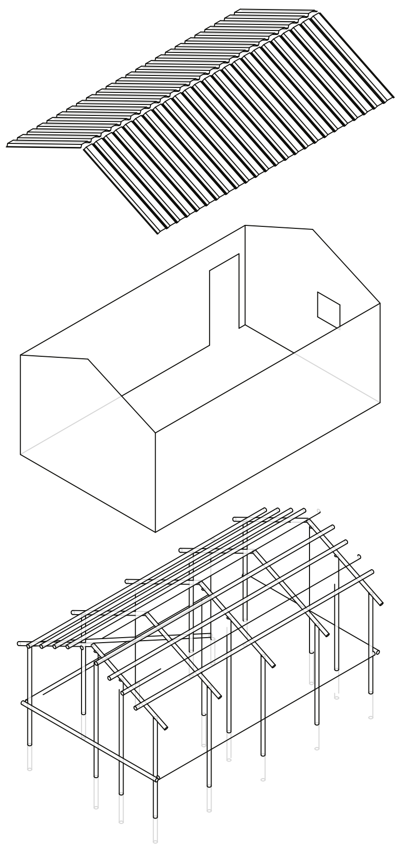
With the use of local material the local community was included in the project. The shelters can be upgraded overtime with improved wall materials. The eucalyptus poles are submerged in the ground creating termite issues. Diagonal bracing increases the wind resistance. But because the poles are just buried and not fixed in the ground the structure has a weak wind uplift protection. As the wall is cladded with bamboo mats, openings can be adapted and individually placed. The use of the bamboo mats also helps to provide good ventilation of the shelter. The price is very competitive because of locally sourced material. Because of the span of six meters internal columns are needed, obstructing the inside space. There is no protection from surface water as the shelter is not elevated. The used corrugated galvanised iron roof can lead to a significant heat up during sun exposure.

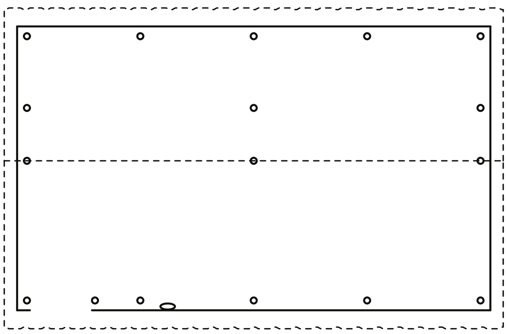
[78] *Shelter Design Catalogue*, p.51.
[79] Ibid., p.51.
[80] Ibid., p.51.

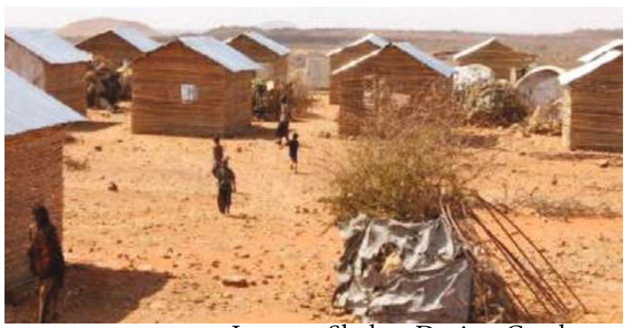


Phase	trans.	Climate	BWh	Earthquake	low
Area m²	21	Price/m² €	34	Lifespan	2-4 years
Plotsize m²		Weight kg		Labour	1/2
Room height	240/340	no per TEU		Build time	1 day
Local Material	yes	Flood safe	no	Extendable	?

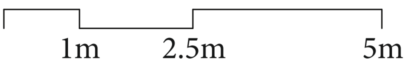








Images: Shelter Design Catalogue



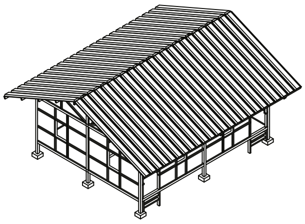
3.3.9 UNHCR Twin elevated shelter

The Twin elevated shelter with its gable roof was designed and built in 2014 in Kachin state, Myanmar to house internally displaced people. Dimensions of the twin unit are 6.7×5.5 m which creates a total of 36 m^2 separated into two units with independent access resulting in 18 m^2 per unit. The design allows an optional extension for a kitchen. It is advised to separate the extension's roof from the main roof for stability reasons.[81]

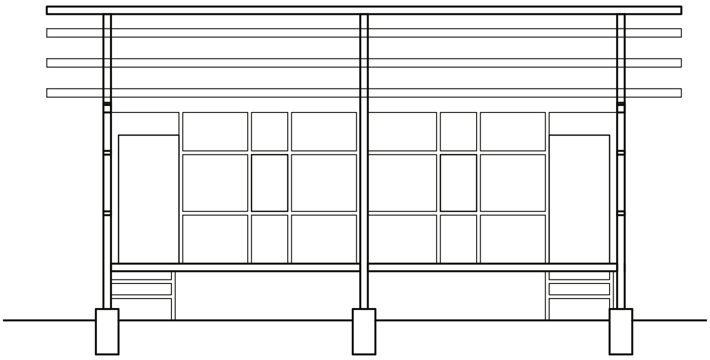
The main structure is made out of timber which is elevated 45 cm from the ground and placed on concrete footings. Timber poles are termite treated with motor oil. The structural timber frame is covered with bamboo mats, which is a local technique and allows for good ventilation and easy repair. Durable corrugated galvanised iron sheets cover the gable roof. The gable roof is extended on all four sides of the shelter by 85 cm. Bigger roof overhangs increase the risk of wind damage. The total cost of the twin unit was 658 $ which consisted of a 454 $ materials bill, 68 $ for transportation and 136 $ for labour.[82]

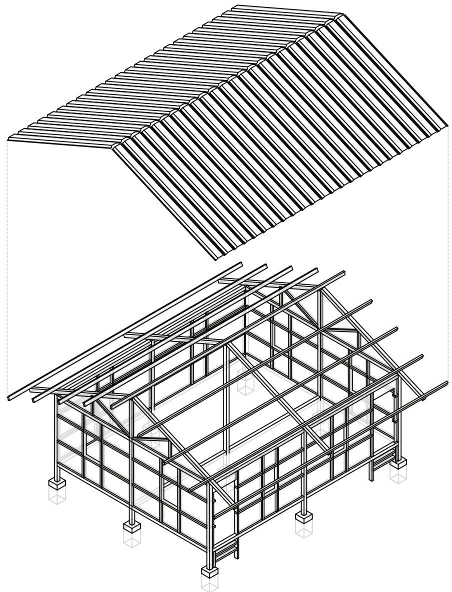
The design uses local materials and is elevated as protection against surface water and features a very competitive price. The roof overhang protects the walls from rain but needs to be balanced with the risk of high wind forces in this area. The foundation with its concrete cubes provides a stable foundation but special attention must be put on the connection of the columns to the concrete foundation to create a secure connection. Bamboo mats provide good ventilation and the high central ridge further helps to ventilate hot air beneath the roof out of the shelter. A down side of the design is the lack of diagonal bracing in the walls and the roof, especially for the rather big twin unit shelter size. In one axis the truss of the roof structure brings some rigidity to the roof. Local material can be put on top of the corrugated galvanised iron roof sheets to reduce the heat up. The structure is not easy to assemble, consists of many parts and requires skilled labour to create all timber connections in a safe way. The individual unit is not big but one family can potentially inhabit both units of a twin shelter.

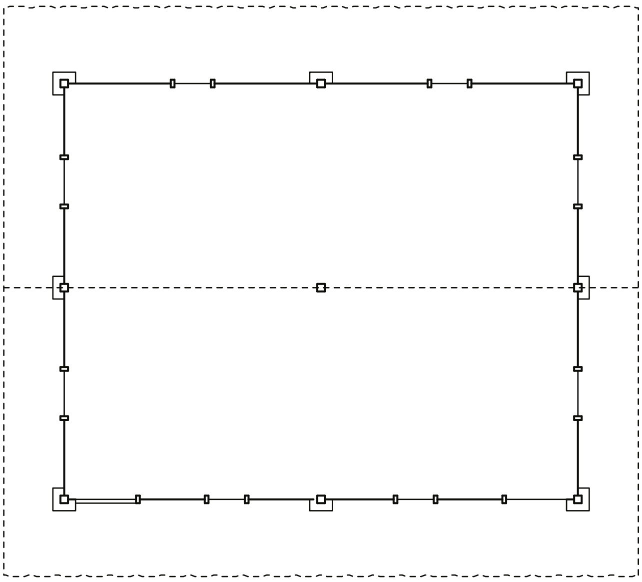
[81] *Shelter Design Catalogue*, p.54.
[82] Ibid., p.54.

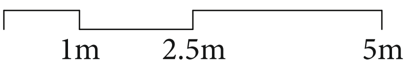


Phase	trans.	Climate	Cwa	Earthquake	very high
Area m²	18 (32)	Price/m² €	18	Lifespan	2-4 years
Plotsize m²		Weight kg		Labour	1/2
Room height	300/370	no per TEU		Build time	2 days
Local Material	yes	Flood safe	yes	Extendable	?









Images: Shelter Design Catalogue

3.3.10 Pakistan - Timber frame 2010

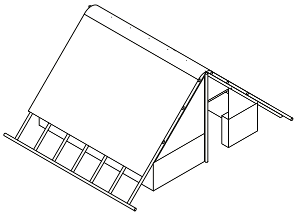
This timber shelter placed in Khyber Pakhtunkhwa and Gilgit-Baltistan, Pakistan was designed in 2010 to support internally displaced people after a flood. Around 10 000 units of the shelter were built.[83]

"The shelter consists of 7 triangular frames, connected by a ridge pole. The ridge pole is supported by two 2.74 m high vertical columns at each end. The shelter is 4.3 m x 5.7 m on plan. It has a low 0.9 m brick wall constructed inside the frame to provide protection against flood damage and retain warmth. The roof is pitched at 44 degrees and is made of corrugated galvanised iron sheeting. The sheeting is nailed to purlins that span between the frames. The roof sheeting is laid on top of locally available insulating material and plastic sheeting. The foundation of the shelter is provided by burying the rafters and columns approximately 0.3 m into the ground on top of stone footings. Guy ropes over the roof sheeting have been used to help prevent uplift under wind loads."[84] For additional wind resistance and durability the design offers an optional low level brick wall, which is not included in the provided kit. The brick wall should not exceed 90 cm of height to keep the structure light which is beneficial during seismic events. Construction time per shelter is one day with a team of four people without the need for heavy equipment or advanced tooling.[85]

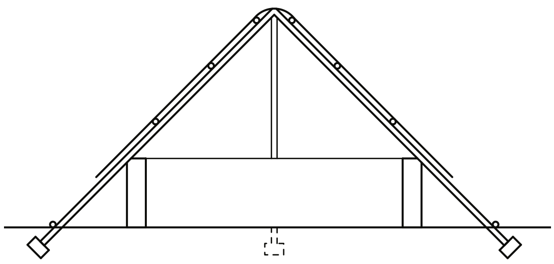
According to the analysis performed by Ashmore and Treherne the foundation and bracing is insufficient and poses a risk in this earthquake active area. Digging the structural timber beams into the ground does not offer good wind uplift protection. Timber joints in the design are not protected using braces, reducing resistance against wind and seismic forces. The roof structure in the current design is not very stable under high wind or snow loads. Additional bracing (purlins) should be added to stiffen it.[86]

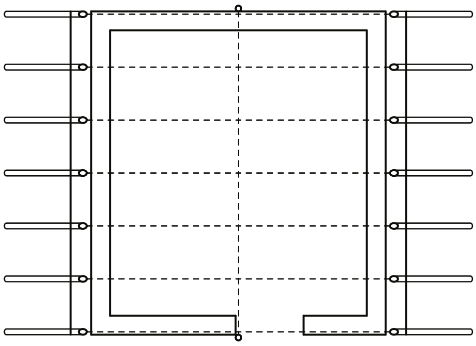
The design uses mostly local materials (insulation, brick) and offers more comfort than tents because of the rigid roof. Also the thermal capacity is improved with the 90 cm side wall. The initial structure can be gradually upgraded and the materials can be reused for permanent buildings. The main living area is not elevated posing a risk of flooding.

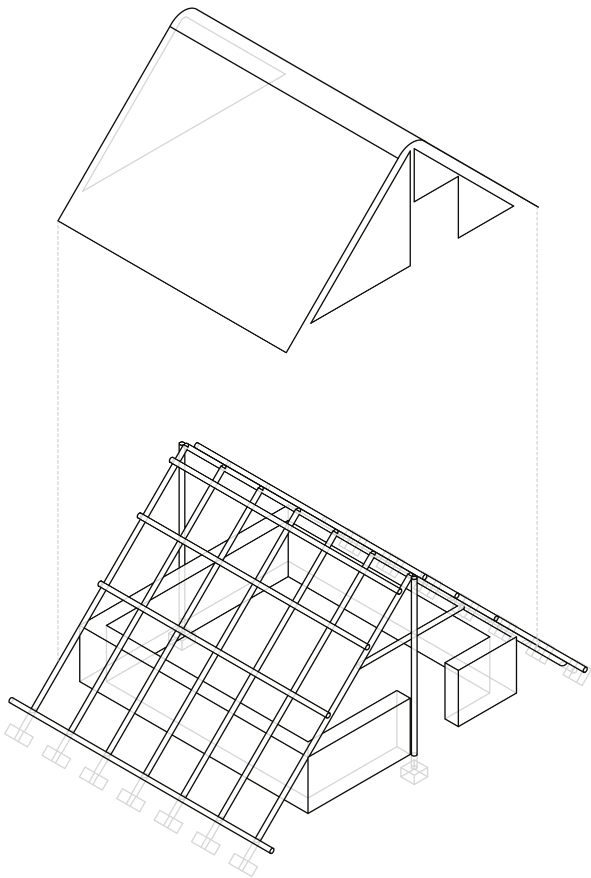
[83] Ashmore and Treherne, *Transitional Shelters Eight Designs*, p.41f.
[84] Ibid., p.41.
[85] Ibid., p.41f.
[86] Ibid., p.41f.



Phase	trans.	Climate	Csa	Earthquake	moderate
Area m²	24.5	Price/m² €	20	Lifespan	1 year
Plotsize m²		Weight kg		Labour	1/3
Room height	90/270	no per TEU		Build time	1 day
Local Material	yes	Flood safe	no	Extendable	?







Images: Shelter Design Catalogue

3.3.11 Peru - Timber frame 2007

This shelter was part of the post earthquake response in 2007 in Peru with 2020 units built.[87]

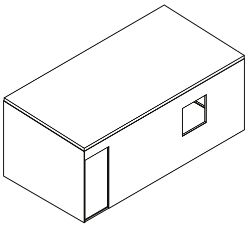
"The shelter has a Bolaina (Bolayna) timber braced frame, measuring 3 m x 6 m on plan with a single pitched roof at four degrees. The shelter is clad with tongue and groove solid timber board walls and a corrugated fibre cement sheet roof. It is 2.4 m high and stands on a new or existing concrete floor slab. In instances where a new slab has been used, wire ties wrapped around nails have been cast into the slab and attached to the frame at all column locations to resist uplift. Where existing slabs have been used the shelter has been staked to posts installed outside the slab. The shelter is constructed as 6 panels which are then nailed together using connecting wooden members, connecting plates and plastic strapping. A central roof edge beam is attached to the panels and purlins (are) nailed on top of this to support the roof."[88] All timber profiles forming the main structure are only 25×50 mm and connected using 6d nails (length 5 cm). The six panels of the shelter are locally prefabricated resulting in a fast construction.[89]

The analysis performed by Ashmore and Treherne shows that the shelter is protected well against seismic events due to its low weight but is vulnerable to high wind loads. Especially protection against wind uplift by changing the foundation design and connections must be performed. For more durable solutions and to increase reusability the timber should be treated to prevent rot and insects. Replacing the existing fibre cement roof with an alternative corrugated galvanised iron roof reduces weight and decreases the danger during seismic events. The existing 4° mono-pitched roof should be increased to at least 5° for faster rain water run-off. With the existing design the floor is only elevated 10 cm from the ground increasing destruction during flood events. The units are combinable to form bigger structures but all walls must be retained to kept structural stability.[90]

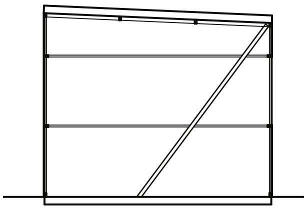
A similar and equally sized alternative design featuring eucalyptus poles was also built 3000 times for the same response with a price of 350 €. In this design ⌀7.5 cm eucalyptus poles were used providing better stability. This design features a flat roof and all sides are covered with plastic tarpaulin and palm matting. The floor is created using 5 cm unreinforced concrete. Bracing is made from cross twisted galvanized steel wires (⌀1.3 mm). Upgradeability of this design is limited to reuse of the structural components. The design has no flood protection. With a redesigned connection of the structure to the concrete slab wind uplift protection could be improved significantly.[91]

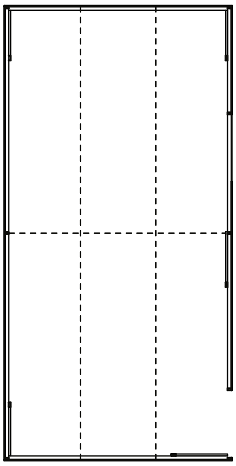
This shelter uses local prefabrication and gives different material options. The structure is made from very light materials and is very compact. It is unclear if the plastic and steel nail connection between the shelter elements is durable. The wall elements itself seem to be rigid because of the diagonal bracing.

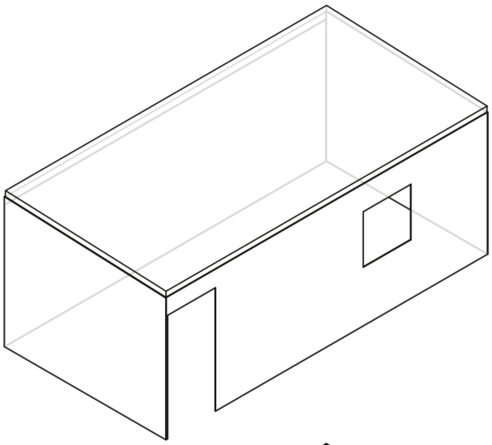
[87] Ashmore and Treherne, *Transitional Shelters Eight Designs*, p.45.
[88] Ibid., p.45.
[89] Ibid., p.45.
[90] Ibid., p.45.
[91] Ibid., p.51ff.

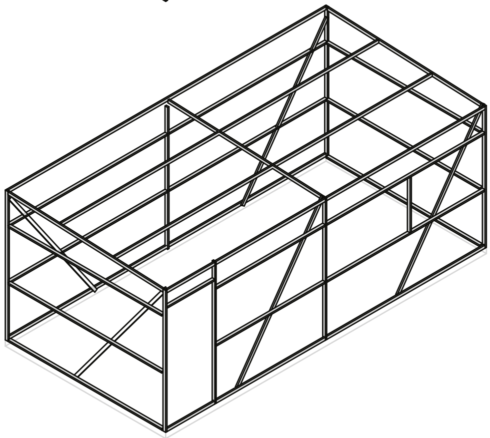


Phase	trans.	Climate	ET	Earthquake	high
Area m²	18	Price/m² €	31	Lifespan	1 year
Plotsize m²		Weight kg		Labour	1/4
Room height	240	no per TEU		Build time	1 day
Local Material	yes	Flood safe	no	Extendable	no

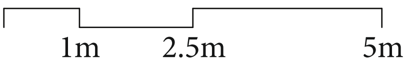








Images: Ashmore and Treherne, Transitional Shelters



3.3.12 Indonesia - Steel frame 2005

During this shelter response to the Tsunami in 2004 more than 20 000 shelters were built. *"The structure consists of a cold rolled, hot dip galvanised steel frame with a pitched roof of 24.3 degrees and a raised floor. The height is 2.8 m to the eaves and 4.15 m to the ridge. The platform area of the shelter is 25 m2 with a cantilevering balcony at opposite sides front and back and a cantilevering roof covering the balconies. There are 6 columns fixed using column base plates nailed directly into the ground. Metal roof sheets are screwed to steel purlins spanning between primary roof beams. Limited lateral stability is provided by timber plank wall cladding fixed to timber studs that are in turn screwed to the steel frame. The floor consists of timber planks spanning between steel joists."*[92] Material price is 4765 € but including the whole program cost it is 5100 €. Construction time per shelter with four to five people is three days with one day of frame construction and two additional days for wall cladding.[93]

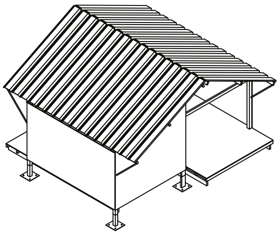
The main structure consists of two steel profiles: One with 150×50 mm and a thickness of 1.6 mm for the central columns and 100×100 mm with a thickness of 1.6 mm for the corners. The bracing is made from steel rods ⌀26 mm with 1.6 mm thickness.[94]

As analyzed by Ashmore and Treherne the design is performing well against floods with the 45 cm elevated floor. The earthquake risk can be improved by using structural plywood panels for the walls and by improving the stability of the floor. Especially the wind resistance (uplift and sliding) needs to be improved by adapting the foundation. The current foundation, consisting of just metal plates (400 × 400 × 8 mm) fixed with ⌀19×600 mm nails to the ground, needs to be replaced with proper concrete pad foundations.[95]

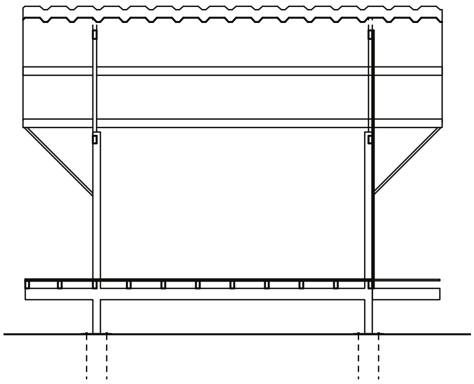
The shelter kit consists of the metal frame, plywood panels, tools and timber planks. The rest, like windows and cladding material, was intentionally required to be sourced locally. While the metal frame was manufactured locally the steel sheets and the timber was procured internationally.[96]

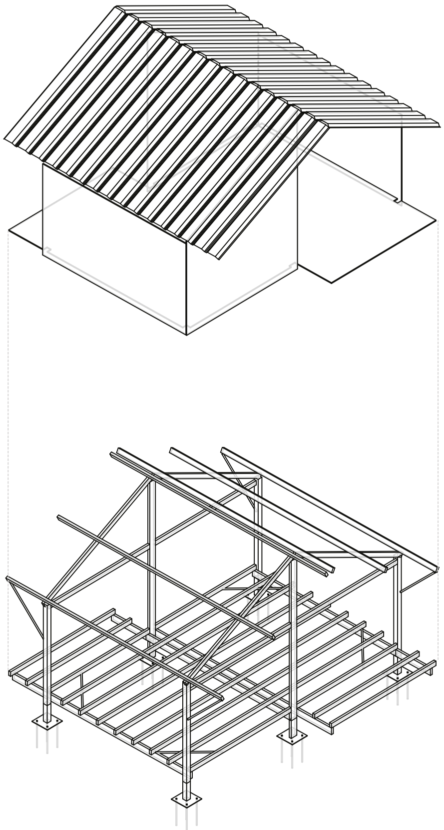
This design was included because the covered and raised outside space allows to perform work during the wet season. The used steel structure is also very durable and the high room height allows for good airflow. Connecting the prefabricated pre-drilled steel structure elements in a safe way is easy and does not require engineering skills. Local insulation on the corrugated galvanised iron sheets could reduce the heat up and also reduce the noise during heavy rainfall.

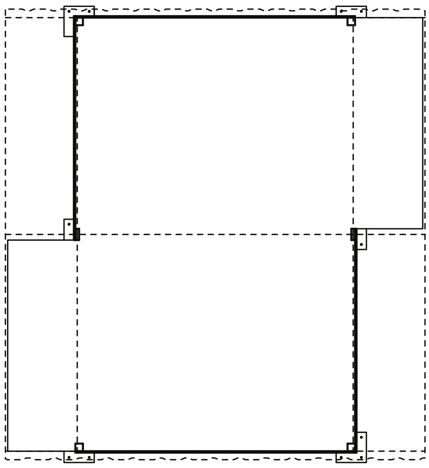
[92] Ashmore and Treherne, *Transitional Shelters Eight Designs*, p.63.
[93] Ibid., p.63.
[94] Ibid., p.67.
[95] Ibid., p.66f.
[96] Ibid., p.66f.

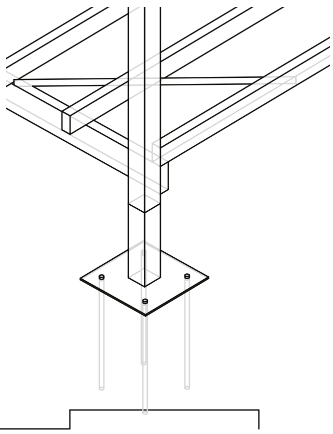


Phase	trans.	Climate	Af	Earthquake	high
Area m²	53	Price/m² €	96	Lifespan	5 years
Plotsize m²		Weight kg		Labour	1/4
Room height	280/415	no per TEU		Build time	3 days
Local Material	both	Flood safe	yes	Extendable	?









1m 2.5m 5m

Images: Ashmore and Treherne, Transitional Shelters

3.3.13 Maggie Shelter

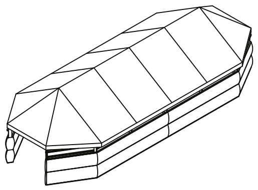
The maggie shelter invented in 2015 *"looks like a tent, but has the virtues of a fixed building using a double layered wall with insulation."*[97] It aims specifically for places where *"fixed structures are not permitted, practical or desired."*[98] The program focuses mainly on schools, community centers and medical wards but can also be used for shelters. It was designed to counter existing issues with tent structures like the lack of insulation, thermal mass and sustainability because of heating costs. The design aims for multi purpose, modular combinations, climate flexibility and local upgradeability. In hot climates the inside temperature does not exceed 30 °C. For cold climates inside temperature is never below 15° and the structure can withstand a snow load of 0.4 kN/m^2. Units can be solitary or combined to clusters of up to three units forming a triangle with an inner courtyard. Different lengths ranging from around 6 m (35 m^2) to 18 m (110 m^2) are possible. The length can only be increased by steps of 3 m (module length). Windows can be either placed on the top of the wall or in the roof forming a skylight. The floor can be elevated using an aluminium frame construction with insulation beneath if needed.[99]

The design is flexible but a common unit is 110 m^2 with 17.5×6.6 m. Maximum useable room height is 412 cm and the minimum along the sides is 260 cm. The structure holding the walls is made from extruded aluminium profiles with integrated bracing. The roof is insulated with 25 cm, covered by PVC tarpaulin with a weight of 650 g/m^2 and sitting on a aluminium profile construction. The same tarpaulin is used to form the inside and outside layer of the wall sections. The 30 cm space in-between is filled with material like sand, recycled plastic or other local materials for thermal capacity and insulation. Windows with a height of 50 cm are placed in the upper part of the wall section. The final design can resist wind loads of 165 km/h without guy ropes. The uplift is not a big problem as the fully filled structure can weight up to 40 000 kg.[100]

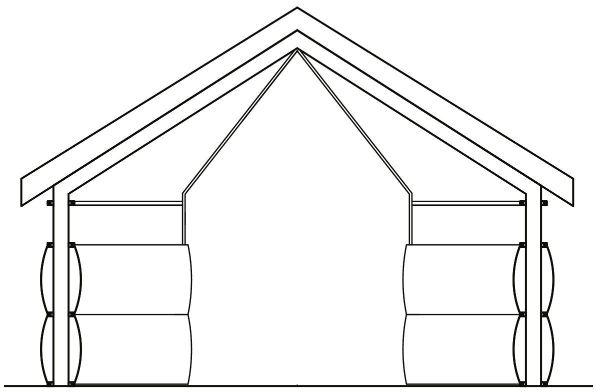
With a team of six people the structure and the roof can be built without the need for heavy equipment in one day. An additional day is required to fill the local materials to form the walls. A maggie unit kit with 110 m^2 weights around 1800 kg and takes 4 m^3 of transport volume.[101] Price of one 110 m^2 unit is 30 000 €.[102]

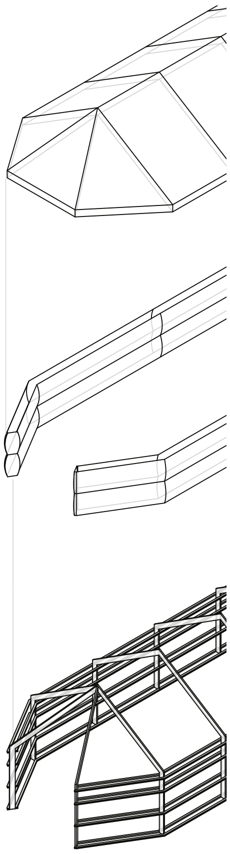
Depending on the infill, high thermal mass or thermal insulation can be achieved. The metal structure is durable and the fabric reusable. The transportation weight is low and filling the walls with local material can be performed by the future inhabitants. The placement of windows is very limited because of the heavy weight of the structure. This weight also poses a risk in seismic active areas. The foundation is not specified in the design but the floor can be elevated using aluminium profiles to protect the interior from flooding.

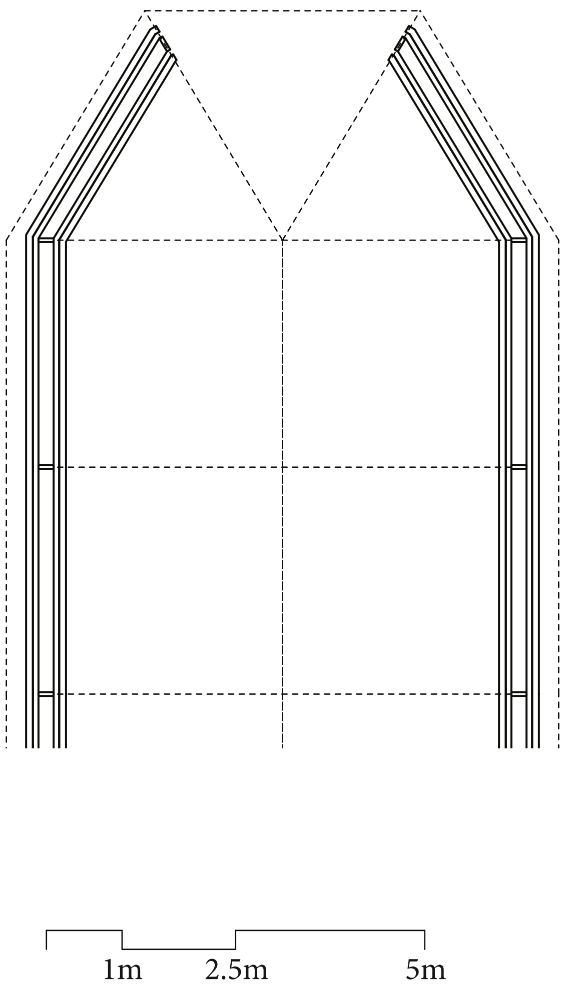
[97] Benjamin Denef. *The Maggie Shelter*. 2016. URL: http://maggie-program.org/maggie-shelter/Maggie_TechBroch_LR.pdf (visited on 10/01/2022), p.5f.
[98] Ibid., p.1.
[99] Ibid.
[100] Ibid.
[101] Ibid.
[102] Benjamin Denef. *Master Thesis - Maggie Shelter Price*. E-mail. 4th Mar. 2022.



Phase	trans.	Climate	Am	Earthquake	low
Area m²	100	Price/m² €	300	Lifespan	15 years
Plotsize m²		Weight kg	1800	Labour	1/5
Room height	260/412	no per TEU	6	Build time	2 days
Local Material	both	Flood safe	yes	Extendable	yes







Images: Benjamin Denef. The Maggie Shelter

Super Adobe

Super Adobe, *"a form of earth bag construction using sandbag and barbed wire technology, is an economical, time efficient, energy efficient and ecologically friendly system developed by Iranian-born architect Nader Khalili."*[103]

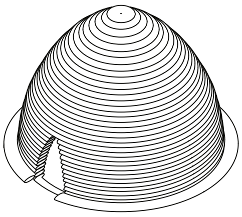
Load bearing structures like walls, arches and domes are created by filling long plastic bags with earth material. The filling can be earth or earth mixed with stabilizers like cement or lime. Layers of bags are stacked on top of each other with barbed wire between layers to increase friction. Depending on the desired lifespan structures without a cladding can last for one year, returning to just earth (and plastic bags) after their lifespan. With proper maintenance and cladding the structures can become permanent houses. By only using super adobe only dome style roofs are possible. Construction does not require heavy tools, requires little technical skill and can be done easily involving the whole community.[104]

As an built example the eco-dome, a project of the CalEarth foundation founded by Nadar Khalili is given. The eco-dome has a diameter of 4.6 m resulting in 16 m^2 of usable space in the main dome which requires around 1800 m of bags (with 45 cm wall width). With the super adobe dome calculator[105] an internal dome height of 420 cm and a requirement for 1000 m of barbed wire is calculated. The rough material price for the bags is 2000 € adding 200 € for the barbed wire.[106]

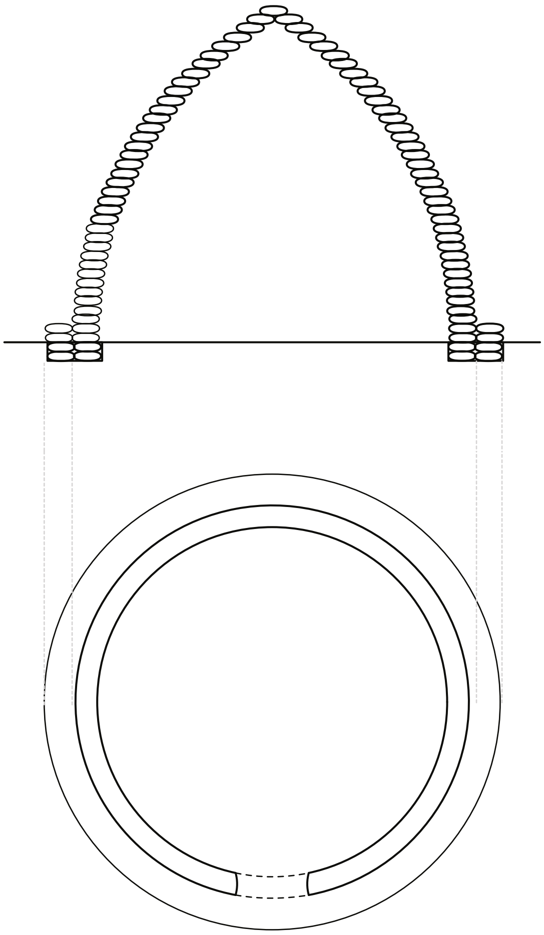
As foundation a trench with 30 cm depth is used to place the first layers of super adobe bags. Without a raised floor the structure can be affected by surface water. The wind uplift risk is small as the structure incorporates roughly 22 m^3 of filling material which estimates around 22 t depending on the exact mixture.[107]

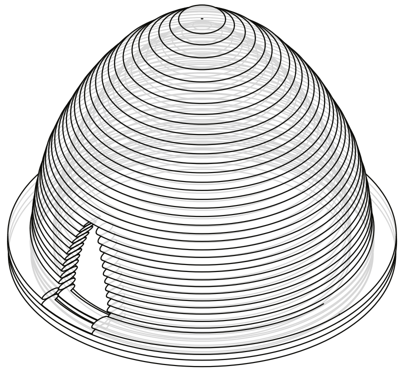
The design is similar to the Maggie shelter but here no inside metal structure is needed. Also the material is filled into the bags and not between the two layers as in the Maggie shelter. With this construction only dome shapes buildings are possible. Multiple domes can be combined by letting them partly overlap. Depending on the infill the domes offer very good thermal capacity and insulation. Also just the sandbags and the barbed wire needs to be shipped resulting in very low transportation volume. It is not specified how rain water proofness is ensured. Although a dome shaped structure is very rigid the massive weight of the infill is not beneficial during seismic events. The collapse of the massive dome roof can cause casualties.

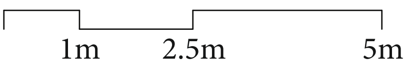
[103] Razia Kamal and Saifur Rahman. *"A Study on Feasibility of Super Adobe Technology –an Energy Efficient Building System Using Natural Resources in Bangladesh"*. In: *IOP Conference Series: Earth and Environmental Science* 143 (1st Apr. 2018).
[104] Ibid.
[105] Curvatecture. *Superadobe Dome Calculator.* URL: https://www.curvatecture.com/services-superadobe-dome-calculator (visited on 30/06/2022).
[106] *CalEarth.* 2021. URL: https://www.calearth.org/superadobe-bags (visited on 30/06/2022).
[107] Ibid.



Phase	perm.	Climate	Af	Earthquake	very high
Area m²	16	Price/m² €	138	Lifespan	10 years
Plotsize m²		Weight kg		Labour	1/5
Room height	420	no per TEU	10	Build time	20 days
Local Material	both	Flood safe	yes	Extendable	yes







Images: CalEarth

3.3.14 CRS T-shelter Haiti

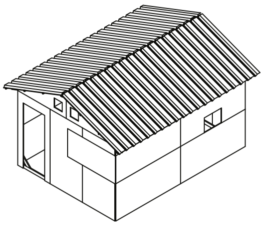
This shelter measuring 3.7×4.9 m was built around 10 000 times in Haiti after the earthquake on 12th January, 2010. A version with only 3.7×3.7 m with 13 m^2 for small plots was also developed. The structure forms three frames made out of treated timber. A double gable roof strapped to the structure and made out of corrugated galvanised iron panels covers the shelter. The smaller version uses a single pitched roof. Walls mainly consist of plywood panels. Precast concrete foundations were used in later phases to speed up the shelter construction process. Prefabrication was introduced to reduce space requirements in the dense urban areas where the shelter was deployed. Users were involved in construction and assembly.[108]

The publication recommends to avoid a two-phased responses which provide temporal settlement first and then replace it with permanent settlement at a different place. It was carefully monitored how the people adapted the shelter to adjust the prefabrication process according to their needs. For example inhabitants changed the geometry of the ventilation windows and also replaced the tarpaulin used to cover the windows with wooden shutters for security. Also inhabitants customized the appearance of their shelter by putting colors and paintings.[109]

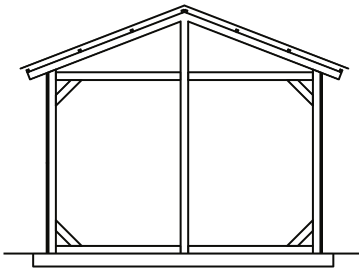
A similar project in Haiti showed issues with logistics and the labour intensity of the design. Timber procurement posed a challenge after the widespread post earthquake devastation. The prefabrication center was also used to educate locals to improve their chances on the job market.[110]

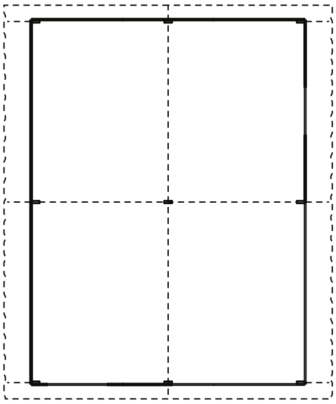
The design is locally prefabricated with local available materials. The local community benefits from jobs at the prefabrication facility and also improves their technical skills. Diagonal corner bracings and the plywood panels help for the rigidity. As the plywood panels are non structural, easy modification for window placement is possible. The shelter can be easily adapted in length by adding more prefabricated trusses. The ventilation openings in the roof support a good air circulation. Also the design features a big window like opening covered with tarpaulin during rainfall. A downside of the design is a central column and the lack of surface water protection. There is also no covered outside space like a porch available for the inhabitants.

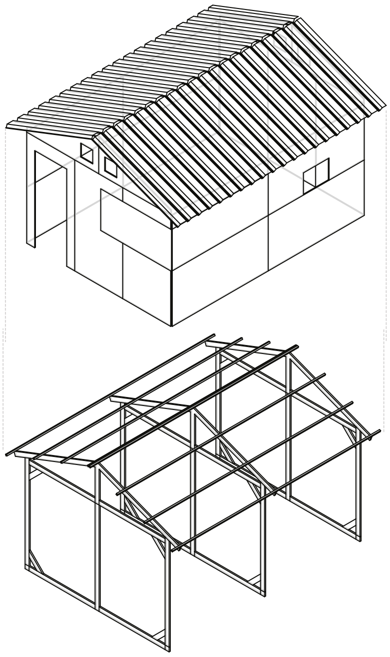
[108] *Learning From The Urban Transitional Shelter Response In Haiti*.
[109] Ibid.
[110] *Shelter Projects - Haiti 16 Case Studies*. Jan. 2020. URL: `http://shelterprojects.org/shelterprojects-compilations/Shelter-Projects-Haiti-2020-Hires.pdf` (visited on 20/01/2020), p.31.



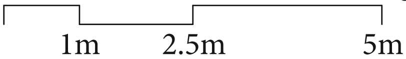
Phase	trans.	Climate	Aw	Earthquake	moderate
Area m²	17.8	Price/m² €		Lifespan	3-5 years
Plotsize m²		Weight kg		Labour	
Room height	330/360	no per TEU		Build time	
Local Material	yes	Flood safe	no	Extendable	yes







Images: Learning From the Urban Transitional Shelter Response in Haiti



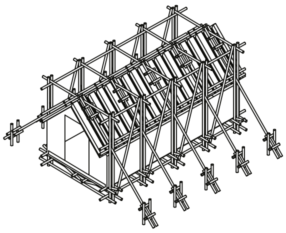
3.3.15 Architecture for the Mass - Nepal 2015

The shelter consisting of a bamboo structure holding metal sheets was designed by Charles Lai and Takehiko Suzuki as post earthquake response for Nepal in 2015. Focus was on cheap and locally available materials and easy construction without the need for skilled labour and tools. Locally available materials reduce transportation problems especially for remote villages. The shelter with its gable roof has a floor size of 2×4 m creating 8 m^2 of liveable space. A version with 3×6 m creating 18 m^2 is also mentioned. The living area is elevated by 87 cm to provide rain protection.[111]

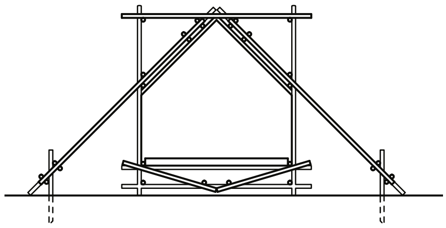
The bamboo poles creating the construction are connected using zip ties and metal wire. Rafters of the bamboo frames forming the structure are extended to the ground. Twenty horizontal 100 cm bamboo columns secure those extended rafters with the ground by anchoring them 40 cm deep to create an uplift protection. The central columns do not have any form of foundation and directly sit on the ground. The walls are made out of thick metal foil which can be delivered in rolls. The metal foil and the corrugated galvanised iron sheets forming the roofs are nailed to the bamboo structure. Price for a first prototype was just 500 €.[112]

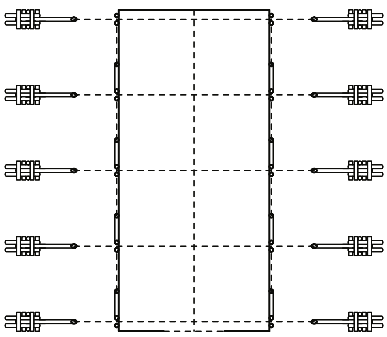
The design is interesting as a lot of effort is put into simple bamboo to bamboo connections while still providing a good protection against wind and surface water. Also except the corrugated galvanised iron panels and metal foil, which are assumed to be available locally, only local material is used. This is especially important in remote post earthquake responses where usually the road infrastructure is completely damaged. The used corrugated galvanised iron sheets can later be reused to upgrade damaged existing structures or build new permanent homes. All surfaces consisting of metal foil are non structural and openings can be easily cut by the inhabitants. Because of the lack of insulation it is assumed that the shelter will heat up substantially during sun exposure. As the bamboo structure is not protected from rain, rapid decay is expected during wet season. The actual required area is almost double of the inhabitable space inside because of the roof construction.

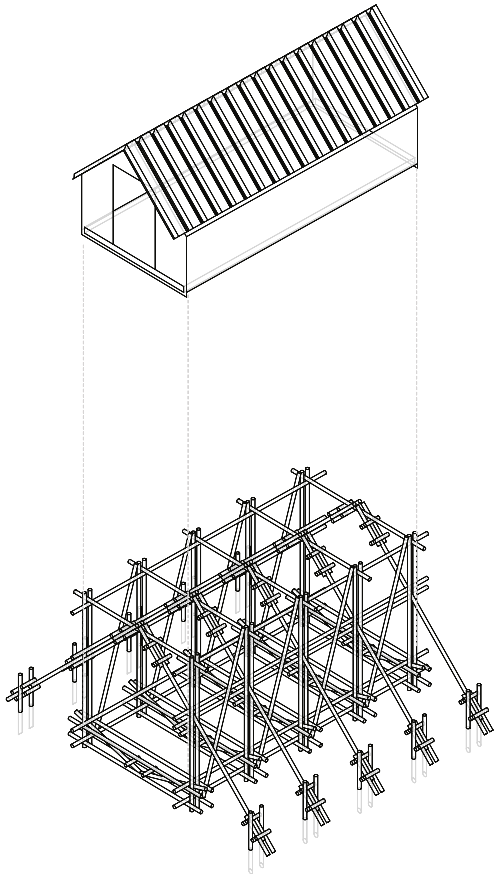
[111] Amy Frearson. *Prototype Shelter for Nepal Earthquake Victims Could Be Built by Unskilled Workers in Three Days.* 11th July 2015. URL: https://www.dezeen.com/2015/07/11/prototype-bamboo-shelter-nepal-earthquake-victims-built-by-unskilled-workers-three-days/ (visited on 20/01/2022).
[112] Ibid.

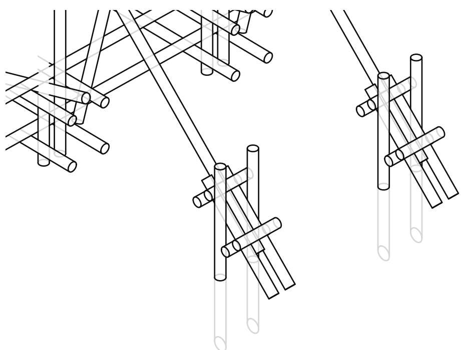


Phase	trans.	Climate	Cwb	Earthquake	very high
Area m²	8	Price/m² €	62.50	Lifespan	1 year
Plotsize m²	40	Weight kg		Labour	4/10
Room height	90/185	no per TEU		Build time	2 days
Local Material	yes	Flood safe	yes	Extendable	yes

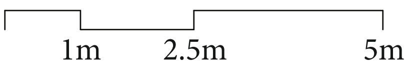








Images: Frearson



3.4 Durable shelter design

This section anaylises projects allowing for a gradual transition to permanent buildings. Construction time, skill and materials required increase a lot mainly for creating concrete foundations and massive walls.

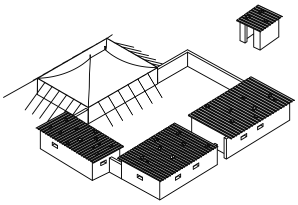
3.4.1 West Sahara - Adobe Brick with Khayma

This self built compound in the Rabouni camp, Algeria housing a mother and six children consists of one Khayma (Tuareg style tent) and multiple adobe brick buildings. The camp was already mentioned in Section 2.1.7. The Tuareg style tents were part of an initial UNHCR response (Section 3.2.3) and this one is still used as main gathering and sleeping place because of nomadic tradition. The whole compound is around 220 m^2 in size with 130 m^2 of built area. Besides the tent the compound consists of three adobe brick houses acting as bedrooms, one storage room and one kitchen. All rooms are grouped along a fenced courtyard. A toilet is placed outside in a separate adobe brick house.[113]

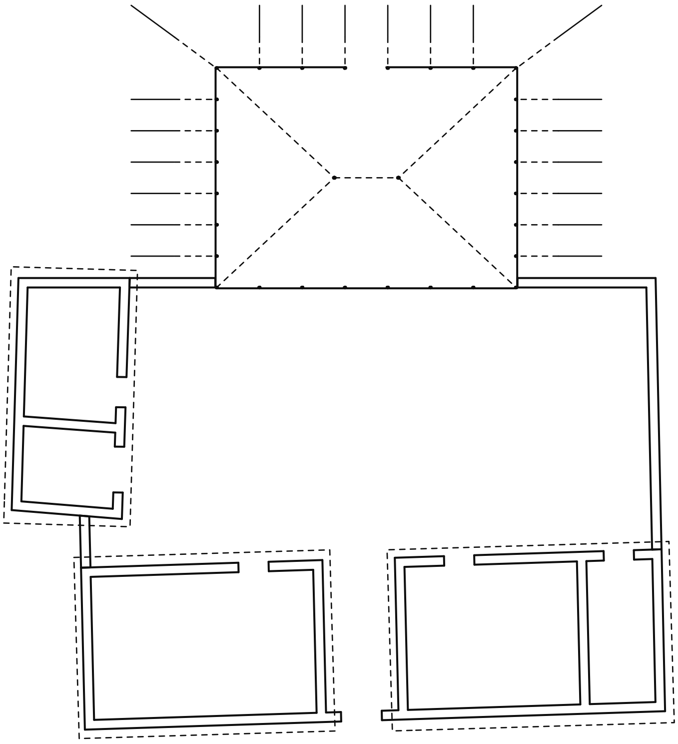
Commonly one layer of adobe brick is used to create a foundation on the flat ground. The floor is then covered with mats and carpets. Corrugated galvanised iron panels are placed on wooden beams residing on the walls. Fabrics hung under the ceiling create a thermal buffer and covers the structure. Rocks are used to protect the metal sheets from uplift. Building a house commonly requires two month with two constructions workers. Adobe brick can be produced on-site or procured locally. Commonly the whole family helps in the construction process. The price of a house can vary a lot but starts around 1500 €.[114]

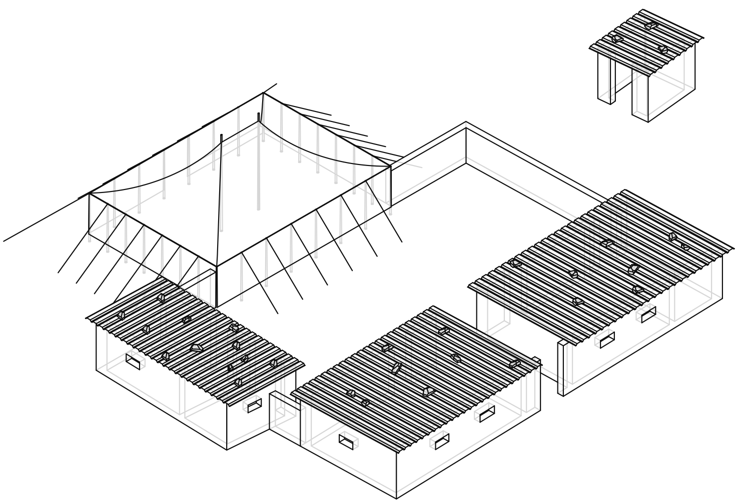
This example shows how an initial emergency shelter just consisting of a tent is upgraded into a permanent compound. As the population was evicted from their country of origin the relocatable tent can still be seen as the hope to return at some point. The compound uses the emergency tent structure still as center and integral part. The different structures and surfaces create options for summer and winter. Placing the toilet outside of the compound improves odour avoidance but can pose a security risk during night times. The locally known and locally constructed abobe brick houses allow easy repair. The brick houses suffer from rain water washing away the adobe brick requiring periodic maintenance. Except for the tent, the structures are not protected adequately for seismic events because of the lack of any ring anchors or strong bracings. The roofs, although protected with added stones, suffer from strong winds during sandstorms.

[113] Herz, *From Camp to City*, p.130.
[114] Ibid., p.125ff.

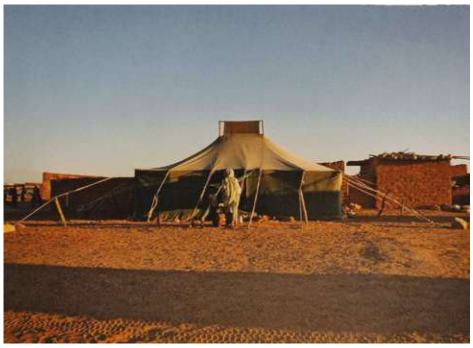


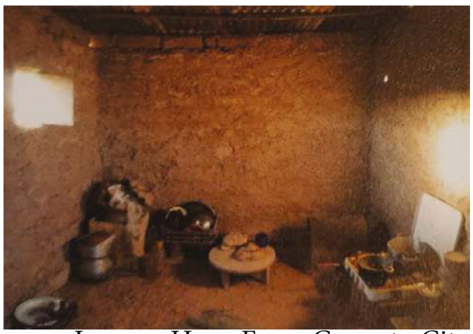
Phase	perm.	Climate	BWh	Earthquake	low
Area m²	130	Price/m² €	11.54	Lifespan	10 years
Plotsize m²		Weight kg		Labour	2/2
Room height	200/350	no per TEU		Build time	60 days
Local Material	yes	Flood safe	no	Extendable	-





1m 5m





Images: Herz, From Camp to City

3.4.2 Shigeru Ban - Emergency shelter Nepal 2015

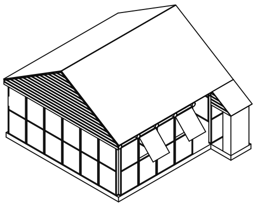
This durable shelter was designed as post earthquake response with special focus on an earthquake safe design. The 5.4×5.4 m shelter features structural walls made from timber frames (90×210 cm) filled with brick made from rubble. The double 20° pitched roof is made from ⌀16 cm paper tubes connected with plywood connectors. The roof structure is planked with plywood for bracing and thatched with straw. A tarpaulin layer in-between ensures rain proofness. Internal room division supports one big room (19.5 m^2) attached with two smaller bedrooms. Wall frames are placed on brick foundations and the main floor is 20 cm compacted earth as flooding protection.[115]

A small kitchen and toilet are attached outside but covered from a roof overhang. Both are built with the same filled timber frame technique. The toilet is only reachable from outside through a separate door.[116]

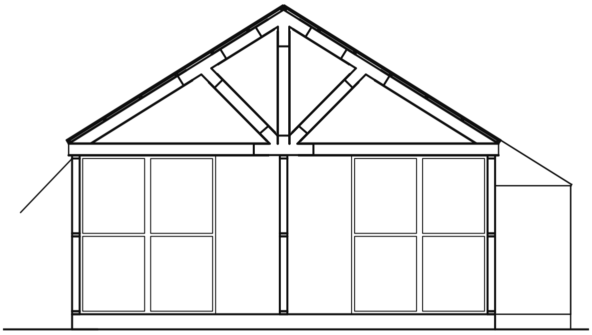
The design aims to bring visible timber to the construction because of inhabitants fear over pure brick constructions but also incorporates the gravel of the ruins into new wall filling material. Mechanical stress tests of the wall frame structure resulted in good resistance against earthquakes.[117]

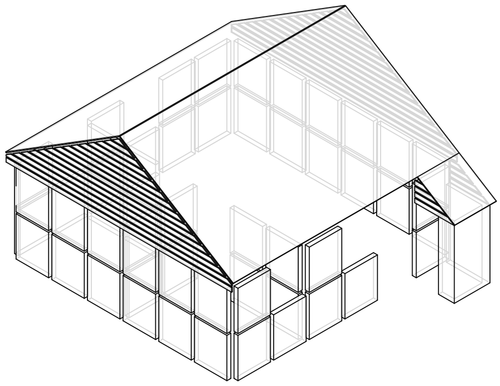
This design is interesting because it provides a solution of how to dispose or use the existing rubble after disasters. The roof can be wide spanning because of the known quality of the paper tubes. Besides the paper tubes only local material is used. The prefabricated plywood connectors for the roof simplify the buildup process. It is one of the few designs not using the common corrugated galvanised iron panels but relying on plywood panels and straw as roof material. The plywood panels make the roof more rigid under seismic stress. The design also features simple windows which can be opened even during rain fall. The external, attached toilet solves the problem of odour and avoids building thermal bridges. The downside is that the building needs to be left during night times for toilet use. The open area in the roof truss allows for a good ventilation and the open connection to the roof space for a good air circulation. While the floor is raised to prevent surface water damage the wind uplift risk is unclear as the anchoring of the walls to the foundation is not specified. Build time and cost is unclear as an email to the studio was unanswered.

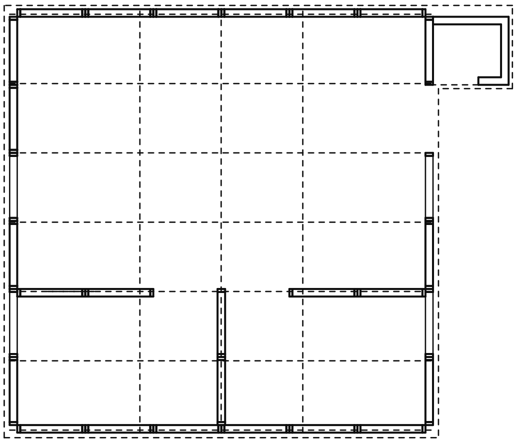
[115] Shigeru Ban. *Nepal Project*. 2015. URL: `http://www.shigerubanarchitects.com/works/2015_nepal_earthquake-3/index.html` (visited on 19/01/2022).
[116] Ibid.
[117] Ibid.

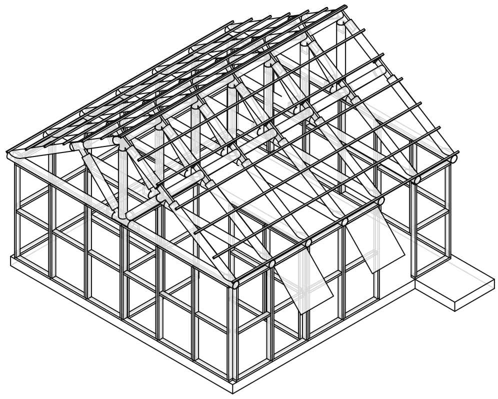


Phase	perm.	Climate	Cwa	Earthquake	very high
Area m²	29	Price/m² €		Lifespan	10 years
Plotsize m²		Weight kg		Labour	
Room height	210/310	no per TEU		Build time	
Local Material	both	Flood safe	no	Extendable	yes









Images: Shigeru Ban. Nepal Project

1m 2.5m 5m

Extendable houses - Alejandro Aravena

The original idea that a house is not static but rather an ongoing project with the residence as creators was described first by John Turner.[118]

While not originally inventing the idea of houses completed only partly during initial construction Alejandro Aravena made heavy use of this idea in the aftermath of the massive 8.8 earthquake hitting Constitución, Chile in February 2010. Because of the economic situation middle class houses with typically 80 m^2 were not feasible.[119]

The design features just half a house with 20 m^2 on each of the two floors (3.1×6.9 m). The gable roof covering the house is built entirely in the initial phase, covering the empty second equally sized half of the house which is left open for later construction by the inhabitants themself. In the unfinished part only three beams stabilizing the exterior wall and forming the future ceiling are constructed initially. While half of each house is visually identical, deviation and individuality can be seen in the later finished second half. The design suggests room and furniture layouts for the second half of the house.[120]

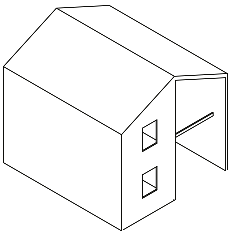
Aravena mentions that *"in case you can't do everything, focus on (A.) what is more difficult, (B.) what cannot be done individually, (C.) what will guarantee the common good in the future."*[121] Besides aspects of urban planning (location, urban layout) the design pays attention to *"provide a structure for the final scenario of growth (middle class)"*.[122]

For another project with 100 unfinished houses in Iquique, Chile the budget was 7500 € per unit. Technical drawings including site plans for four incremental housing projects are available on the website of Alejandro Aravena's studio Elemental.[123]

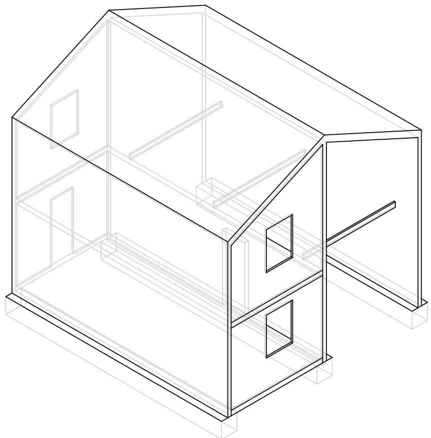
A UNHCR response applying this concept is the Shape shelter designed for Iraq, 2011. The shelter is L-shaped (7.25×6.6 m) with roughly 35 m^2 of useable space. The remaining part of the L-shape which is 3.9×3.3 m can be extended by the inhabitants later. Internal room division allows for two rooms and one toilet (1.35×2 m). Two entrances from two sides provide independent access. A total of three windows with 1×1.1 m provide adequate light. Two units can be attached side by side to save the costs for one external wall. The material price for the construction is 6650 €.[124]

Unlike the design from Aravena the UNHCR design does not provide a roof for the extended structure, greatly increasing complexity for the future upgrade. Also in contrast to Aravena the roof in this design is only slightly inclined resulting in potential leaks over time. Both building and extending it require some sort of construction knowledge or supervision. Also the internal room division is already fixed.

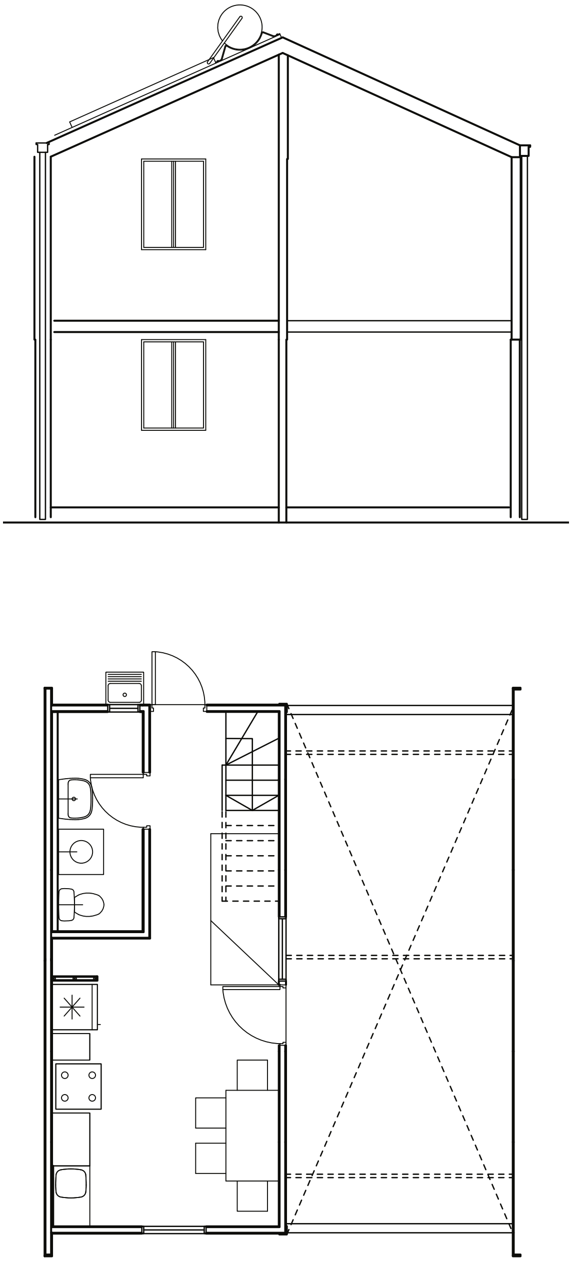
118 John Turner and Robert Fichter. *"Housing as a Verb"*. In: *Freedom to Build : Dweller Control of the Housing Process*. The Macmillan Company, 1972.
119 Sam Greenspan. *Half a House*. 10th Nov. 2016. URL: `https://99percentinvisible.org/episode/half-a-house/` (visited on 27/06/2022).
120 Ibid.
121 Alejandro Aravena. *4 Incremental Housing Projects*. July 2018. URL: `https://www.elementalchile.cl/wp-content/uploads/2018/07/ABC-VIVIENDA-ELEMENTAL-HOUSING.zip` (visited on 27/06/2022).
122 Ibid.
123 Ibid.
124 *Shelter Design Catalogue*, p.62.

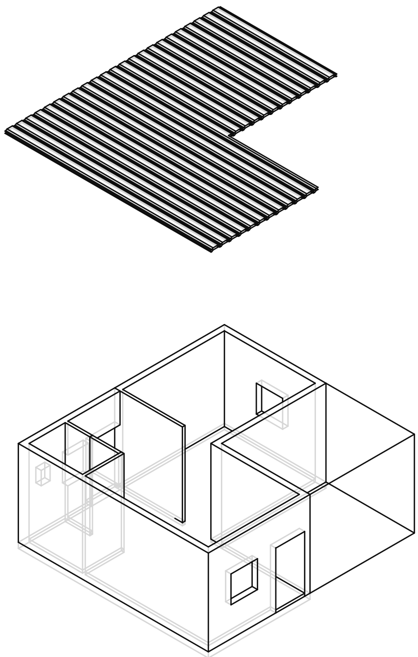


Phase	perm.	Climate	Csb	Earthquake	high
Area m²	40/80	Price/m² €	96.80	Lifespan	20 years
Plotsize m²	80	Weight kg		Labour	
Room height	230	no per TEU		Build time	
Local Material	yes	Flood safe	no	Extendable	yes



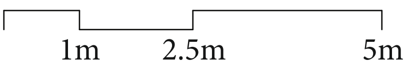
Extended house structure
Alejandro Aravena





UNHCR Shape Shelter

Extended house plan, section
Alejandro Aravena



Images: Alejandro Aravena ; Shelter Design Catalogue

RE:BUILD

This project realized by Pilosio Building Peace in the Za'atari refugee camp, Jordan creates a 16×16 m wide structure for a school. It consists of four buildings. Although this project is a school the building system can be used for clinics or private homes as well.[125] The design is attributed to the Iranian architect Pouya Khazaeli who is active in the field of emergency architecture.[126]

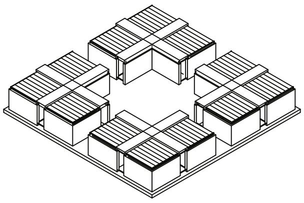
The skeleton of the system consists of a standard scaffolding metal structure which already incorporates bracing beams against wind loads. To create the walls two layers of reinforcement steel meshes are used with a local infill in-between. An additional wire frame keeps the gravel and earth / sand infill inside of the wall layers. With an outer layer of mud cladding the steel meshes are protected from rain. The roof was constructed from metal sandwich panels which were covered with earth. A raised floor on scaffolding tubes was built and the whole structure was placed on a concrete slab. Total construction time with six paid but unskilled labourers took two weeks and the price was about 30 000 €.[127]

The use of a standard scaffolding metal beam system make the design interesting because it requires very little construction know-how. This scaffolding system has fast and safe connection points and is used in the scaffolding area since many years. The infill is local material lowering the transportation costs. Because of the heavy wall infill only small openings can be created. Ventilation is paid attention to by raising the roof structure above the corridors. The scaffolding can be reused when the structure needs to be relocated. Availability of the system in crisis regions is doubted as well as the high price for the structure. Given the heavy walls it is unclear how earthquake resistant the structure is. The location is an area with medium seismic risk. The walls are expected to have a quite high thermal mass creating a stable climate for the school children. With the wall thickness of 20 cm and weight of the walls wind uplift is not expected to be a relevant issue.

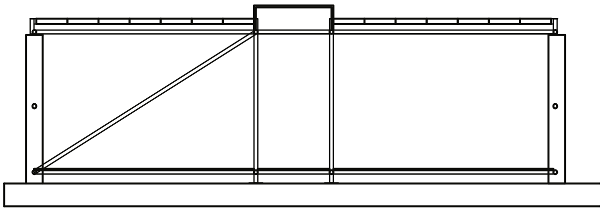
[125] Lucy Wang. *Revolutionary Construction System Builds Low-Cost Syrian Refugee Schools out of Sand.* 4th Aug. 2015. URL: https://inhabitat.com/revolutionary-construction-system-builds-low-cost-syrian-refugee-schools-out-of-sand/ (visited on 30/06/2022).

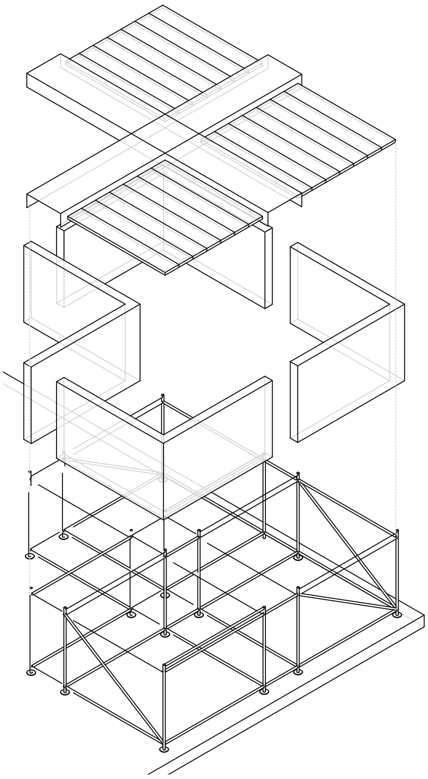
[126] Pouya Khazaeli. *Bamboo Structure Project / Pouya Khazaeli Parsa.* 2009. URL: https://www.archdaily.com/93922/bamboo-structure-project-pouya-khazaeli-parsa (visited on 30/06/2022).

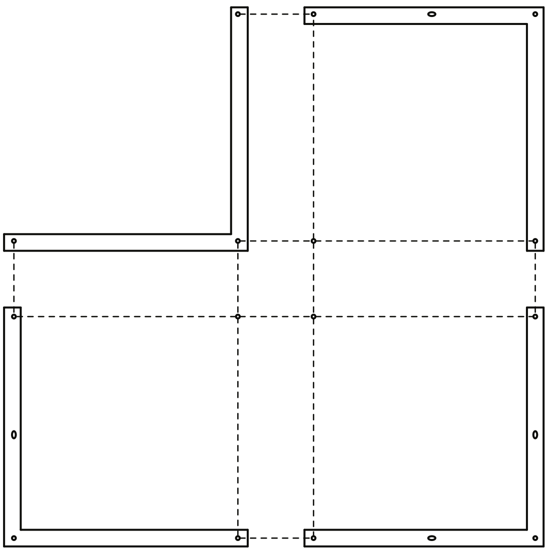
[127] Pouya Khazaeli. *RE:BUILD*. 2015. URL: https://wdo.org/site-project/rebuild/.



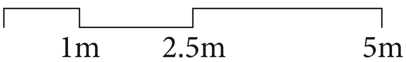
Phase	perm.	Climate	BSk	Earthquake	moderate
Area m²	256	Price/m² €	117	Lifespan	
Plotsize m²		Weight kg		Labour	1/6
Room height	210	no per TEU		Build time	16 days
Local Material	both	Flood safe	no	Extendable	yes







Images: Lucy Wang



Aranya low-cost housing - Balkrishna Doshi

The project with initially 80 model houses is located outside of Aranya, India and provides small plots ($35\,m^2$) to former slum dwellers. The master plan with six mixed land-use sectors was created for 6500 units and consisted of different sized plots to create a mix between poorest and middle class families of different religions.[128]

On the plot just a plinth, a service core (latrine), one room and connections to electricity and water networks are provided. It was planned that the inhabitants continue with initially building the kitchen and then gradually expanding their house over time. A loan was given with a price depending on the income of the dwellers. The foundation was built using concrete and the initial construction using load bearing brick walls.[129]

This project is not directly disaster response architecture but it is interesting under the don't rebuild twice principle. The project aims for permanent houses but puts a strong emphasis on the costs and the infrastructure. A raised foundation and water and electricity infrastructure as key factors for safe constructions and living are provided for all plots. The inhabitants could develop a stronger connection to their houses as the design and layout is strongly influenced by them. It is not stated in the sources if the built houses were inline with safe construction principles as only the foundation was constructed by professional companies. It is expected that without professional supervision the same building mistakes common to informal architecture are made. With only the latrine as initially provided structure the future inhabitants must provide financial resources to construct a first structure for living. It may even be better to provide a tent to allow the inhabitants to stay on the construction site to speed up construction but this would contradict the don't build twice principle mentioned above.

(a) Initial view with plinth and sanitary room

(b) Houses completed by inhabitants

Figure 3.40: Images by Mollard

[128] Manon Mollard. *Revisit: Aranya Low-Cost Housing, Indore, Balkrishna Doshi*. 14th Aug. 2019. URL: `https://www.architectural-review.com/buildings/revisit-aranya-low-cost-housing-indore-balkrishna-doshi?tkn=1` (visited on 30/06/2022).
[129] Ibid.

vivihouse / wikihouse

The vivihouse project aims to bring a construction toolkit which allows to erect multi-story buildings with a wooden structure according to Eurocode and Austrian national requirements. An integral part of the concept is the do-it-yourself culture where future inhabitants can participate more actively than in traditional construction projects. This project uses prefabrication for all elements (columns, walls modules, roof modules) which are assembled on the construction site using a crane. Steel connections between wooden parts allow full disassembly and relocation. Currently a three floor prototype located in Vienna, Austria is constructed.[130]

The idea is related to the wikihouse project which is licensed under a Creative Commons–Sharealike license. But the construction is very different with all parts of the design built with structural plywood or structural OSB plates. The design consists of buildings blocks which are available in a library section on the website allowing the download of the 3D files for self construction. In contrast to the vivihouse the wikihouse is not aiming for four or more stories and in general for smaller sized buildings. It is designed for temperate climates with an U-value of $0.14\,\mathrm{W/(m^2\,K)}$ but supports cold climates by adding additional insulation. Locations with high wind loads are not supported. The design works ideal for detached houses and small structures. Multi story flats are not supported because of issues with the acoustic insulation and regulatory fire protection rules.[131]

The mentioned systems are one of the few available modular wood systems. While they apply a do-it-yourself principle to include future inhabitants the scale of the structures does not fit this context. For emerging country contexts complying with strict building regulations and support for three stories is not needed and requires a rescale of the structure and connectors. Also both systems rely on prefabrication with trained labour for all elements including walls, floors and the roof.

(a) vivihouse three story prototype (b) Wikhouse at Archive-opia

Figure 3.41: Images from Fürst, Nikolas and Schulz, Paul, *WikiHouse - Design Guide*

[130]Michael Fürst, Kichler Nikolas and Schulz, Paul. *vivihouse - Ein Toolkit für urbanen Selbstbau*. 2017. URL: `https://www.vivihouse.cc/toolkit/` (visited on 06/12/2020).
[131] *WikiHouse - Design Guide*. 2022. URL: `https://www.wikihouse.cc/guides/design` (visited on 01/07/2022).

Chapter 4

Issues and Manifest

Based on the analyzed displacement responses in chapter 3 common issues are summarized in this section. The result of this summary of issues is a manifest showing options of how to overcome the noticed problems. Future shelter design should build upon the found principles in this manifest to create better transitional shelters.

Construction Many analyzed examples had great weaknesses in structural stability against high wind loads, and against seismic activity. Often the reasons were inadequate connections to the ground and missing structural bracings. Proper wood to wood connections are complex to create and not as strong as steel connectors.

An ideal shelter provides proper bracings and structurally safe connectors to reduce the risk of collapse during seismic activity. The structure is properly fixed to the foundation to handle pull forces resulting from wind uplift. For wooden constructions metal connectors should connect the wooden parts to form safe connections. To reduce seismic risks a light roof should be preferred.

Surface water Commonly local and global shelter types were not raised and thus heavily affected by surface water. Drainage infrastructure is commonly subjected to neglected maintenance increasing the risk of surface water damaging the shelter.

An ideal shelter is at least slightly raised or erected on a mound. This keeps the belongings of the inhabitants safe and the shelter inhabitable during floods.

Climate adaptability Many of the global shelter designs are totally unfit for the climates they are deployed in. The materials are often inadequate for cold climates and often also for warm and humid climates. Sometimes winterization kits are available but commonly don't provide insulation but just improve the heat resistance of the surfaces allowing for heaters. Heating uninsulated structures is economically and environmentally infeasible.

For an ideal shelter the hull is adaptable to local climatic conditions. This not only includes climate appropriate materials but also the design of openings for natural ventilation and insulation for cold climates. For areas with high day-night temperature swings thermal mass is needed for comfort.

Lifespan Despite that displacements of more than two years are common many analyzed projects only have a lifespan of around two years or less.

An ideal design needs to distinguish between the surface lifespan and the lifespan of the main structure. While the surface lifespan may require regular maintenance and can be shorter, the main structure should at least last for ten plus years. Only locally available materials should be required to perform periodic repairs of the surfaces.

Relocation ability The more solid examples in the reference section will be considered as permanent buildings by the local population, greatly reducing their acceptance. These shelters can not be relocated and thus prevent the inhabitants to take the structure back to their place of origin.

An ideal structure is still considered temporal by the local population to ease the search for locations. Also the structure should be partly or fully disassembleable to allow for the return of the refugees to their originating country with their shelter without starting from scratch again.

Local building techniques The analyzed shelters were divided into global designs where the same design is used all around the world and local designs which were designed for a particular crisis response. While local designs are more climate adapted and able to incorporate the local building techniques and the preferences of the displaced, new designs have to be created for every response rendering this approach very labour intensive from the point of aid agencies.

The ideal shelter should use local building techniques and designs but should not require a reinvention of the load bearing structure and roof every time. This could be achieved by separating the load bearing structure from the main design elements like walls and the roof. Ideally different options for the wall and roof construction are available allowing for culturally appropriate choices.

Size / configuration Nearly all analyzed examples have a fixed unit size which in most cases can not be combined to form bigger structures. Space requirements differ substantially depending on personal, climatic, cultural and economic situation. Requirements also change during the time of displacement with families growing and shrinking.

As there is no one-size-fits-all solution the ideal shelter is dynamically extendable or combinable to bigger structures over the time. Adaption of the size both extending and shrinking needs to be possible during the whole lifespan of the structure.

Transportation Some of the analyzed shelters have a low unit per transportation ratio. Often transportation options are limited in a crisis aftermath because of destroyed infrastructure or occupied transportation resources.

Ideally the material for many units can be fitted in just one container to reduce transportation costs. Material usage which is not locally sourceable should be limited as much as possible. On-site material has the least transportation costs and should be preferred if available at the needed quantity and cost.

Self-empowerment A common problem of shelter design is the involvement of the future inhabitants during construction and maintenance phase. Often structures are erected by dedicated teams leading to a later lack of maintenance from the inhabitants themself originating from the lack of responsibility for the structure.

An ideal shelter involves the future inhabitants to participate at least partly in the construction. This also creates a stronger bond to the shelter and inside the local community if construction work is done together. When the construction methods are known, future adaptions by the inhabitants themself can be performed in a structural safe way.

Materials / Complexity Some of the analyzed shelter structures are complex to manufacture, rendering local construction impossible. Also some projects relied heavily and entirely on high tech materials which usually can only be sourced in industrial countries.

An ideal shelter minimizes the need for special materials and complex manufacturing equipment or methods. Material is ideally sourced mostly from within the country to support local economy and reduce transportation times and costs.

Adaptability / Individuality For displacements exceeding half a year there is an increasing need for individuality and adaptation of the structure. Some references offer the inhabitants a choice of different materials for their shelters. For most analyzed structures adaptions to the hull are not possible without damaging the façade or creating structural weaknesses. Also commonly global designs offer very limited variation, often not even allowing to change the outside surface color. For global designs in camps this leads to visually uniform structures making orientation hard and denying the inhabitants any individuality.

An ideal shelter provides the flexibility of adapting to allow for changed functionality over the years. At least the possibility to visually adapt the inside design of the shelter should be given to the inhabitants.

License For some projects only renderings and visualizations exists while also leaving enquiries about detailed plans unanswered. This greatly complicates the process of analysing and potentially improving already existing solutions. Many designs are only supplied by commercial manufacturers who optimize their production costs to meet only the minimal requirements set by the ordering institutions. Closed and complex designs do not allow to produce spare parts locally to repair and maintain existing structures.

An ideal shelter design is published entirely under an open license allowing everybody to use, contribute, improve and adapt the design to their needs.

Price The analyzed shelters range from around 10 €/m^2 to more than 1000 €/m^2. If all structures with just a lifespan of one year or less are excluded the median is 91 €/m^2 with an average of 135 €/m^2.

While they do provide greatly different levels of living comfort and quality it is important to focus on affordable shelter solutions. If the price per shelter can be reduced by half the double amount of displaced can be supported.

Part II

Design

Chapter 5

Idea

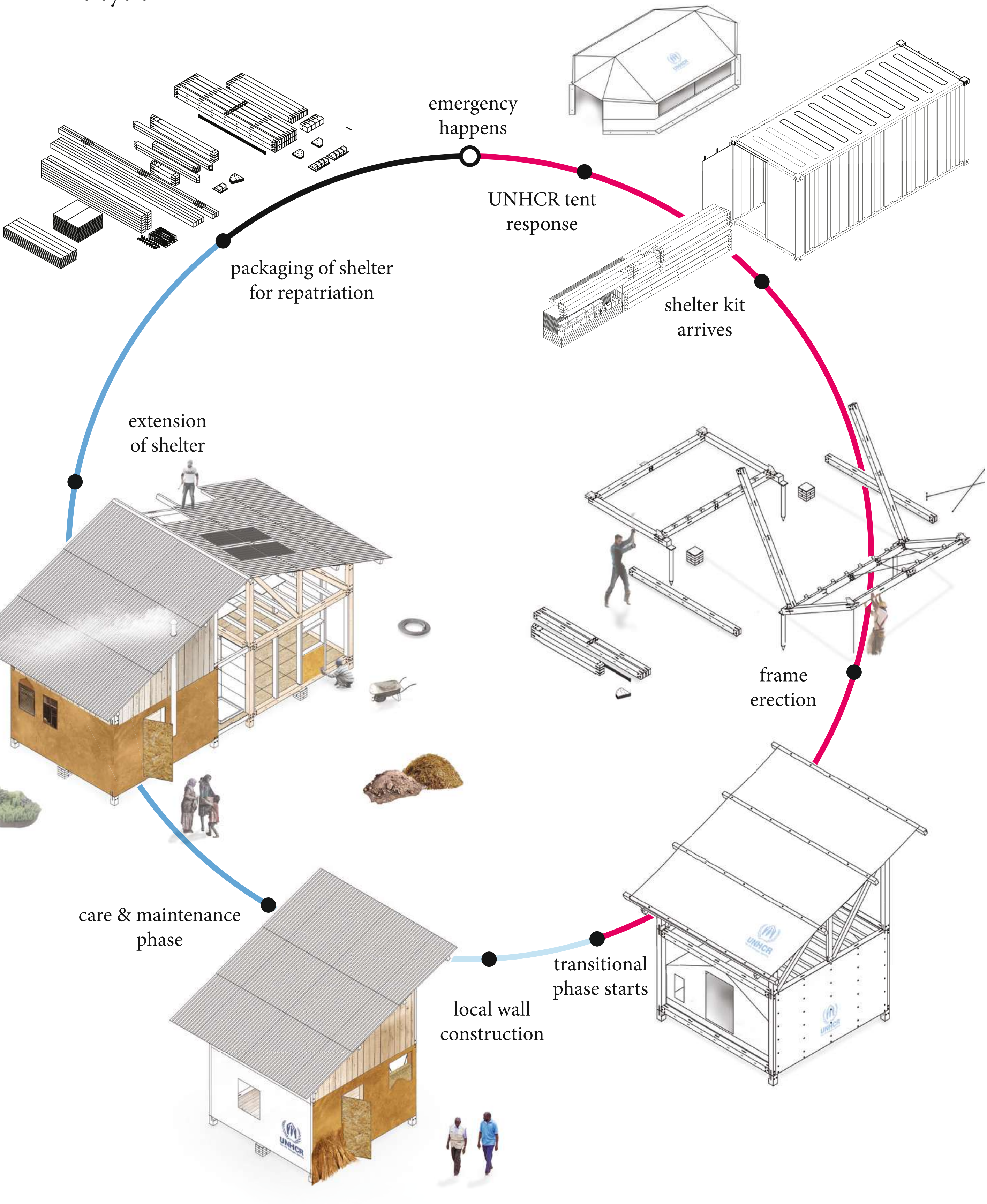
This work presents one possible novel design for a transitional shelter addressing the issues from the manifest. The design can be applied in most settlement options described in section 2.3.4 especially in organized and unorganized camps and rural self-settlements. Deployment in an urban context is possible but does not utilize all strength of this design.

The core idea of this design in this thesis is that only the structural frame including all connectors are prefabricated and provided to the future inhabitants. The structural frame includes a roof structure and is made from timber beams. Metal connectors with plates and bolts allow easy assembly and disassemblement of the whole structure. All connectors and timber processing steps are designed in a way that they can be performed using low tech machinery allowing local prefabrication in developing countries. Providing the structural frame prefabricated avoids the common problem of structural shortcomings of existing transitional designs. To be surface water resistant the structure is always slightly elevated. It also comes with metal rod bracings to be wind and earthquake resistant.

All elements are dimensioned in a way that they can be carried and mounted without the use of heavy mechanical equipment by not more than four people. No complex technical skills are required to assemble the structure. By protecting the timber structure from rodents and water the lifespan is expected to be 10+ years.

The walls are constructed by the future inhabitants using materials available locally on-site. Separating the walls from the structure allows to adapt the building hull to the requirements of the local climate. In this work material and construction suggestions for a desertic, cold continental and a wet and humid climate are given as reference. Using local materials for walls allows to stick with building tradition and cut (transportation) costs. It also allows for customizations, possibilities for self repair and maintenance. Inhabitants can choose the wall material and construction freely as walls only have to bear their own load. The roof can be covered with corrugated galvanised iron panels, using local materials or by combining both methods together. Openings can be placed arbitrarily where they are needed. The design comes with an optional suggestion of a wall module size to allow prefabrication of wooden frames to ease on-site construction of the walls.

Life cycle



emergency happens
UNHCR tent response
shelter kit arrives
frame erection
transitional phase starts
local wall construction
care & maintenance phase
extension of shelter
packaging of shelter for repatriation

For construction, pre-fabrication, transportation and structural calculation reasons a standard size of 4×4 m per module was chosen. According to the Sphere recommendation with this roughly 14.7 m^2 two to four people can inhabit one unit according to the climate. To allow for the growth of space requirements multiple units can be combined together in a defined way to increase the usable space. Units can be added at any time during the lifespan of the structure as every module is independent from a structural perspective. This work also includes designs for prefabricated modules for sanitation and kitchen spaces as they are hard to build on-site.

With the disassembleable structure the most expensive, technically complex and important part of the dwelling can be moved to another location when the circumstances change. This allows the inhabitants to not start from scratch after the return to their home country or safe place. This sense of ephemerality is especially important for the host community to not create tensions over resource and space usage with the displaced people for a longer timespan. To further ensure no permanent degradation of the site the design suggests screw foundations instead of concrete foundations. Screw foundations provide good stability and protection from wind uplift.

The design is published under an open source license allowing every institution and individual to improve and manufacture the module kits. The kits can be provided during international relief operations or built locally with funding from partners or the government. A partial upgrade strategy ensures that this design can benefit directly from the existing emergency responses like tents by upgrading them to improved transitional structures.

5.1 Requirements

While the design can be applied globally the ideal case are local crisis or disasters which do only affect parts of the country, keeping supply chains and pre-production capacities in the other parts intact. Ideally the country has an existing timber industry allowing to procure construction timber locally.

Because air lifting the kit of this design is too expensive at least a partly restored road network withstanding the weight of trucks is necessary for this design to work. Other infrastructure like electricity, fresh water and waste water is not strictly necessary but beneficial.

Material for the on-site wall construction like clay and straw should be locally sourceable which is more commonly the case in rural environments.

The ideal site is owned by the inhabitants and was affected by a political crisis or by a natural disaster but is safe to settle again. For displacement situations the site selection is more difficult as there is commonly strong rejection of the local population towards permanent camps. This design tries to overcome this issue by offering a fully disassembleable architecture which does not leave any damages to the site after a relocation. Also the possibility of relocation with the structure can help inhabitants to return to their original place sooner, reducing the tension with the local population.

Chapter 6

Life-cycle

This sections goes into detail in which phase this design fits and how it interacts with the phases before and after. No design can be evaluated in isolation. To be efficient all existing resources from previous phases must be incorporated and reused in this design as identified in the manifest. Also this design itself must be reusable for later phases without wasting resources.

6.1 Emergency

This design starts earliest at the end of the emergency phase. Reasons are that providing tents is faster and more cost effective under all circumstances. For natural disaster affected providing tarpaulin during the emergency phase is also the fastest response to allow repair of damaged structures temporally. After the initial demand for emergency shelter is satisfied planning of providing kits of this design to allow an upgrade of the existing tents can start. For damaged structures in non-displaced situations this unit can be used to apply the build back better principle. Especially the tarpaulin can be reused very effectively as wall or roof material in this design.

During camp planning extra space for this design next to the tent space should be reserved. Space requirements in camps were discussed in section 2.5. If the requirements were not met it makes sense to relocate parts of the populations into new dedicated areas with reduced density before the construction of more transitional shelters begins. With this design taking up $16\,m^2$ of space and the UNHCR tent taking up $61\,m^2$ of space both shelters should fit easily on a plot.

For non-camp-site deployments like disperse settlements and when tent deployment is not possible an early distribution of kits of this design should be considered. It is more resource efficient if displaced persons do not have to build an own shelter structure before receiving the shelter kit from this design. If this is unavoidable because of the time delay, special attention must be paid on reusing the material from the existing shelter as much as possible. For example this can be achieved by reusing existing materials to fill the walls and construct the floors.

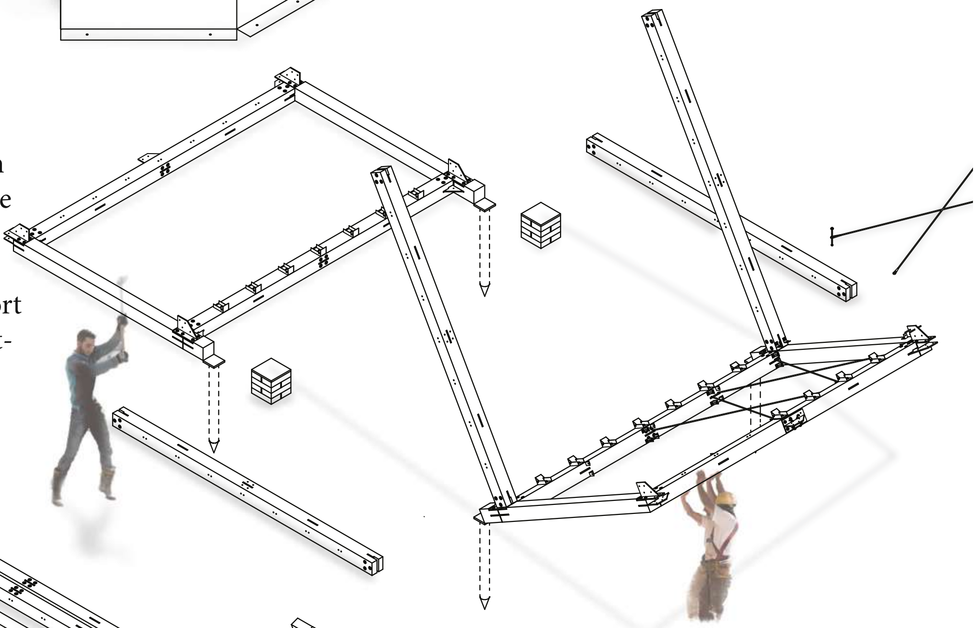
This design is dimensioned in a way that the standard UNHCR self standing family inner tent can be placed inside the structure. With a corrugated galvanised iron roof and the raised floor platform with OSB boards the tent is much more durable against rainfall. Still keeping the tent as shelter while gradually upgrading the walls around to more durable solutions allows to use the space and resources very efficiently.

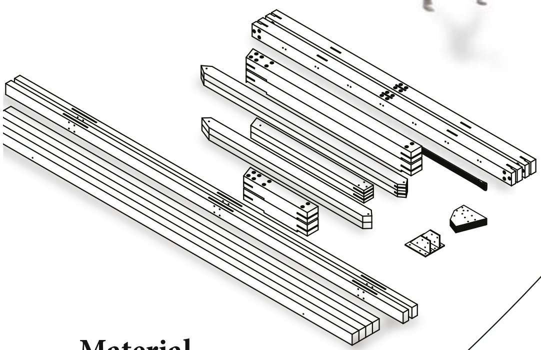
Core frame construction of this design can be done in a day after delivery by a team of four. Logistics and a qualified support team should be scheduled accordingly. The kit must come with the generic manual for the safe frame construction including the rules of where and how many bracing rods need to be put. Especially during the more chaotic emergency situation it is essential that the construction happens timely after kit delivery to prevent theft. Besides the optional ground screws the frame can be errected without heavy equipment. The sides (150 kg) are assembled on the ground and then lifted up by using the attached beams as counterweight.

Final state at the emergency phase is a fully erected core structure with a usable floor made from OSB plates and a rainproof roof. If available corrugated galvanised iron sheets were used as roof cover but tarpaulin is also sufficient for the first weeks. The structure is properly grounded and protected against wind forces and all necessary bracing rods are installed and tightened. The UNHCR inner tent is placed sheltered in this frame and fixed to the primary structure. All walls are covered with tarpaulin as wind and rain protection for the inner UNHCR tent.

Construction

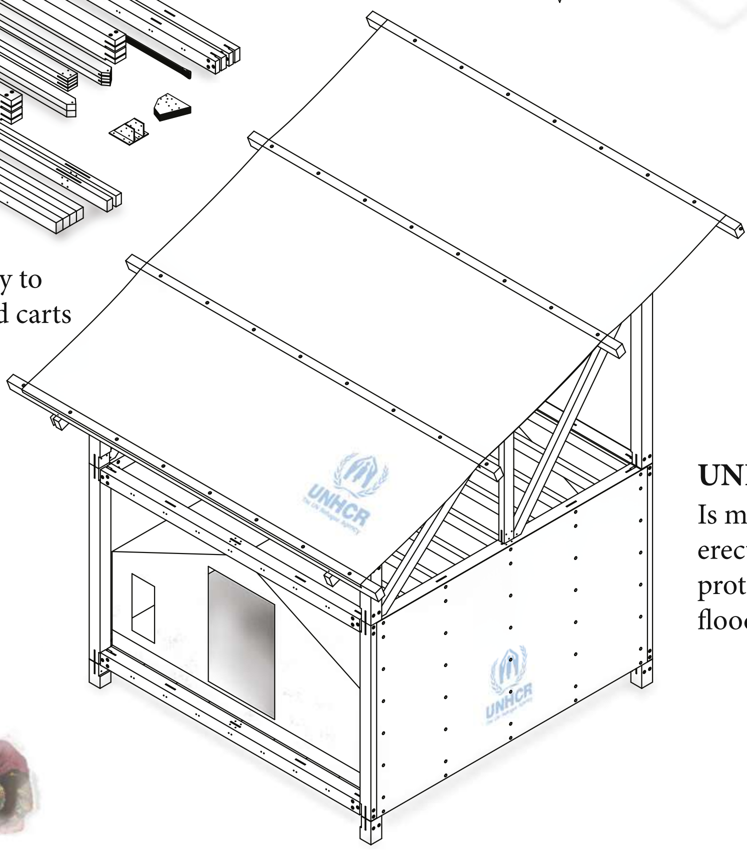
The two sides are assembled on the ground. Then the two bottom beams are attached on one side to allow easier lifting up. Small brick towers support the beam till it is connected to the other side.





Material

Is delivered directly to the plot using hand carts for the last meters.



UNHCR inside tent

Is moved inside the erected shelter to better protect it from wind and flood damage.

6.2 Transitional

During the transitional phase the initial frame with the UNHCR tent inside is steadily improved by creating walls based on local tradition and availability of local material. Depending on the climate the walls should be made from insulating material. Insulation can be also added into the inner space between the floor and ceiling secondary structure. For areas with big day-night temperature swings dense materials can act as buffer adding thermal mass.

For this task a bigger social group is beneficial as creating walls is a very time consuming and labour intensive task. Ideally one person of the group brings some construction knowledge to not build construction defects. But as the main structure is fully load bearing and the roof was also already finished under partial supervision during the emergency phase, construction deficits are not life threatening.

To ease the construction a reference manual for building the walls is given. This manual should consider the local known building technique and the locally available materials. The manual should be more focused on the different possible construction techniques rather than finished designs.

If not done before a small solar panel and a wall battery should be attached to be able to generate and store electricity for phone charging and lights.

As suggested by the Sphere guidelines a household toilet should be created on the plot. Also a septic tank needs to be dug under the toilet. See section 7.6.2 for different sanitary options.

If the inside kitchen module in culturally applicable and is available it should be added to provide a proper, efficient and safe cooking place. The kitchen module can be also used to heat the house during cold winter times. Section 7.6.3 gives details about this module.

The state of the building at the transitional phase should be a building with four locally produced and climate adapted walls including a door and windows for light and ventilation. It is an isolated and winter safe unit which provides privacy and dignity with the household toilet and attached kitchen. The UNHCR inner tent is fully removed and the inhabitants use this enclosed space as their main living area. Sides which are planned for future expansion or extension modules should be only temporary covered with OSB plates. The roof is final and provides a durable rainproof cover. It is covered with corrugated iron sheets or other locally available roof cover materials. Local material can be also placed on top of the corrugated galvanised iron sheets to reduce noise during rainfall and reduce the heatup during the day. Previously used tarpaulin can be reused to create animal sheds or create a second rain proof layer under the roof panels.

UNHCR tent
Is reused to shelter animals or to store materials

Local wall
A local wall with a straw mud mix and a clay exterior plaster is created

Modules
Modules constructed from timber help to fit the straw mud mix later in place and allow for easy window placement

Tarpaulin wall
Not all walls have been converted yet

UNHCR wash household toilet
A household toilet provides security and comfort

6.3 Extensions / Maintenance

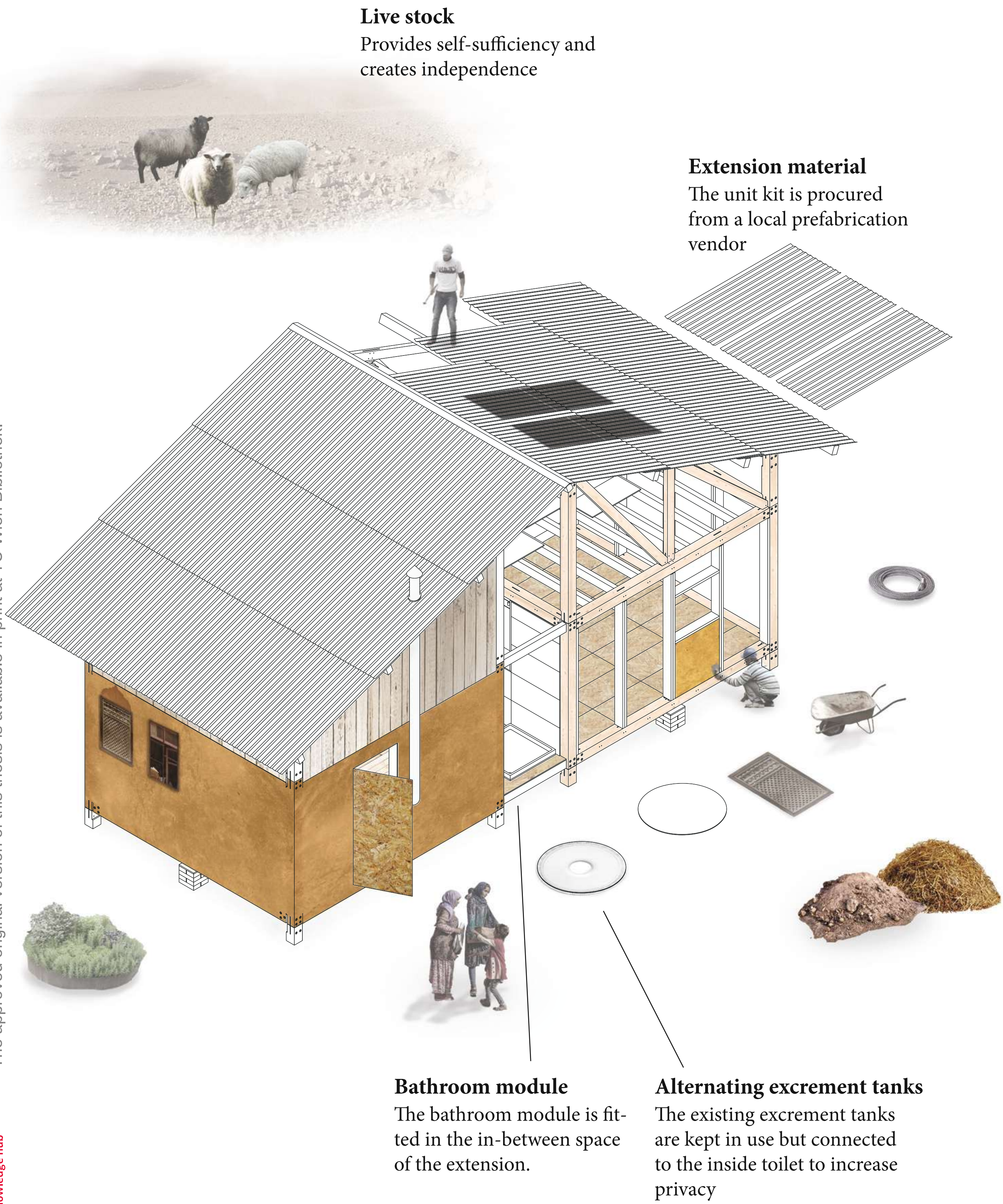
During the displacement period social bonds and families can grow. Quite commonly space for children and parents is needed. To accommodate for these changes the design is adaptable in size. Also the quality of the dwelling can be improved by adding a sanitary module containing a shower and toilet to the in-between space of two units. The sanitation module is discussed in detail in section 7.6.2.

During this extension period partially economic self-sustainability is assumed. Material for extension units is expected to be acquirable from local businesses as the pre-fabrication techniques are low tech and plans are available freely. Extended support through international relief organisations is also possible but less likely as international relief organisations need to focus on new emerging crises for various reasons. Also the willingness of donations from international sponsors declines with the duration of the displacement.

Usable space is not only increased by the new unit but also by the covered in-between space forming between two adjacent units. This space adds an extra of $5\,m^2$ to the main living area. With this extra space the extended roofs can be combined seamless and no major modifications to the roofs are needed. Based on the mechanical load calculation each column in each unit can take the extra load from the added in-between space. Different unit layouts combining up to six units are possible and discussed in detail in section 7.7. Extension units are statically independent and need to be braced according to the rules from the manual.

The process of adding a new unit starts with purchasing the kit from a local vendor. Then the foundation next to the existing unit with a distance of 128 cm is built. Having the target height of the new unit on the same level as the existing unit makes space usage easier but is not required. The structural frame is partly assembled on the ground and then lifted up. After adding the secondary structure forming the sub-structure for the floor and ceiling the OSB plates are added. Shorter beams combining both units are attached to outside mounted connectors on both sides. The walls are filled with local material according to the climatic requirements. Finally both spaces are connected by creating an opening in the previous outside wall now facing the new unit.

Regular maintenance needs to be performed by the inhabitants to extend the lifespan of the shelter. Because the structure and the walls were erected by the inhabitants it is assumed that the closer connection to the shelter results in more thorough maintenance. Depending on the used material most maintenance tasks concern the locally created wall surfaces. The primary structure should ideally be covered on the outside to prevent moisture and insects. If the bracing got loose it can be tightened to bring extra stability during high wind loads. In case the short riser columns at the corners which are closest to the ground got deteriorated by moisture or insects they can be replaced separately. Besides this no regular maintenance tasks for the primary structure are required.


Live stock
Provides self-sufficiency and creates independence
Extension material
The unit kit is procured from a local prefabrication vendor
Bathroom module
The bathroom module is fitted in the in-between space of the extension.
Alternating excrement tanks
The existing excrement tanks are kept in use but connected to the inside toilet to increase privacy

6.4 Reuse / Relocation

It is common that refugee sites are just temporal and that displaced people eventually repatriate or relocate to a permanent place after a certain duration. Section 2.1.7 covered the displacement durations in detail.

If the displaced were able to stay in close distance to their originating country or place it is reasonable that transportation for the main structure can be organized during a return or repatriation. In case a local integration in the host country is possible a relocation to another plot of land also allows to take the main structure and possibly also valuable materials from the wall construction like bricks etc.

Because of the financial cost of transporting the unit repatriation can be financially or logistically supported by international organisations or the government. It is also possible to sell one module locally to collect money for covering the transportation costs of the rest of the structure.

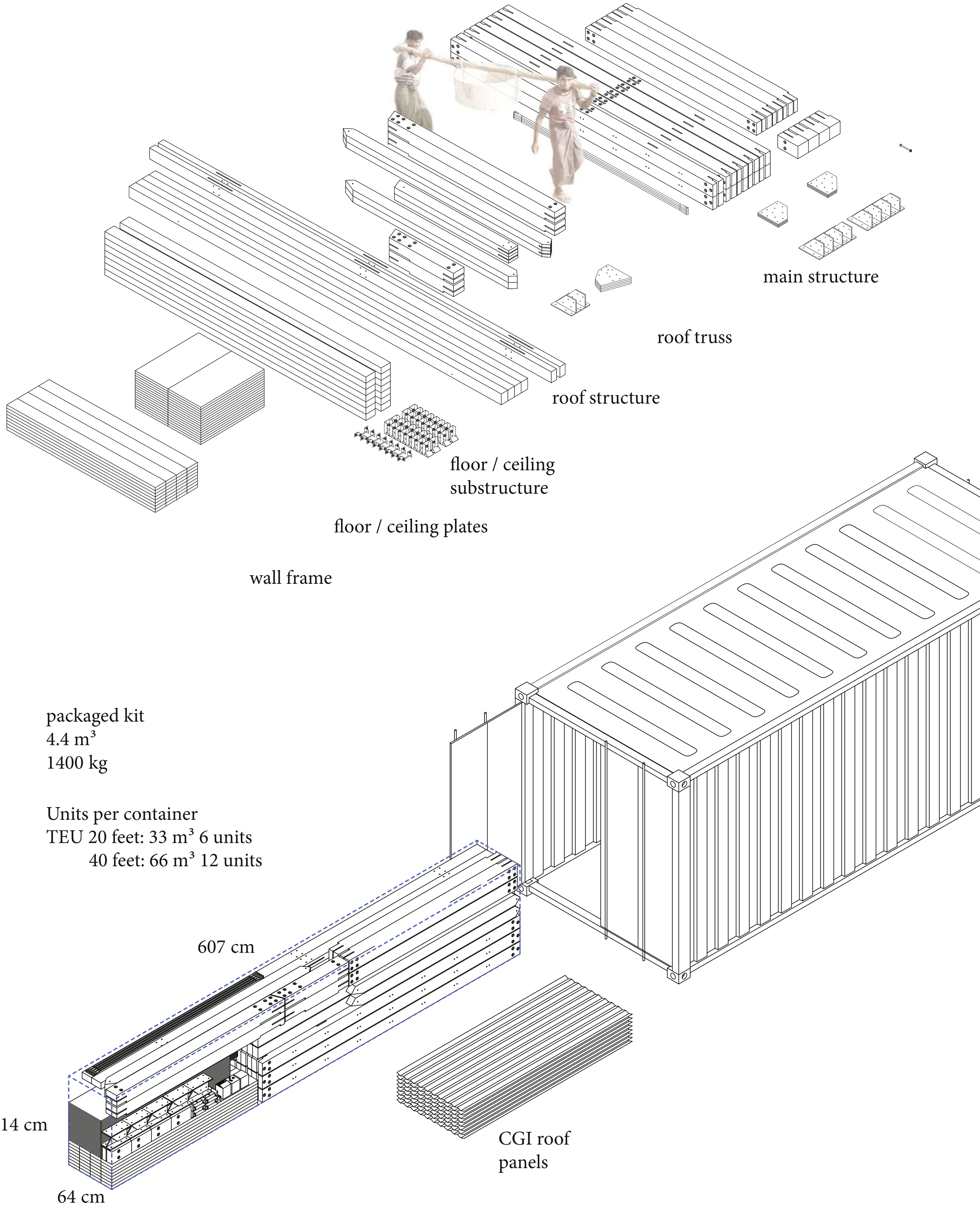
If only a relocation to a third country is possible most likely the structure can not be taken along and must be sold locally, allowing other families to benefit. The structure could be also sold back to an international relief agency to be deployed at another crisis. Damaged or worn parts can be replaced to create a refurbished kit. The different options for a permanent solution with advantages and disadvantaged were discussed in section 2.2.3.

All parts of the main structure are just bolted together using threaded rods, washers and nuts. This allows the whole structure to be disassemble-able after the locally built walls are removed. Also the wall modules are bolted using drive-in nuts. Depending on the level of corrosion rust remover might be needed to be able to unscrew the nuts.

The main structure with its wide spanning timber beams and columns and all the predrilled holes and metal connectors is consider more financially valuable than the locally sourced and created walls. Also the lifespan of the core structure of 10+ years is more than the expected lifespan of the walls. The local materials like bamboo, straw and mud are expected to be left behind after disassembly as they would take up too much transportation weight or volume. If only traditional biodegradable materials were used it is likely that leaving behind the wall material does not create pollution on the land. With the wall material left on-site the transportation size of the main structure is equal to the original kit size.

All materials can be recycled if a reuse is not possible. The steel can be sold and remelted and the timber from the structure can be used for heating.

Relocation and reuse is a key aspect of this design as it allows for an eventual disassembly and relocation of the buildings which greatly increases the acceptance of the local population.


main structure
roof truss
roof structure
floor / ceiling substructure
floor / ceiling plates
wall frame
packaged kit
4.4 m³
1400 kg
Units per container
TEU 20 feet: 33 m³ 6 units
40 feet: 66 m³ 12 units
607 cm
114 cm
64 cm
CGI roof panels

Chapter 7

Generic design

7.1 Construction

This section describes the key aspects of the core timber beam structure of the design.

7.1.1 Overview

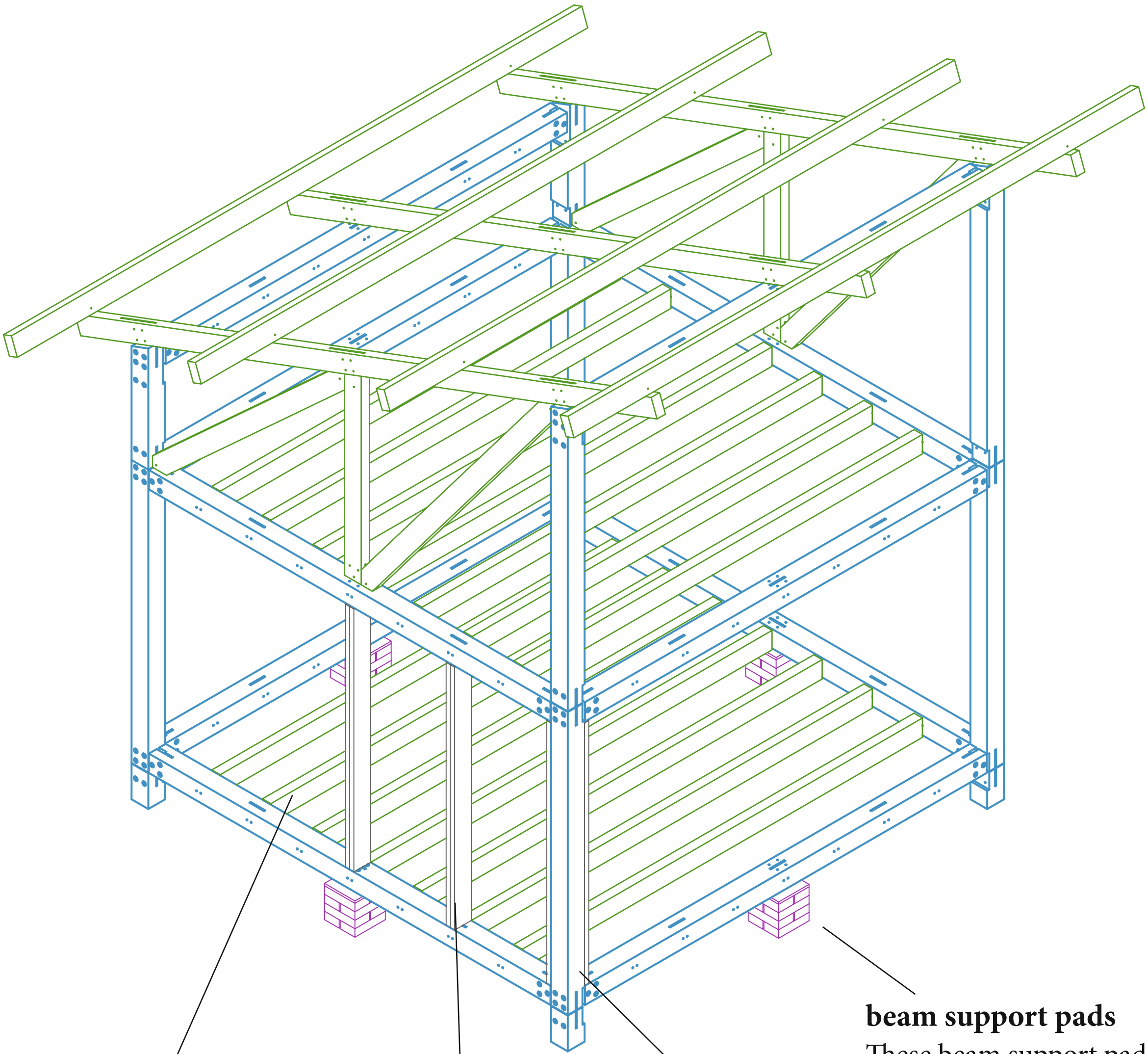
The primary structure is made from timber columns and beams with a diameter of 160×160 mm. All beams are 384 cm long and are forming around 15 m^2 of usable living space on the primary floor. The columns of the primary floor create 218 cm of usable room height. The roof truss holding the extended roof creates an upper living space with room heights ranging from 95 cm to 245 cm. All columns and beams of the primary structure are connected using metal connectors, bolts and nuts. This allows the structure to be easily assembled and disassembled if needed.

To elevate the whole structure from the ground the whole structure is placed on 30 cm riser columns. This elevation prevents rain water from entering the shelter and reduces the risk of termites and rodents.

A secondary structure consisting of timber with a diameter of 80×160 mm forms the support structure for the floor and the ceiling. OSB panels are screwed onto the floor and ceiling support structures to form the floor and ceiling.

Also the truss supporting the substructure for the mono pitched roof is of the same diameter. The corrugated galvanised iron panels for the roof are bolted onto this substructure creating a roof with at least 60 cm overhang on all sides. This overhang protects the walls from rain. To reduce the solar heat up of the corrugated galvanised iron panels the roof can be covered with local materials like reed or straw. This also decreases the noise level during heavy rainfalls.

To ease the on-site construction of the walls, modules consisting of timber with a diameter of 40×160 mm are supplied. These wooden strips are used to create the 96 cm wide modules which are connected to the primary beams using bolts. The infill of these modules depend on the local climate and is created from locally available material. Modules with heavy infill are just supported on the primary floor as the roof area should stay light for stability reasons.



beam support pads
These beam support pads are only needed for heavy walls, like mud walls

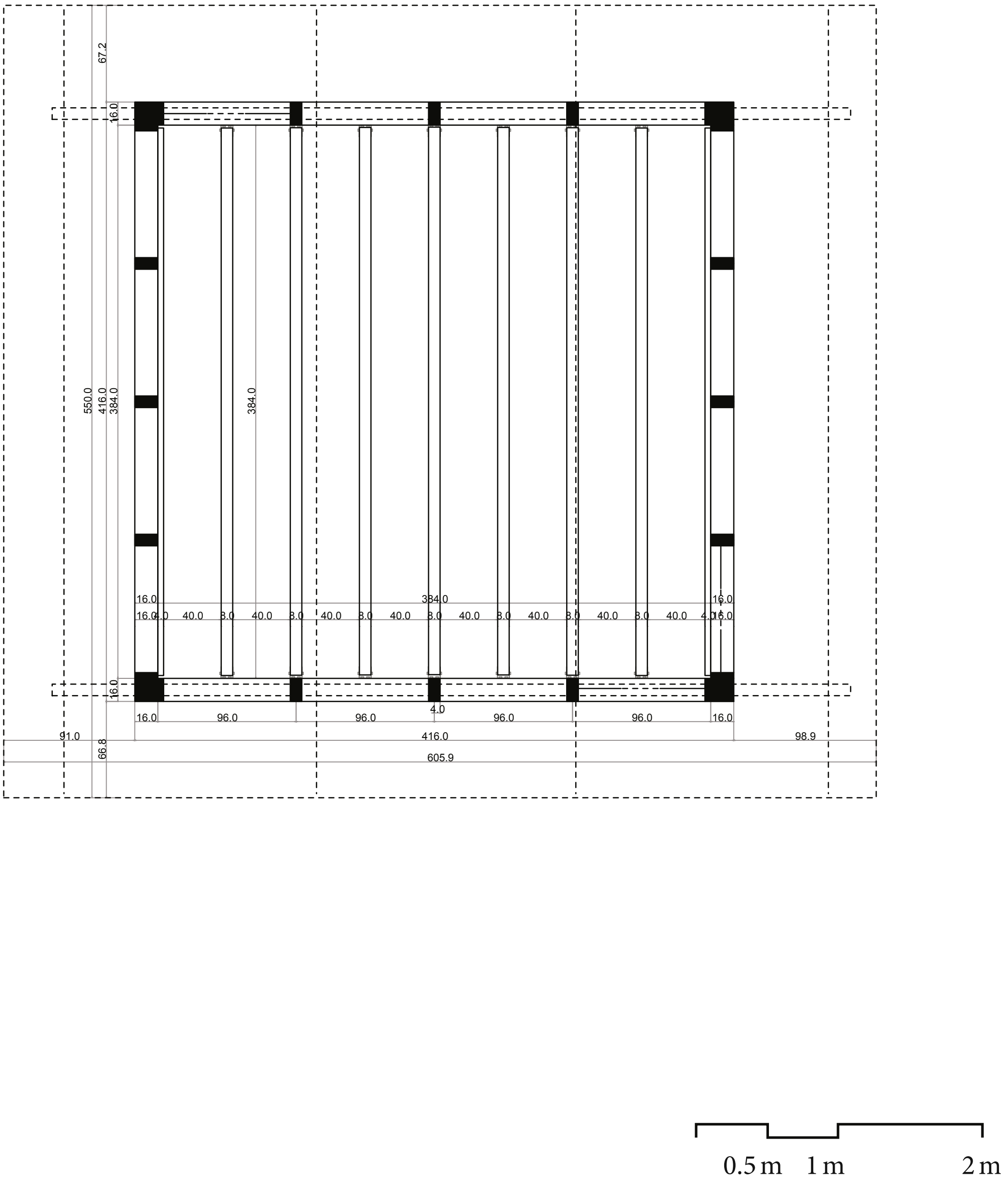
8 x 16 cm
Is used for all secondary long spanning beams and for the light roof

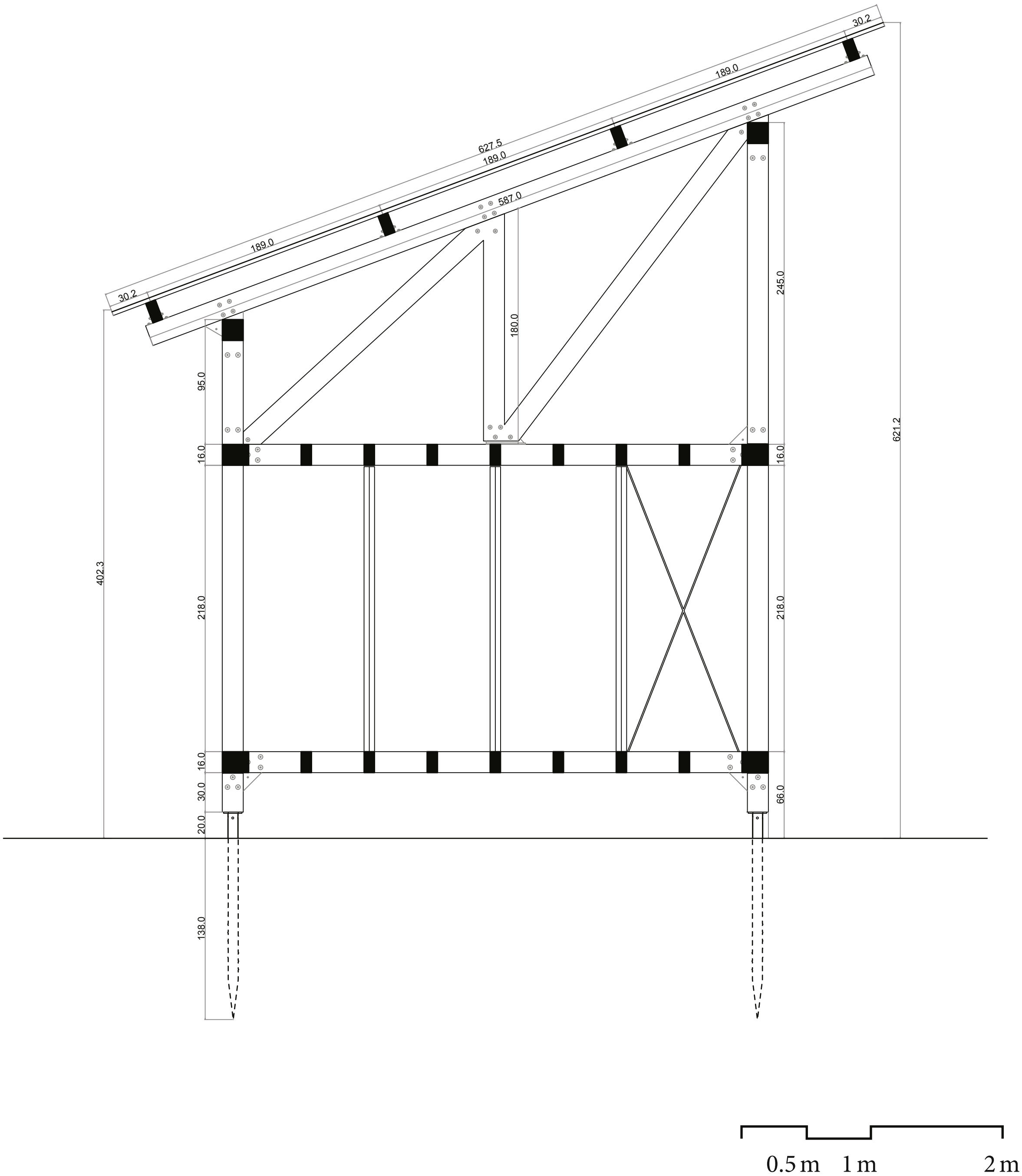
4 x 16 cm
used for the optional wall modules to speed up on-site local wall construction

16 x 16 cm
used for the main structure, to provide good stiffness and torsion resistance

7.1.2 Plans

This double page shows the unit kit alone with plan and section in scale 1:50.




627.5
189.0
189.0
189.0
30.2
30.2
587.0
180.0
245.0
95.0
16.0
218.0
16.0
30.0
20.0
138.0
402.3
621.2
66.0
0.5 m
1 m
2 m

7.1.3 Metal connectors

Traditional buildings techniques rely on complex 3D wooden connections which require expert labour and also complex machinery for fast prefabrication. The traditional wooden connections can commonly not be easily disassembled. Additionally when the prefabrication or assembly is done incorrectly structural problems can arise. As expert labour and complex machinery is commonly not available for the setting of this work this design relies on prefabricated metal connectors.

The state of the art timber constructions use multiple thin metal sheets inserted into slotted beams. The timber is connected with the steel plates by inserting a large number of nails fitted through holes in the sheets. This type of connection is very strong and does not weaken the wood profile as in the traditional method. Downside is that a number of holes need to be accurately drilled and multiple slots created. Also the metal sheets can not be disconnected from the timber at reasonable effort which prevents easy disassembly.[1] Most commercially available metal connectors which support a full disassembly are either protected by patents or dimensioned for multistory buildings rendering them way to expensive for this design. Two systems which can be fully disassembleable and reused were analyzed in section 3.4.2.

To support the disassembly and to simplify the prefabrication process this design uses a single 10 mm thick metal plate inserted into a slot of the beam. The metal plate is connected with the timber by inserting three ISO M10 threaded metal rods which are fixed with nuts on both sides. To reduce the number of parts all connectors are designed to be usable in multiple places of the design. To allow for this each connector type has different hole configurations which are drilled on each piece to allow easy preproduction. With this connectors the advantage is that the structure can be easily assembled on-site requiring very little tools. Also the nuts can be opened to allow for a full disassembly of the structure.

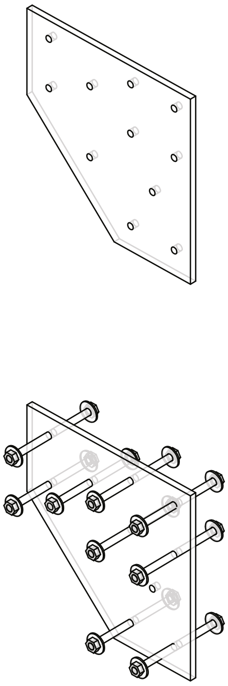
In particular five types of metal connectors were designed for this design to allow to bolt together the whole primary structure of a unit. This connectors are referred to as Type I, Type II and Type III connector in this work. Type III is an adaption of the Type I connector used only in the roof of the structure. Type IV connectors are used to connect the primary structure to the secondary structure and Type V is mostly used to connected the wall modules to the primary structure.

The holes in all plates are 11 mm in diameter to give an extra 1 mm for inaccuracies during fabrication. The 160 mm long threaded M10 rods are secured with a washer and a M10 nut on each side. For tightening these connections a wrench and a socket wrench are the only tools required. With the recommended steel quality of 4.8 described in section 7.10.2 a maximum tightening torque of around 20 N m is recommended. While wrenches with integrated tightening force indicators exist it is unfeasible to ship them for this design because of their price.

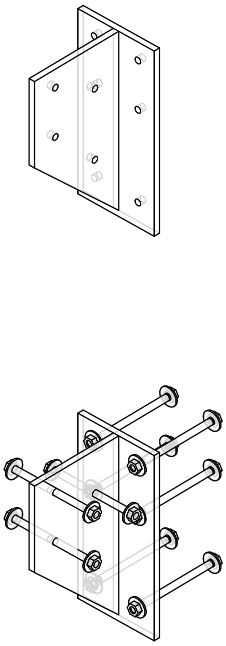
[1] Rebhan, Matthias. *"Ein Beitrag Zur Modellbildung von Fachwerken Im Ingenieurholzbau"*. MA thesis. TU Graz, May 2014.

Connector type overview

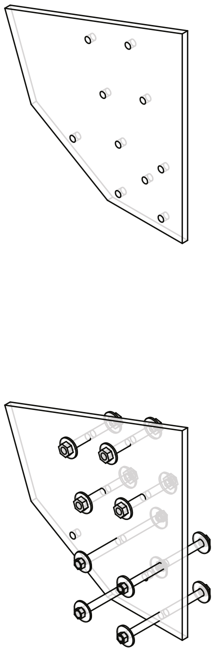
Type I
Primary structure



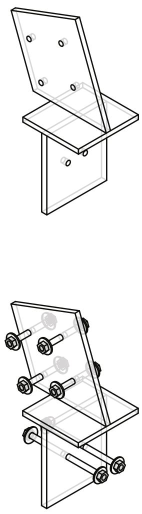
Type II
Primary structure



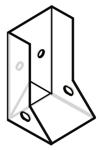
Type III
Primary structure - roof sub-structure

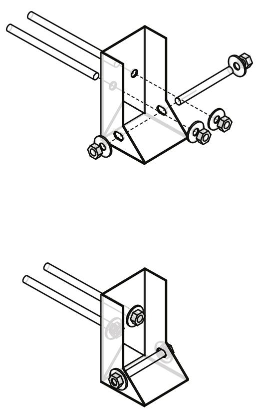


Type III B
Primary structure to middle roof sub-structure

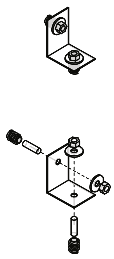


Type IV
Primary structure with secondary structure

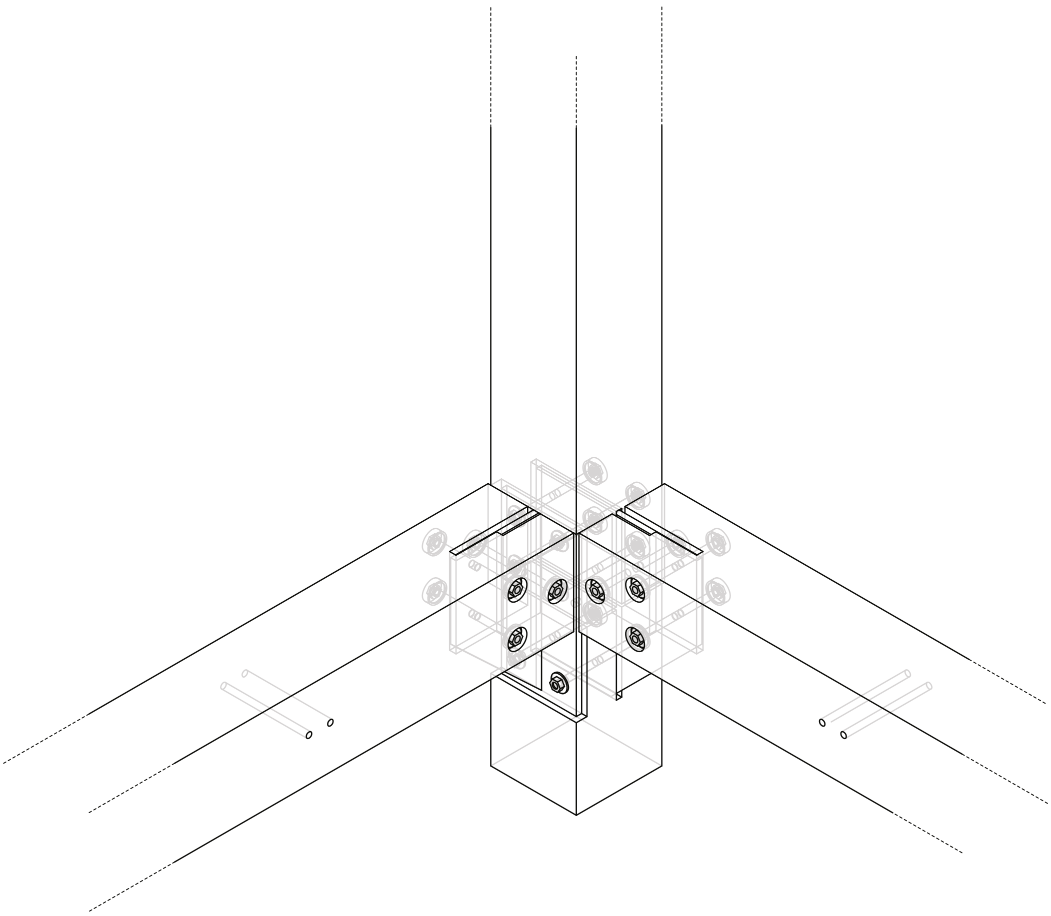




Type V
Modules with primary structure

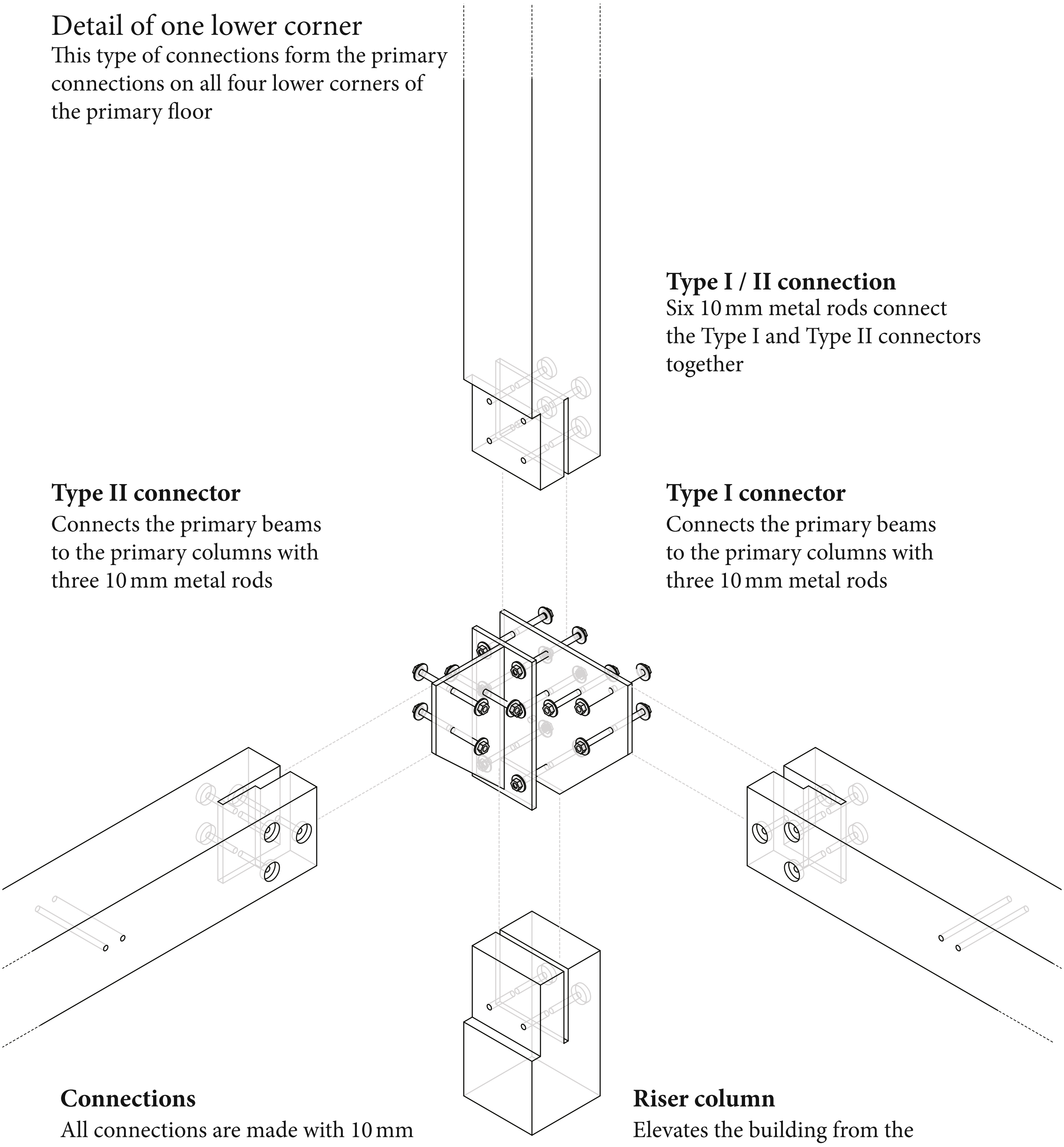


As visualized on the right the Type I connector bolts together with the Type II connector forming the eight corners of the primary floor. These are the strongest connections in this design and are purposely designed in a very stiff way to reduce the need for extra bracing in certain circumstances. For the bottom four corners the lower parts of the Type I and Type II connectors also secure the riser column. The reason for the riser column to be separated from the main column is to allow an easy replacement in case the wood gets damaged by water or insects.



Detail of one lower corner

This type of connections form the primary connections on all four lower corners of the primary floor



Type I / II connection
Six 10 mm metal rods connect the Type I and Type II connectors together

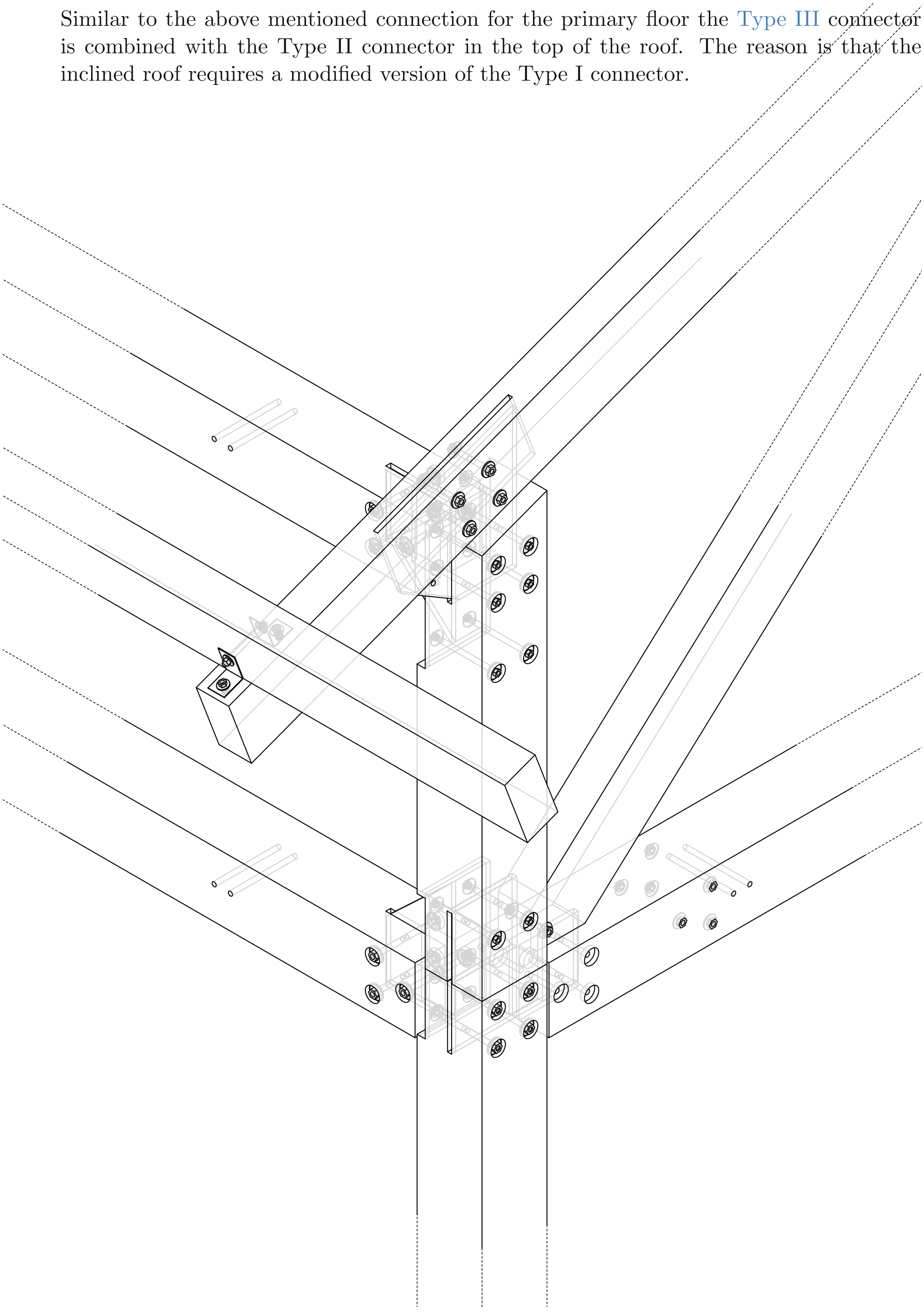
Type II connector
Connects the primary beams to the primary columns with three 10 mm metal rods

Type I connector
Connects the primary beams to the primary columns with three 10 mm metal rods

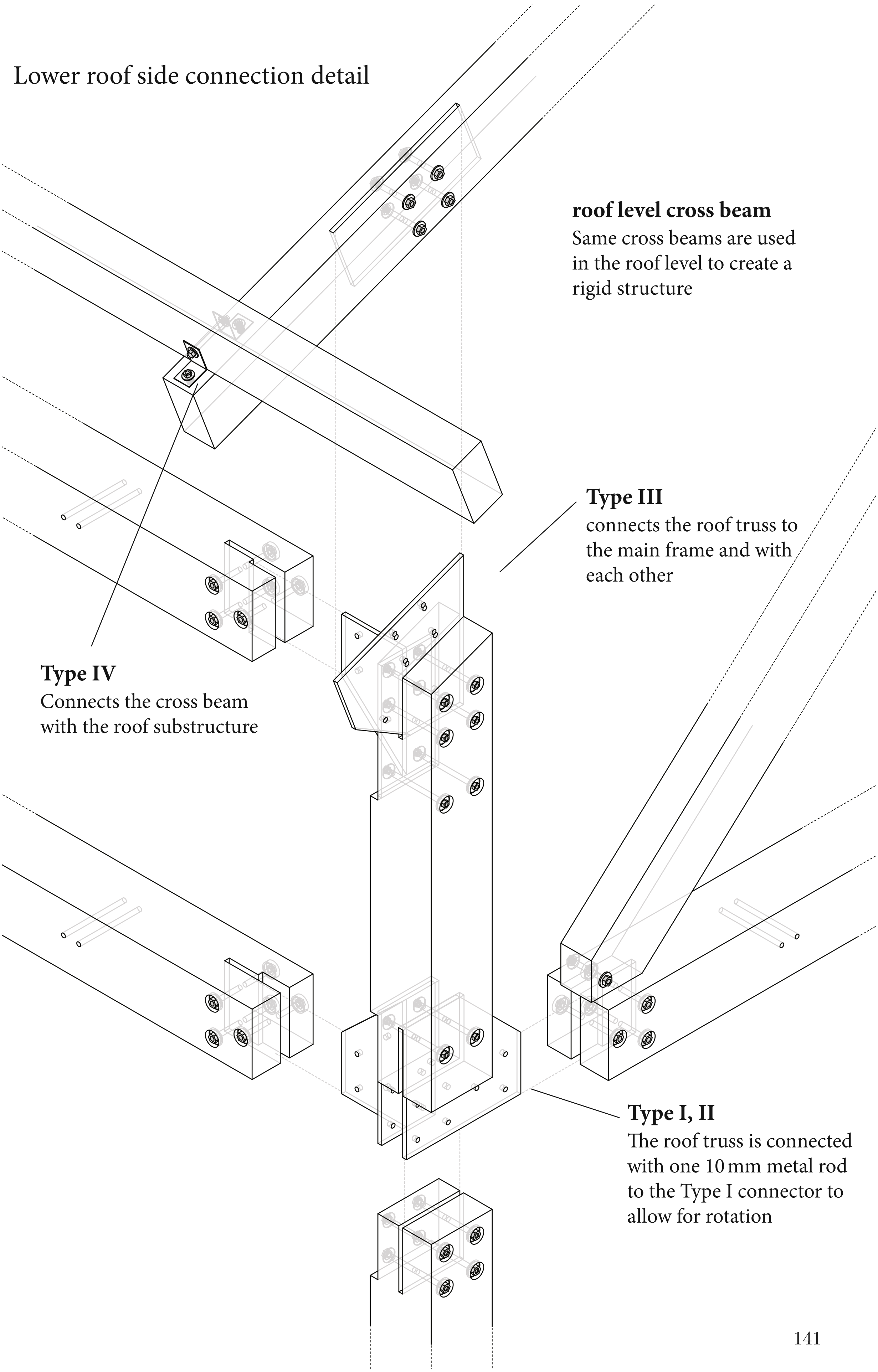
Connections
All connections are made with 10 mm threaded M10 metal rods which are fasted with M10 washers and nuts on both sides. The nuts are submerged in predrilled holes

Riser column
Elevates the building from the ground and can be higher if more clearance is needed. Also allows easy replacement if wood rot is occurring

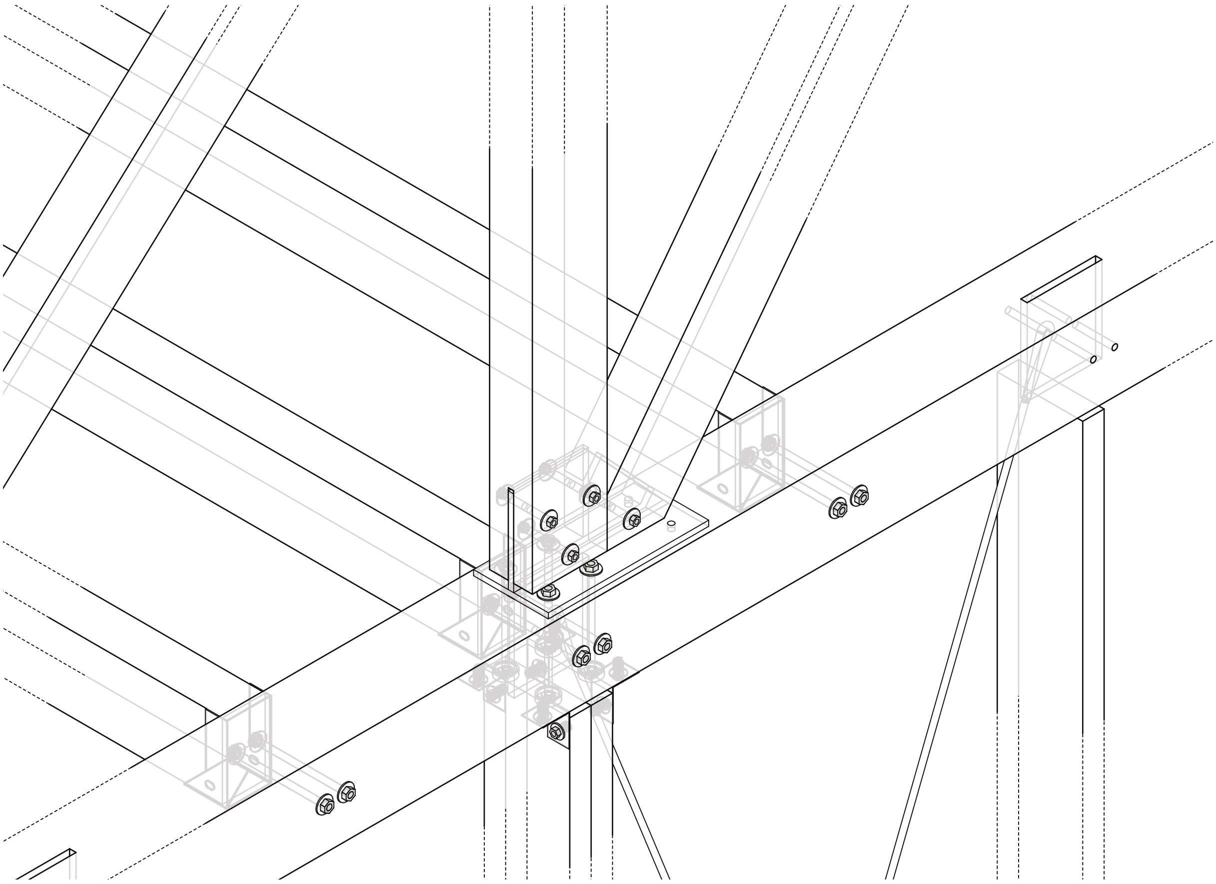
Similar to the above mentioned connection for the primary floor the Type III connector is combined with the Type II connector in the top of the roof. The reason is that the inclined roof requires a modified version of the Type I connector.



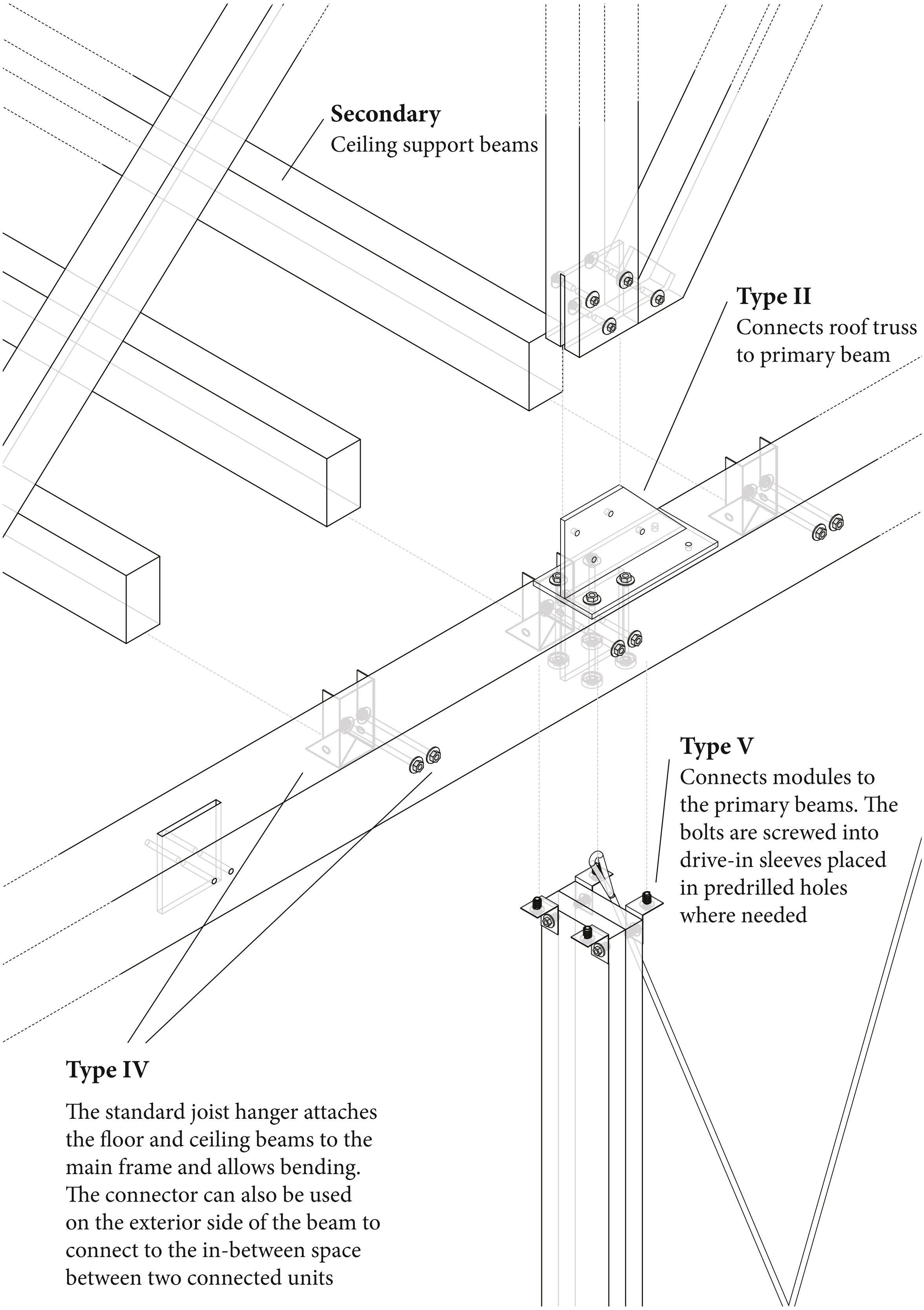
Lower roof side connection detail



To connect the secondary structure supporting the floor and ceiling plates to the primary structure another connector named Type IV is introduced. This connector made from 2 mm steel plates is very similar to existing joist hangers with the only adaption that it contains two 11 mm holes in the backplate allowing to insert M10 threaded rods for fastening. On the backplate two holes are needed to prevent any torsion forces. Also on the side a single 11 mm hole takes the bolt connecting the connector with the beam of the secondary structure. Only one rod is used because the floor beams need to be able to bend freely to not inflict torsion to the primary beams. The same connector is also used on the exterior side of the primary beams when another unit is connected. It secures the beams of the in-between space to the same bolts as the floor and ceiling structure.



Module and roof truss middle connection



The standard joist hanger attaches the floor and ceiling beams to the main frame and allows bending. The connector can also be used on the exterior side of the beam to connect to the in-between space between two connected units

One instance of the Type II connector occurs in the middle of the roof truss fixing the roof truss to the primary beams.

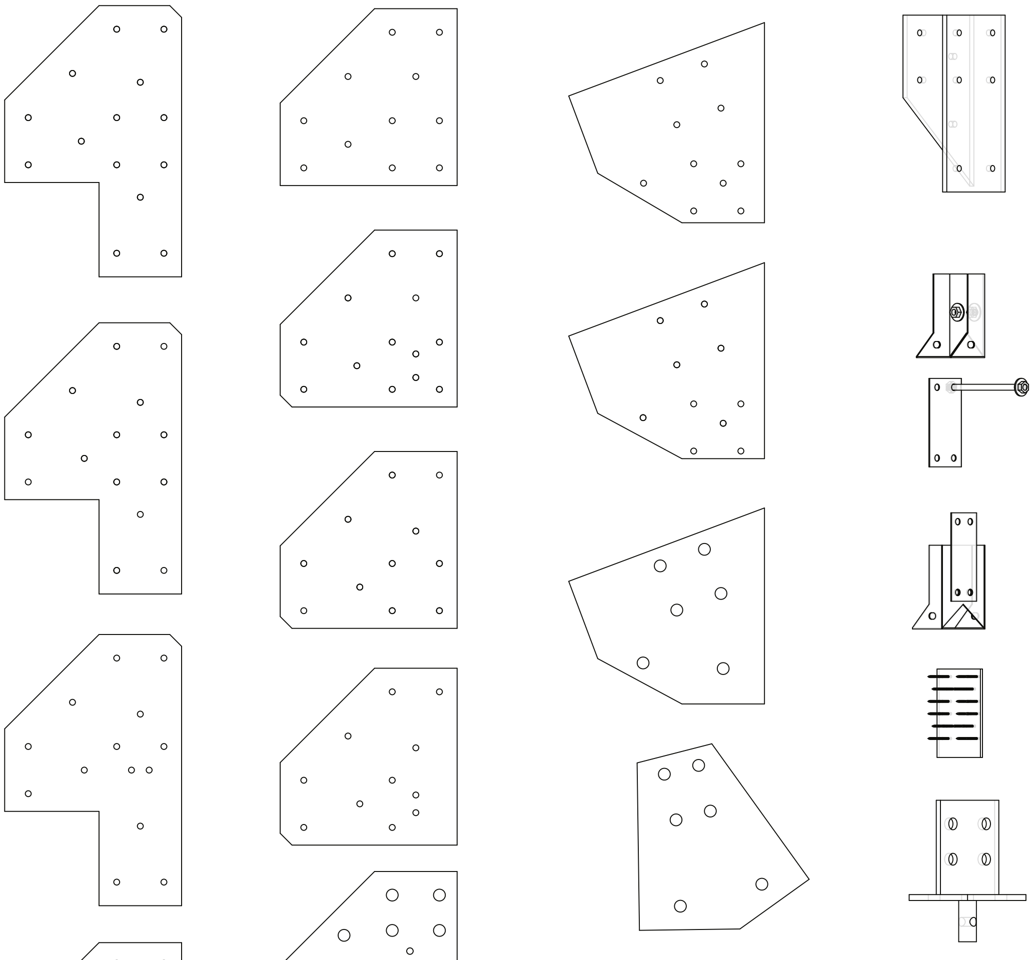
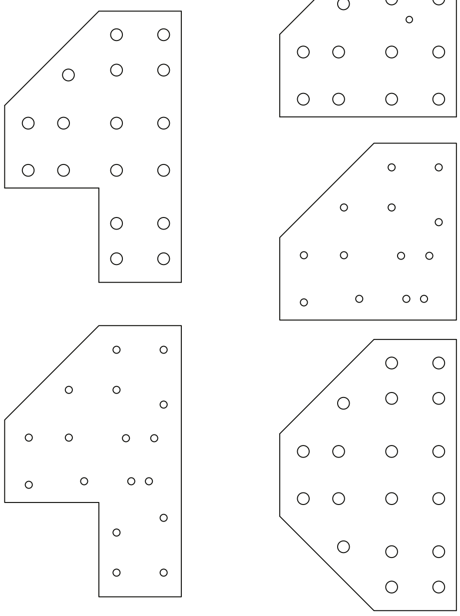
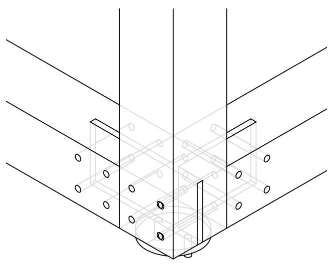
Details about the bracings can be found in section 7.1.4. The bracing rods are connected to the Type I, II or Type III connectors forming a strong connection of the bracing to the primary structure.

Finally a small angled connector named Type V to secure the planks for the modules to the primary structure was designed. This connector made from angled 2 mm thick metal has two holes allowing for M8 screws to be the screwed into the pre-installed drive-in-nuts. The same connector is also used to secure the substructure holding the corrugated galvanised iron plates of the roof onto the ridge beams.

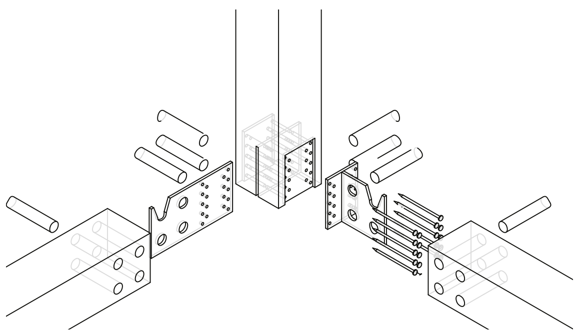
The connectors do not allow for much tolerance and need to be fitted exactly with the three to four holes per beam. Because in our setting precise prefabrication can not be guaranteed, inaccuracies need to be factored in. It is assumed that the metal connectors are manufactured precisely, that the holes in the wood are precisely drilled relative to each other and that the major variance comes from inaccurate wood lengths, bent wood or inaccurate placement of the drilling templates on the wood. As the 10 mm holes in the timber closely match the diameter of the 11 mm holes in the steel connectors the 10 mm steel rods can not equalize any inaccuracies. The inaccuracies must be handled by bending and moving the wood alone. To bend the 160×160 mm columns tension belts can be used.

When designing the connectors a constant trade-off between material usage and simplicity of the prefabrication had to be evaluated. Over more than ten major design iterations the metal connectors were shaped in a way that they can be easily produced in developing countries by just relying on very basic machinery but also that they can be mounted by non-technical people easily. This includes the reduction of different parts and reusing a small set of connectors on different locations in the frame. The trade of a reduced number of parts is that parts need more fittings because different locations require different fittings. The metal connectors were design in a way that they are as symmetrical as possible to reduce errors of mounting them in the wrong way. Assembly tests in 1:1 scale showed that even for people familiar with the design it is hard to get the orientation right if pieces are not completely symmetrical.

Connector design iterations

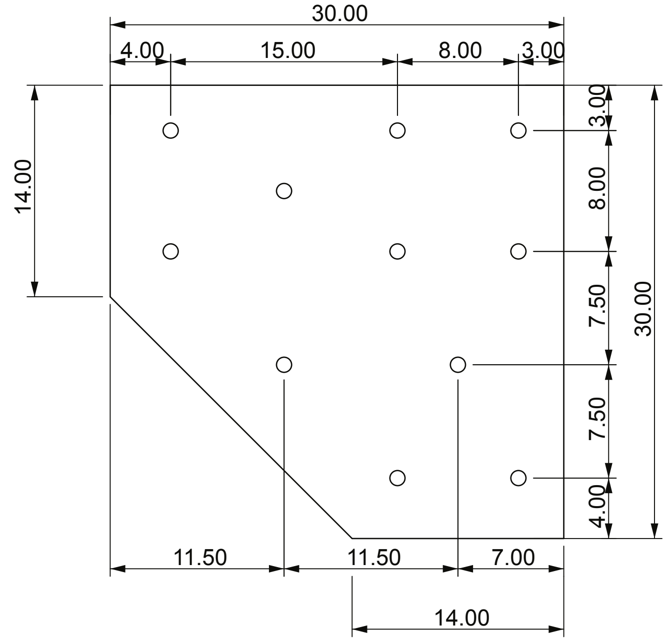




Iterations
All connectors underwent more than 13 iterations in 3D till the final design



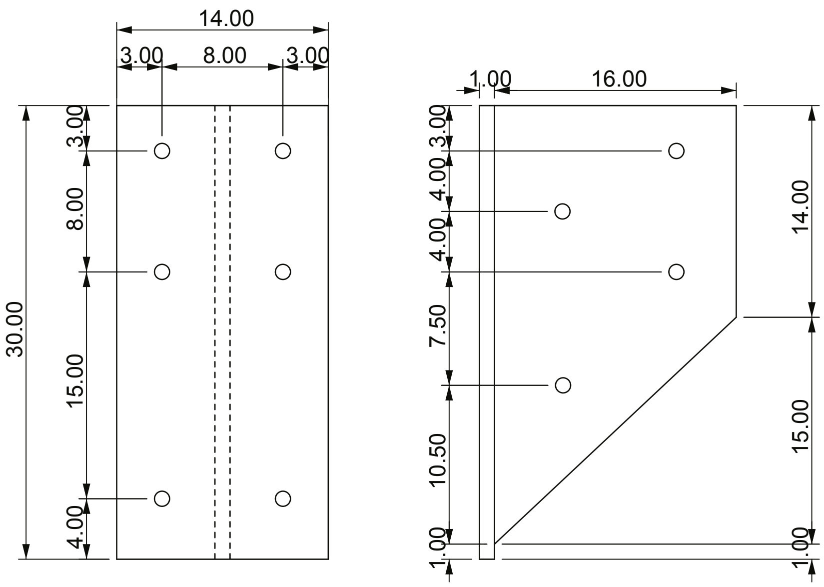
Type I
Connects the frame together. Thickness is 10 mm
All holes are 11 mm in diameter.

1:5



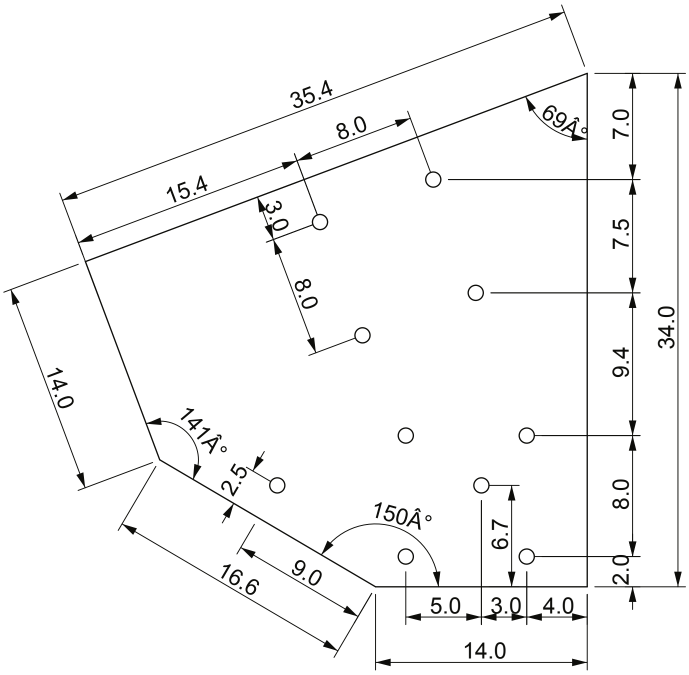
Type II
Connects the sides to the main frame. Thickness of all plates is 10 mm.
All holes are 11 mm in diameter.

1:5



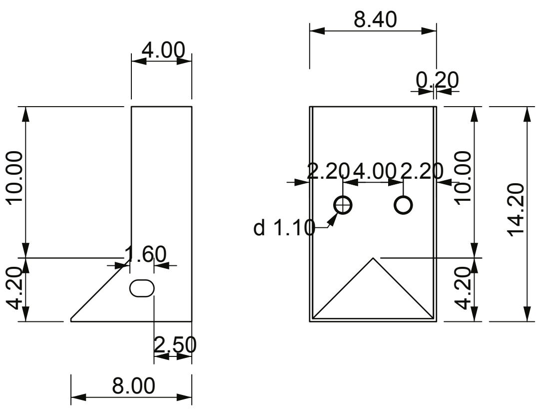
Type III
Derived version from the Type I connector to connect the roof truss together. Thickness of the plate is 10 mm. All holes are 11 mm in diameter.

1:5



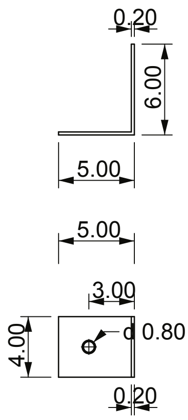
Type IV
Connect the secondary structure (floor sub-structure) to the primary structure. Made from welded 4 mm steel plates.

1:5



Type V
Connects the wall modules to the primary beams. Made from welded 4 mm steel plates.

1:5



7.1.4 Bracing

The roof overhang of this design can create huge wind forces. Also one of the sides of the structure is 468 cm high creating a big surface for the wind. Even though the upper areas of the shelter are expected to be partially wind permeable this geometry needs bracing to resist wind loads.

In general to establish proper stability in all axis, three sides need to have bracings. This can be achieved with shear resistant walls, by creating stable triangles using diagonal bracings or by forming stiff edges.

As design choice, to allow flexible usage, the core frame does not enforce the triangular bracings at fixed places. In deployment locations which are shielded from wind forces the stiff metal corner connections are sufficient. This can be the case for middle units in multi unit layouts.

For areas with high wind loads or earthquake risks 10 mm metal rod based bracings are needed. This bracings should be applied to three sides over a length of at least one wall module on the ground floor. The amount of bracing varies depending on the expected wind force at the exact location of the shelter. The bracing rods are bolted to the metal connectors of the primary structure and need to be adaptable in length to allow for tightening and for small adjustments of the box geometry. The tightening is done by rotating a turnbuckle sitting in the middle of the bracing using a wrench.

In the roof two sides are already braced sufficiently with the wooden truss construction. The open tall side requires two bracing triangles on each side to stabilize the roof structure against wind from the side.

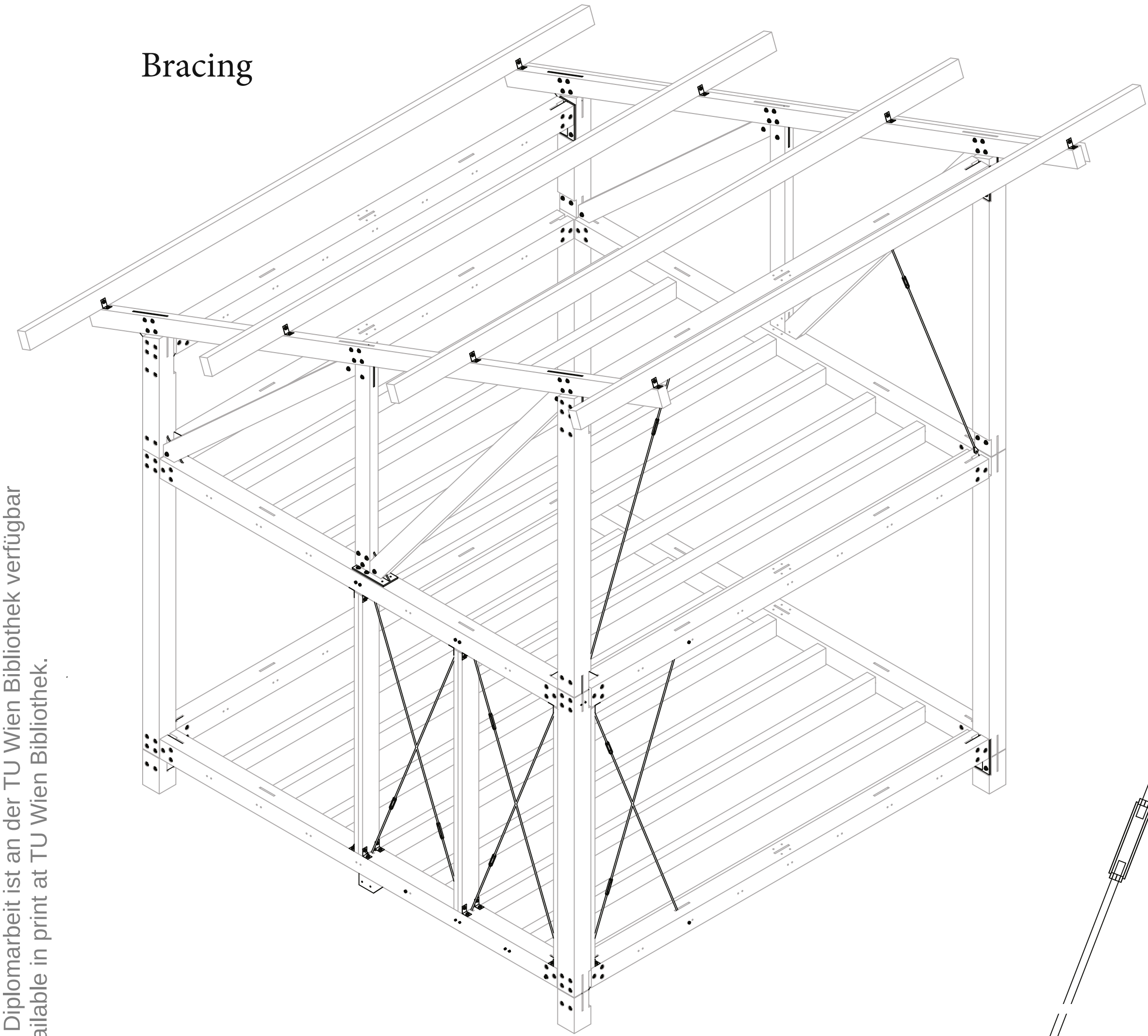
The metal rod bracings are attached during the core frame construction process and all units needs to be braced independently. The placement rules are contained in the user manual to promote safe structures.

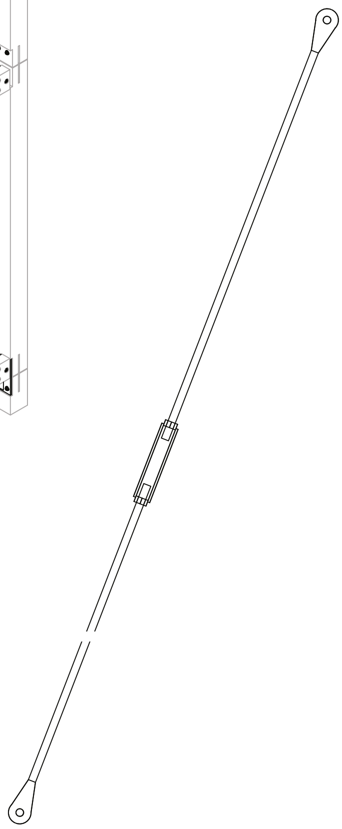
Shear resistant walls are an alternative to the metal rod bracings. They can be created by using structural plywood or OSB/3 plates in the wall modules. Also a solid infill like brick helps to make the walls shear resistant.

As the concept of bracing is commonly misunderstood, ignored or neglected by non engineers supervision might be required to ensure that the bracings are mounted correctly. Also the option of pre attaching one side of the bracing rods to the corner metal connectors to enforce the placement of the bracing should be considered during the pre-fabrication process. The lack of bracing was inherent to most of the analyzed reference projects.

The OSB boards nailed onto the floor substructure make the floor shear resistant. In case no ceiling is put, creating one high living space, additional horizontal bracing needs to be added. These bracing rods span the whole 5 m diameter of the shelter in the roof plane and connect to the metal connectors on each corner.

Bracing

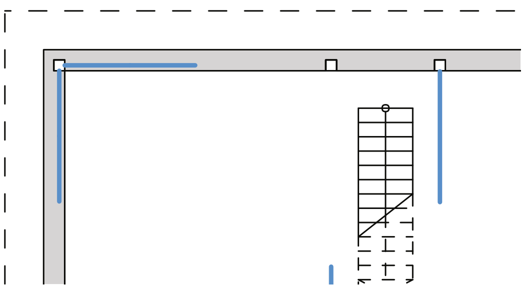




Modules
The bracings always cross out one module. This allows to keep the remaining wall sections usable

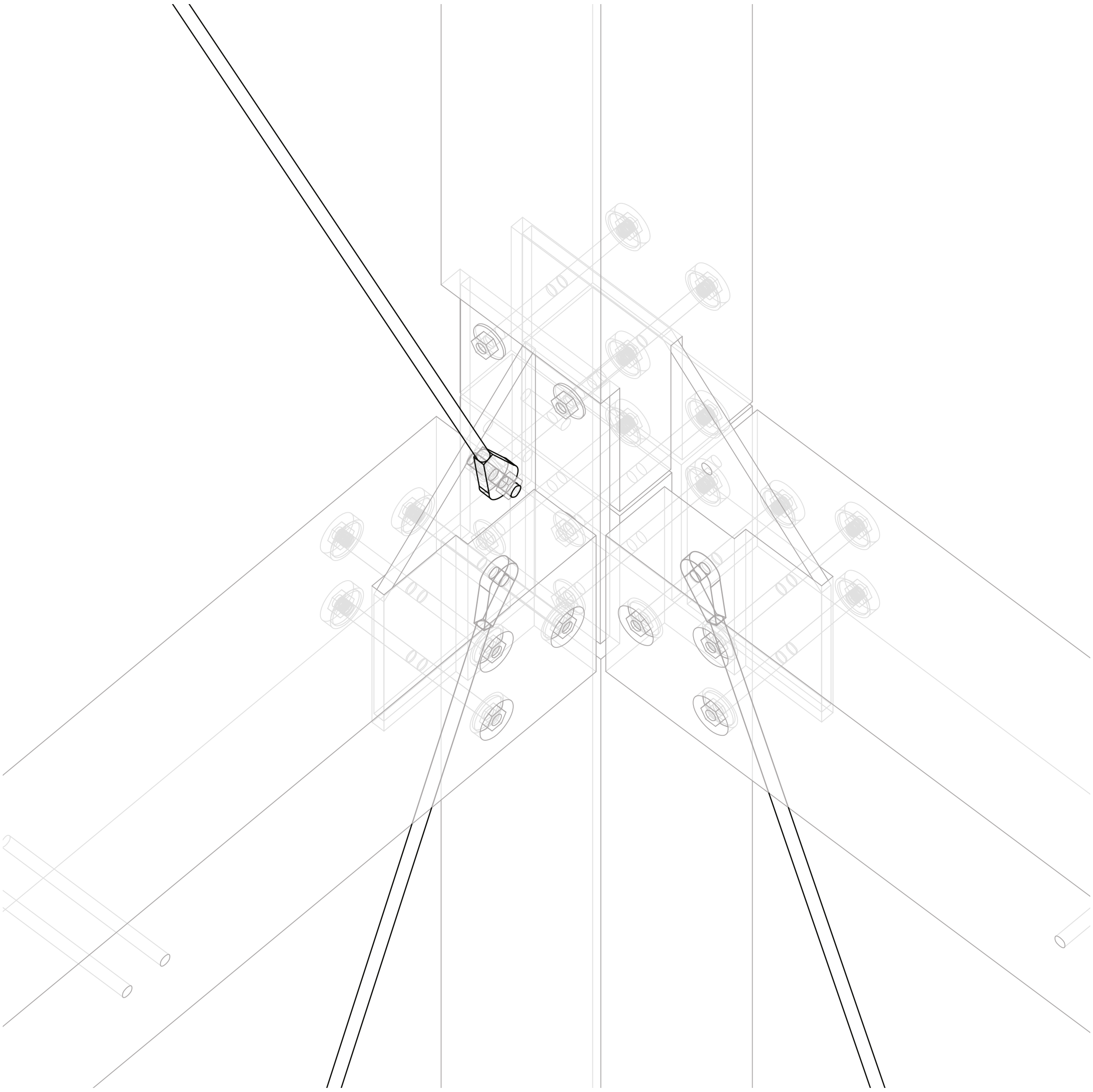
Roof
The upper area also needs bracing to sustain the wind loads

Bracing
Consists of M10 threaded metal rods.
Turnbuckles allow to adjust the distance



Unit bracings
Each unit is independent and needs three sides braced (bracing shown in blue)

Bracing detail



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7.1.5 Foundations

Foundations are always specific to the local soil type and local requirements. This design requires four proper point foundations at the corners. For heavy wall types additional supports in the middle of the primary beams are needed. Those additional supports do not have to take any uplift forces and can be created with more simple constructions.

An irreversible option is to create concrete point foundations. This requires digging out materials, reinforcing it with steel and poring it with concrete. A metal connector should be inserted at the surface to be able to connect to the primary structure. This foundation type can be created with very little financial effort as cement and rebar is commonly available across the globe. Concrete foundations are considered as very permanent and it is hard and expensive to remove them afterwards. Depending on the wind forces a certain depth and size is required, further complicating the restoration of the site afterwards.

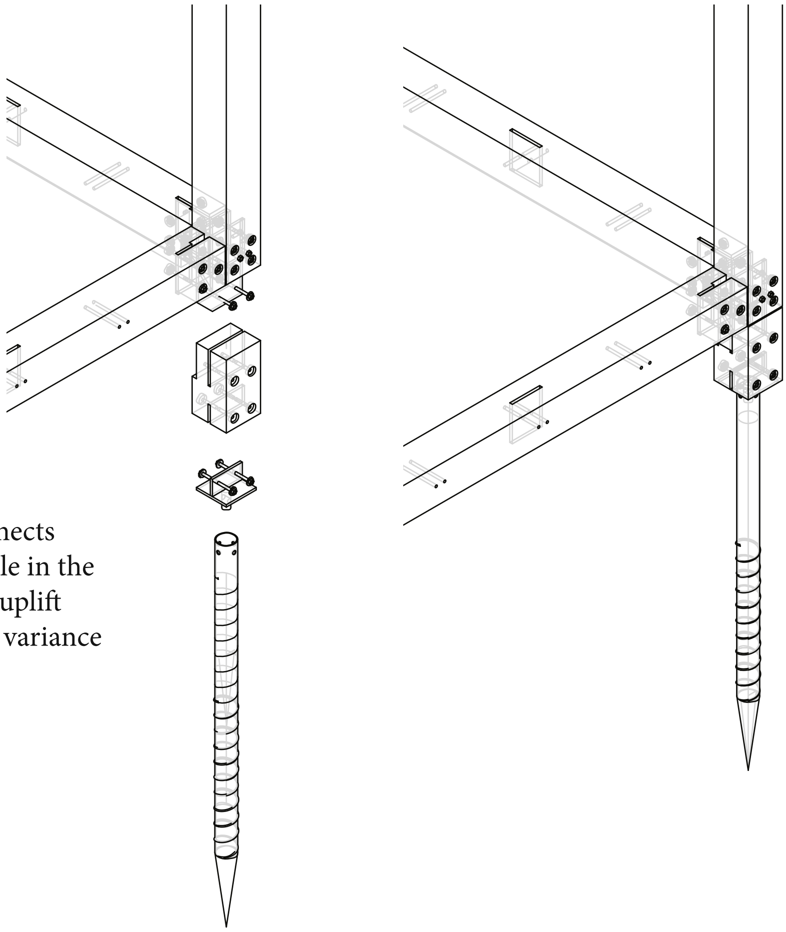
An alternative are steel ground screws which are drilled into the surface. For clayey soil types mechanical equipment can be necessary to screw them in. For soft soils ground screws are the preferred option because they can easily be removed and do not deteriorate the site. This can greatly increase the acceptance of the local population. Because of their depth and coils they offer a very good wind uplift protection. One downside is that there is only a few companies manufacturing big enough ground screws. Also from a price point of view they can not compete with concrete foundations.

With the maximum life and dead loads the whole structure creates a vertical force of 241 kN. The highest load on a single foundation point is 67 kN which can not be handled by a single screw foundation in grounds consisting of light loam. The M114×2000×3.75 - M20 screw from GSPillar could handle up to 64 kN but is not enlisted in the shop at the moment. The next best available option for 65.22 € is the M114×1300×3.75 which has the same diameter but is shorter (1300 mm) but can handle only 40 kN.[2] Also the F140x1600-P screw from Krinner can only handle up to 54 kN in medium loam soils.[3]

If the maximum load is a realistic scenario not a single screw alone can handle the load of the foundation point with the highest force. To work around this issue for those scenarios three shorter and cheaper screws like the M76×1300×3 M16 for 41.31 € from GSPillar can be used. Each of these screws can take 24 kN totaling to 72 kN. In the visualization a possible solution with three screws and a load bearing triangle is shown.[4]

The screws must not only resist the push force but also pull forces resulting from wind uplift. With the custom connector of this design this can be achieved while also allowing for inaccuracies during the screw placement. During seismic events horizontal loads must be absorbed as well without damage to the screws.

[2] *GSPillar Ground Screw List.* URL: `https://view.publitas.com/sia-ponton/ground-screws/page/1` (visited on 04/12/2022), p.1.
[3] *Krinner F 140x1600-P.* Krinner. URL: `https://www.krinner.io/produkte/detail/f-140x1600-p/` (visited on 04/12/2022).
[4] *GSPillar Ground Screw List*, p.1.

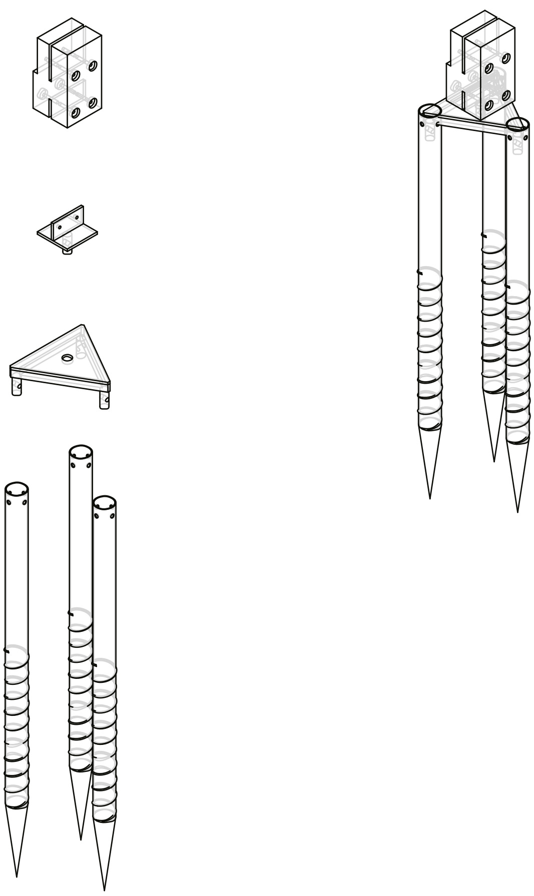


Wind uplift

A thick steel cable connects the baseplate with a hole in the screw protecting from uplift and allowing assembly variance

Heavy versions

for maximum liveload 3 ground screws can be combined



7.1.6 Electricity

Electricity is needed for various important tasks like operating lights at night or charging a mobile phone to stay connected with friends and family. Lights at night are crucial from a security point of view to be able to use external latrines and oversee the area of the house if needed. Commonly payments are also performed using just mobile phones.[5]

While electrical demands for a small light and smartphone charging are very low and can be handled by a single small solar panel, other utilities like fridges require substantially bigger solar panels. Fridges can greatly increase the timespan fresh goods like vegetables and meat can be stored, resulting in less time consumed with day to day food gathering tasks.

In the context of this design connections to the electrical grid are commonly not available or not stable throughout the day. To still provide essential service like light and mobile phone charging a decentralized solution is envisioned. As the creation of electrical circuits should only be performed by technicians it makes sense to perform the required tasks during the prefabrication.

The design comes with an optional but recommended solar panel for the roof area. This panel is connected to a battery module including an inverter which can be placed in a prefabricated wall module. Electrical power is then distributed through wires in the core frame. Outlets in the prefabricated beams allow to connect small electrical devices like phone chargers and LED lights to this circuit.

[5] *Digital Payments to Refugees A Pathway towards Financial Inclusion.* 2020. URL: `https://www.unhcr.org/5fdcd8474.pdf` (visited on 19/01/2022).

7.1.7 Calculations

All calculations were performed according to Eurocode 5 for one unit in the software RStab.[6] Only the structural integrity was analyzed, while deformations for the fitness for use were ignored. One reason for this is the high extra cost in material to comply with all Austrian building regulations. While all of them make sense in their scope of an industrialized country, they are not fully applicable in displacement situations.

Besides the dead weight of the primary and secondary structure the following usage load assumptions were taken:

For the wall construction on the primary floor a dead load of 6 kN/m was assumed. When another unit is attached the load of the in-between space decreases the maximum possible dead load above. The wall section in the upper floor is expected to be lighter to reduce earthquake damages and is calculated with 2 kN/m. This allows to construct walls filled with light loam or insulated with straw. The load assumption factors in half of the load from the in-between space between two adjacent units. The calculation showed that for heavy walls with thermal mass, four additional point foundations in the middle of the main beams must be added. Heavy walls 12 cm thick with broken brick infill are assumed with 1.8 kN/m^2.[7] Those additional point foundations can be constructed in a simple way as they do not need to take horizontal or wind uplift forces. Sandbags or stacked brick as support are sufficient. For lighter walls like tarpaulin or bamboo the corner foundations are sufficient.

For both floors a dead load of 1.24 kN/m^2 is calculated.

For the roof a dead load of 0.7 kN/m^2 was assumed. This allows to place corrugated galvanised iron panels combined with additional local material like reed on top. Corrugated galvanised iron panels with a thickness of 0.6 mm are calculated with 0.32 kN/m^2.[8] As load factor for snow 1.3 kN/m^2 was assumed. If the weight of the snow exceeds this limit it needs to be cleared by the inhabitants. The snow load assumptions of the Austrian building standard range, depending on the location, from less than 1 to more than 10 kN/m^2.[9]

As live load for all floors 1.2 kN/m^2 is assumed. This is less than the recommendation for attics (1.5 kN/m^2) and slabs (2 kN/m^2) by the Austrian building standards but is deemed sufficient for our scenario.[10]

Wind loads of approximately 1 kN/m^2 on each side were simulated to check for deformation and stability. As reference the basis wind load for Vienna, Austria is specified as 0.39 kN/m^2 with a wind speed of 25.1 m/s.[11] The simplified wind calculation with the national addition for Germany range from 0.5 to 0.95 kN/m^2 for buildings lower than 10 m and for sites in the interior.[12]

[6] Dlubal Software. *RSTAB 9 — Structural Analysis Software for Frames and Trusses*. Dlubal. 28th May 2019. URL: `https://www.dlubal.com/en/products/rstab-beam-structures/what-is-rstab` (visited on 14/01/2023).

[7] *ÖNORM B 1991-1-1*. Austrian Standards, 1st Dec. 2020.

[8] Ibid.

[9] *ÖNORM B 1991-1-3*. Austrian Standards, 15th May 2022.

[10] *ÖNORM B 1991-1-1*.

[11] *ÖNORM EN 1991-1-4*. Austrian Standards, 1st May 2013.

[12] *DIN EN 1991-1-4/NA:2010-12*. Beuth Verlag GmbH. URL: `https://www.beuth.de/de/-/-/134751904` (visited on 14/03/2023).

Wind forces can result in suction and pressure forces on the 20.56° inclined roof. The suction forces for German inland topography category IV for this roof are −0.48 kN/m². This results in −0.95 kN/m on the relevant roof beams with 2 m load influence width. The compression forces for the same category are 0.67 kN/m² resulting in a linear load of 1.33 kN/m. Both suction and compression were simulated in RStab. It must be noted that no concurrent wind and snow load was assumed.[13]

The specific wind loads greatly depend on the local topography and the surrounding buildings. Also the local phenomenons like hurricanes or cyclones need to be factored in. It must be stated that the extended roof of this design is not hurricane and cyclone safe. During the prediction of such events the inhabitants must disassemble the roof panels, store them under the raised building or on the ceiling and seal the ceiling with plastic tarpaulin against rain water.

Against wind uplift forces the connection points and the roof sub-structure are the weakest points. The main frame is well connected to the foundation. Different options for foundations are discussed in section 7.1.5.

Earthquake loads consist of different load types depending on the geology and distance to the epicenter and are substantially harder to calculate. This topic is left out for future work.

As this design relies on stiff edges to simplify construction and to reduce bracing needs the calculation with the wood module of RStab was not standard as commonly non-stiff edges are assumed in timber engineering.

In general the wood sizes were optimized to the edge (with respect to the required over provisioning of the load assumptions) to cut the costs and weight as much as possible. The overall calculation of the structural design was reviewed by a civil engineer but it is assumed that further material can be saved by performing an in-depth optimization of the given structure with special attention to the metal connectors.

C24 was assumed as wood quality for all calculations in this work. Ensuring the wood quality during emergency situations in developing countries might be challenging but the over provisioning in the Eurocode 5 on the load and structural side should allow for uncertain quality to some extent. Palm trees, commonly available in tropic climates, can not be used for the structure because of the reduced strength and bending.

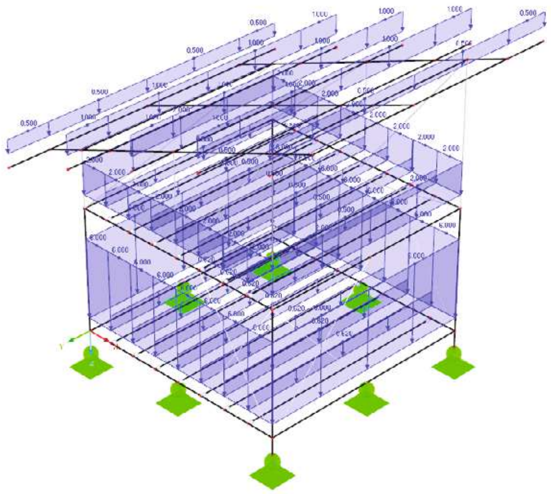
With a total vertical load of 325 kN resulting from the dead and maximum live loads the maximum vertical displacement is 42.3 mm on one of the ceiling beams. This maximal deflection corresponds to around $l/100$ with the length of the beam being 384 cm. The Austrian standards recommend limiting the deflection for fitness of use to $l/300$ to prevent defects.[14] The maximum forces of the bearings to the ground are 56 kN for the high side and 67 kN on the lower side. As the load assumption assumes heavy walls the additional foundations midways between the main columns need to take a maximum of 19 kN and 33 kN depending on the side.

[13] *DIN EN 1991-1-4/NA.*

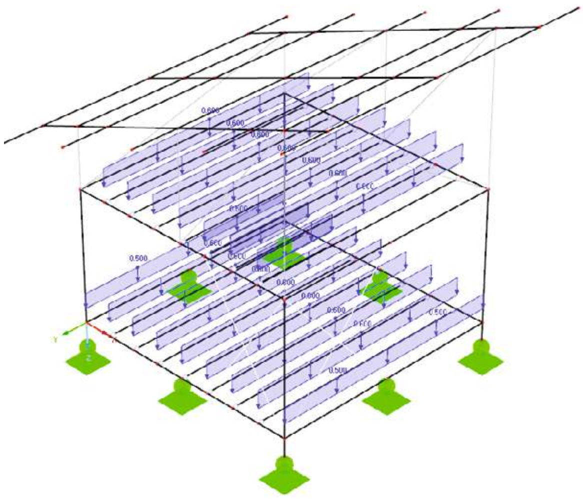
[14] Manfred Augustin, Georg Flatscher and Wilhelm Luggin. *Tabellenwerk Zur Nachweisführung von Holzbauteilen Nach Önorm EN 1995-1-1 Und Önorm B 1995-1-1.* 2017. URL: https://www.ihbv.at/wp-content/uploads/2017/07/IHBV_Holzbau_Kompakt_Tabellenwerk_19.7.17_web.pdf (visited on 14/01/2022), p. IV.12.

Loads

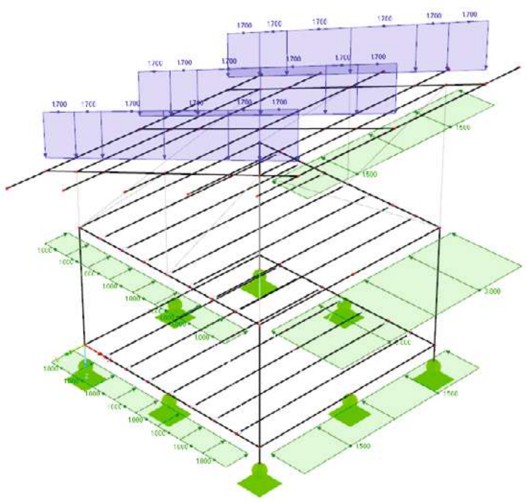
Dead loads
1.24 kN/m² on both floors
6 kN/m for the walls in the primary floor and
2 kN/m for the walls in the upper floor
0.7 kN/m² for the roof



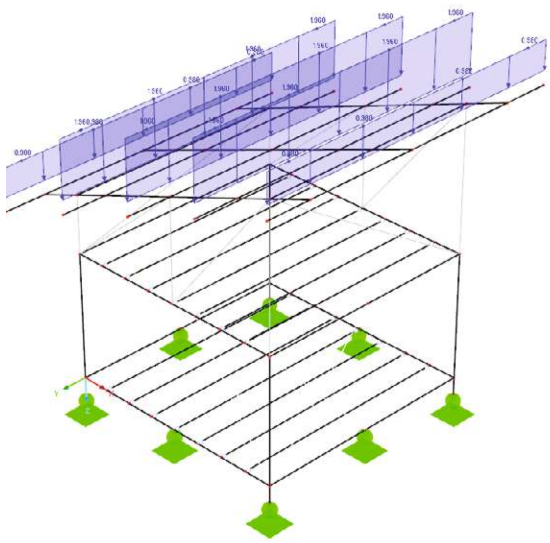
Live loads
1.2 kN/m² on both floors



Wind loads
around 1 kN/m² for both sides
0.8 kN/m² wind pressure

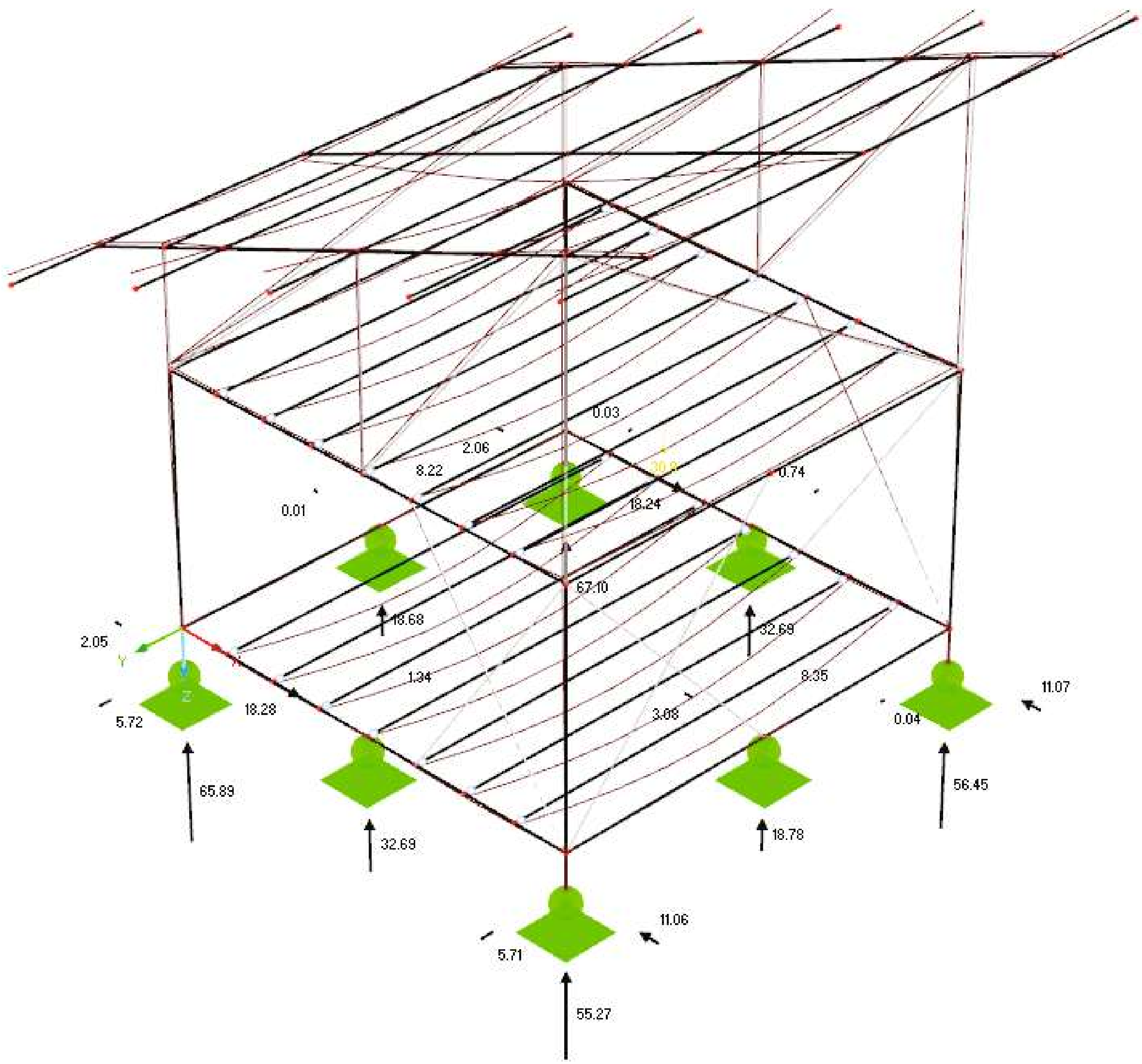


Snow loads
1.3 kN/m²



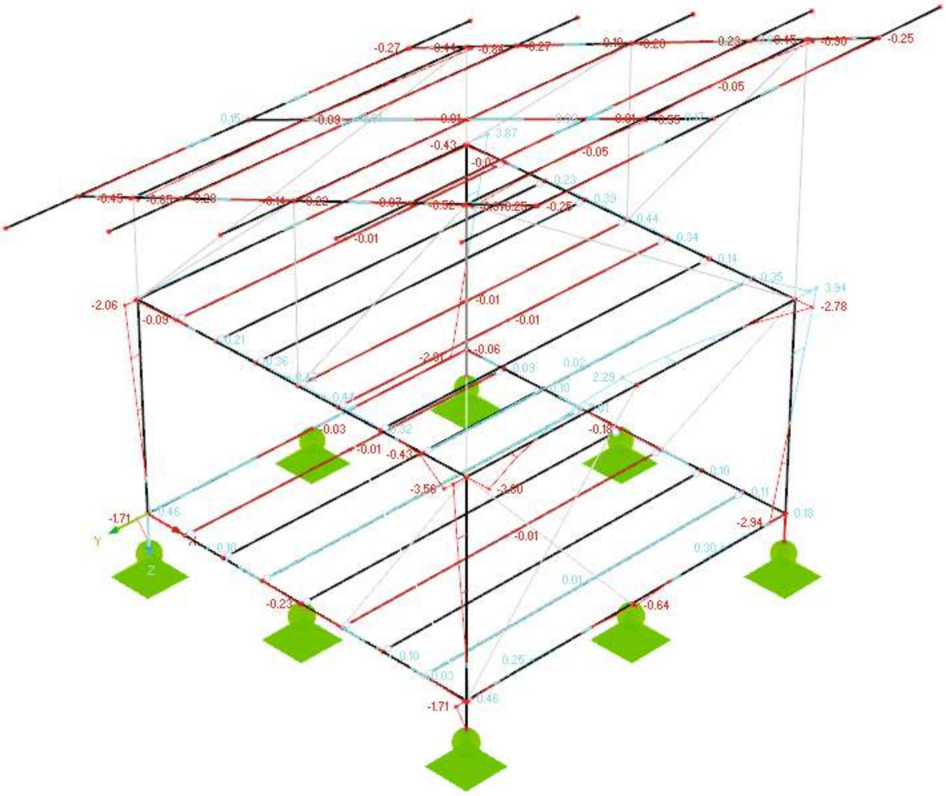
Global deformations

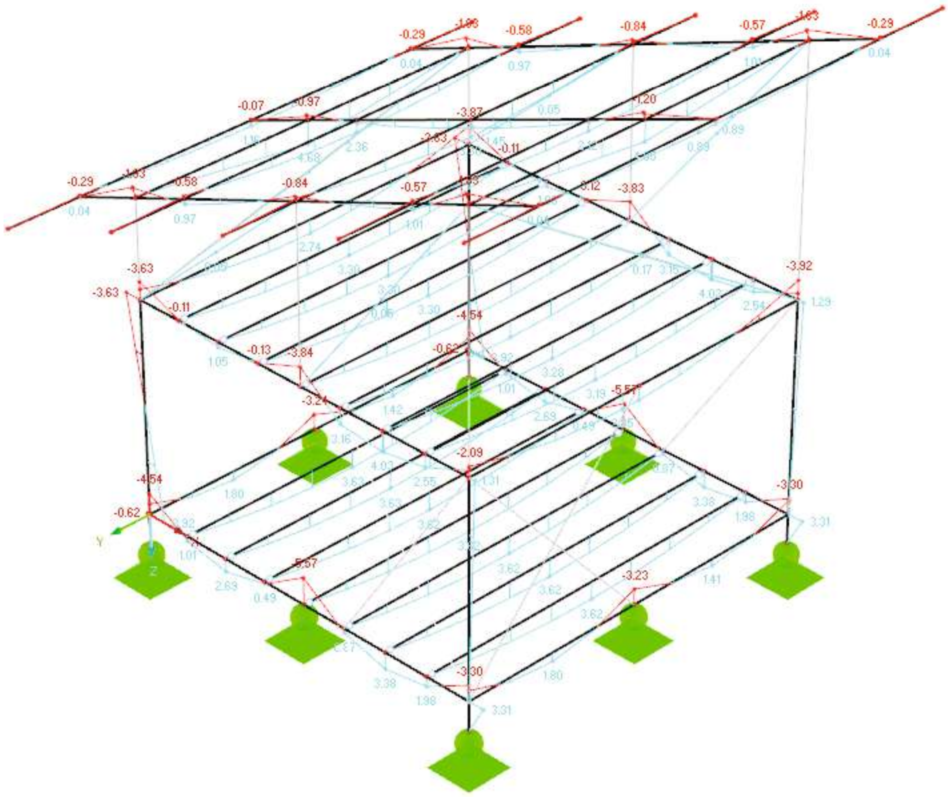
Visualized with an amplification factor of x 10.
1.35 Dead x 1.5 Live x 0.9 Wind
Bearing forces in kN



Bending moment results

Show the results of the check according to Eurocode 5
All units in kNm





7.2 Climate adaptability

Besides snow loads and wind speeds the climate has a limited impact on the structural frame itself. The structural safety was calculated for different climatic requirements including snow loads and wind speeds as shown in section 7.1.7.

Climate adaptability is mainly performed by creating local climate adapted walls. This work gives three examples in Part III in three different distinct climates.

Chapter 8 shows how this design can be adapted to the desertic climate in Jordan. Chapter 9 focuses on the Rohingya refugees in the Bangladesh with its tropical monsoon climate. The last example in chapter 10 covers the crisis in Ukraine with its climate mostly having a warm summer and humid continental climate.

7.3 Lifespan

The main structure consisting of the wooden primary and secondary structure and the roof have a different lifespan than the locally created walls.

The lifespan of the different materials of the main structure is described in section 7.10. The main structure is expected to last at least 10 years when the timber is protected from moisture and insects. Insect protection is improved when the whole structure is elevated and put on steel ground screws as foundation. As the structure is fully disassembleable damaged parts can be replaced easily. Part availability should be easier because all designs are open-source and only basic machinery is required to create them.

For the locally created walls lifespan is commonly much less because outside facing elements deteriorate faster and also require more regular maintenance. The exact lifespan depends on the specific technique and material used. Different local wall types are discussed in Part III.

7.4 Relocateability

To be able to relocate a structure it must be either very light to be able to move it as a whole or it must be disassembleable. This design is fully disassembleable to allow a space efficient transportation of the main structure itself. Section 6.4 already gave considerations about relocatability.

The mentioned screw foundations in section 7.1.5 can also be unscrewed and relocated. With this foundation type and the raised building the site is basically left untouched after the building was relocated. No permanent deterioration of the site greatly improves the acceptance of the local population for the temporal buildings.

Also the modules discussed below were designed with pre-fabrication and relocatability in mind. The kitchen and the sanitary module are both fully disassembleable.

7.5 Local building techniques

While the structure of this design is globally identical the walls are created according to local climate adapted building techniques. This allows to use locally available materials which are known to work in the deployed climate. By using local building techniques the knowledge of the inhabitants or local building specialists can be used, allowing for faster construction and easier regular maintenance.

Only very little restrictions regarding the placement of bracings are given to the inhabitants. Because the walls are not load bearing the placement and size of openings is fully flexible. See Part III about different examples of wall constructions and placement of openings.

For cultures or sites were elevated buildings are not preferred or not needed the corner riser columns can be skipped with the connectors directly connecting to the foundation. With this modification the risk of humidity getting into the main structure increases and shortens the lifespan of the main structure.

The design in this work just features one mono pitched roof version. It can be upgraded to a double pitched version by adding another unit. Different roof types are possible from a construction point of view but skipped here to reduce the number of different parts. Custom roof designs need to undergo a new statical evaluation. The used timber dimensions for the main structure limit the weight of the roof area. While this reduces the options for the wall construction of the upper floor the reduced overall weight improves the resistance to seismic events.

7.6 Sanitary / Infrastructure

Sanitary and more generally water infrastructure is commonly a problem even in organized settlements like camps. The Sphere handbook gives detailed recommendations about quality and quantity of sanitary infrastructure discussed in section 2.5.

Often communal sanitary spaces have issues with security and cleanness compared to sanitary infrastructure allocated exclusively to one household. While communal sanitary spaces do make sense during the emergency phase, a transition to more private options is favoured by the inhabitants during later phases.

Because this design can be applied in many different settings no assumptions about piping networks for fresh and grey water can be made.

7.6.1 Fresh Water

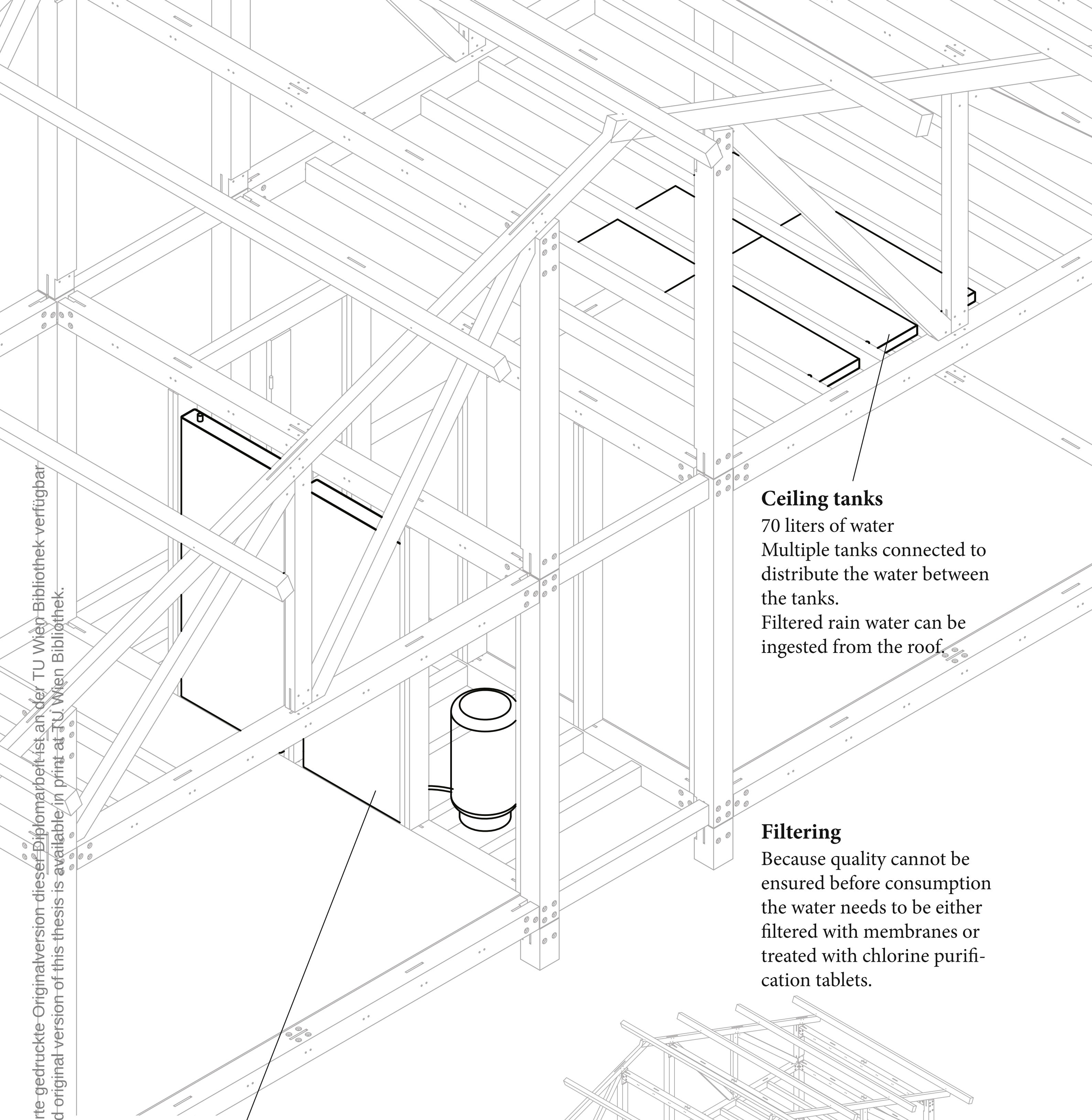
If there is a piped water network in developing countries commonly the water quality can not be guaranteed. Often water is distributed from water distribution facilities. Depending on the distance collecting water from these distribution facilities can take up a lot of time.

To reduce the time spent on gathering water this design features optional fresh water tanks in the inner walls between two units. Rain water can be collected and later filtered in these tanks to provide independence from the water distribution facilities. To ensure hygienic standards the water should be filtered before consumption using membranes. The reasons for placing the water tanks not in outside walls is the chance of freezing destroying the tank.

The wall water tanks are not pressurized because of their box shape. To create water pressure the wall tanks feed a smaller diaphragm based cylindrical tank. For water retrieval this smaller tank contains an internal diaphragm which can be mechanically or electrically pressurized. This pressure is applied to the water and allows to retrieve water from a tap. Common operating pressures are up to 1000 kPa. Diaphragm water tanks made from steel are commercially available.[15]

For climates where sub zero temperatures are not possible no wall diaphragm tanks are needed as the tanks can be placed between the substructure of the ceiling. The thermal mass of the ceiling water tanks can buffer day-night temperature swings. To respect the load limits of this design a tank should be only 70 mm high and only store around 70 L. With this dead load the live loads of the upper floor are limited in the area around the tank. Tanks should be mounted with a small decline towards the outlet. Ceiling water tanks should not be added in areas with high seismic risks because of the raised center of mass.

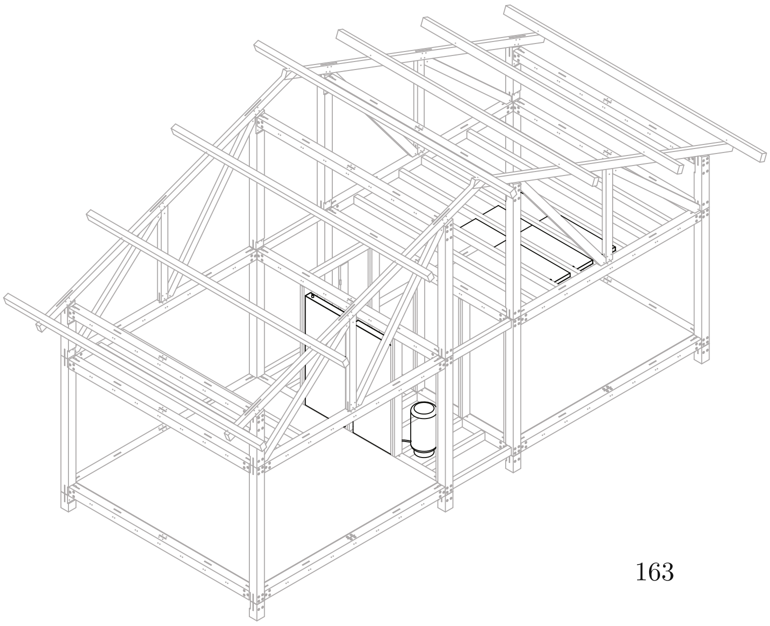
[15] *PressureWave™ — Global Water Solutions.* 26th May 2017. URL: `https://www.globalwatersolutions.com/products/pressure-tanks/pump-applications/pressurewave/` (visited on 19/01/2023).



Ceiling tanks
70 liters of water
Multiple tanks connected to distribute the water between the tanks.
Filtered rain water can be ingested from the roof.

Filtering
Because quality cannot be ensured before consumption the water needs to be either filtered with membranes or treated with chlorine purification tablets.

Wall tanks
180 liters of water.
A diaphragm pressurizes the water so that it can be tapped above the current water storage level.
The diaphragm can be prasured mechanically or electrically



7.6.2 Toilets and Shower

During initial emergency phases communal shared toilets are often the only option. Communal toilets are a huge security risk especially at night for disadvantaged groups like women, girls, disabled and old people. Details about the requirements for camps can be found in section 2.5. Sanitary options should be upgraded to household toilets immediately after the emergency phase.[16]

For household toilets multiple options exist:

One UNHCR design is a dry external detached toilet structure located on a dug circular excrement tank with a concrete lid. The toilet structure itself is constructed using wooden panels and measures 1.5×1.6 m. The design utilizes an alternating pit philosophy where the toilet is physically switch from one 360 L septic pit to the other one when it is full. This capacity should last for one year for a household of four. When one septic tank is nearly full the toilet super structure is moved and the old septic tank is covered with lime and earth to eliminate odours and regulate the pH level. After around 8 months the decomposition result can be used as nutrition rich soil.[17]

Another design option is the attached outside toilet seen in the analyzed reference in section 3.4.2. This allows for an easier creation of a septic tank as not much piping is required. Also the odour problem is eliminated as the toilet module can only be reached from outside. From a security perspective it is not ideal as the house needs to be left possibly during the night.

The third option is an internal toilet which can be delivered as a pre-fabricated module. One toilet design worth mentioning is a prototype under development by Samsung as a response to the reinvent toilet challenge of the Gates Foundation. The design does not need a connection to a waste water network and dries and burns human excrement.[18]

This design relies on an external detached toilet with alternating pits during the emergency phase. Reasons are that creating external detached toilets is a very established technique. For a large enough external toilet module extra foundations and roof extension would be necessary which are costly and hard to realize during the emergency phase.

During the transition phase this design introduces a sanitary module consisting of a shower and a toilet. The upgrade module is placed in the in-between space between two units. The existing two septic tanks can be reused by creating pipes from the module to the tanks. An additional water sink for grey water needs to be dug under the module and filled with gravel.

[16] Robert Gensch et al. *Compendium of Sanitation Technologies in Emergencies*. UNHCR WASH. 2016. URL: `https://wash.unhcr.org/download/compendium-of-sanitation-technologies-in-emergencies/` (visited on 20/01/2023).

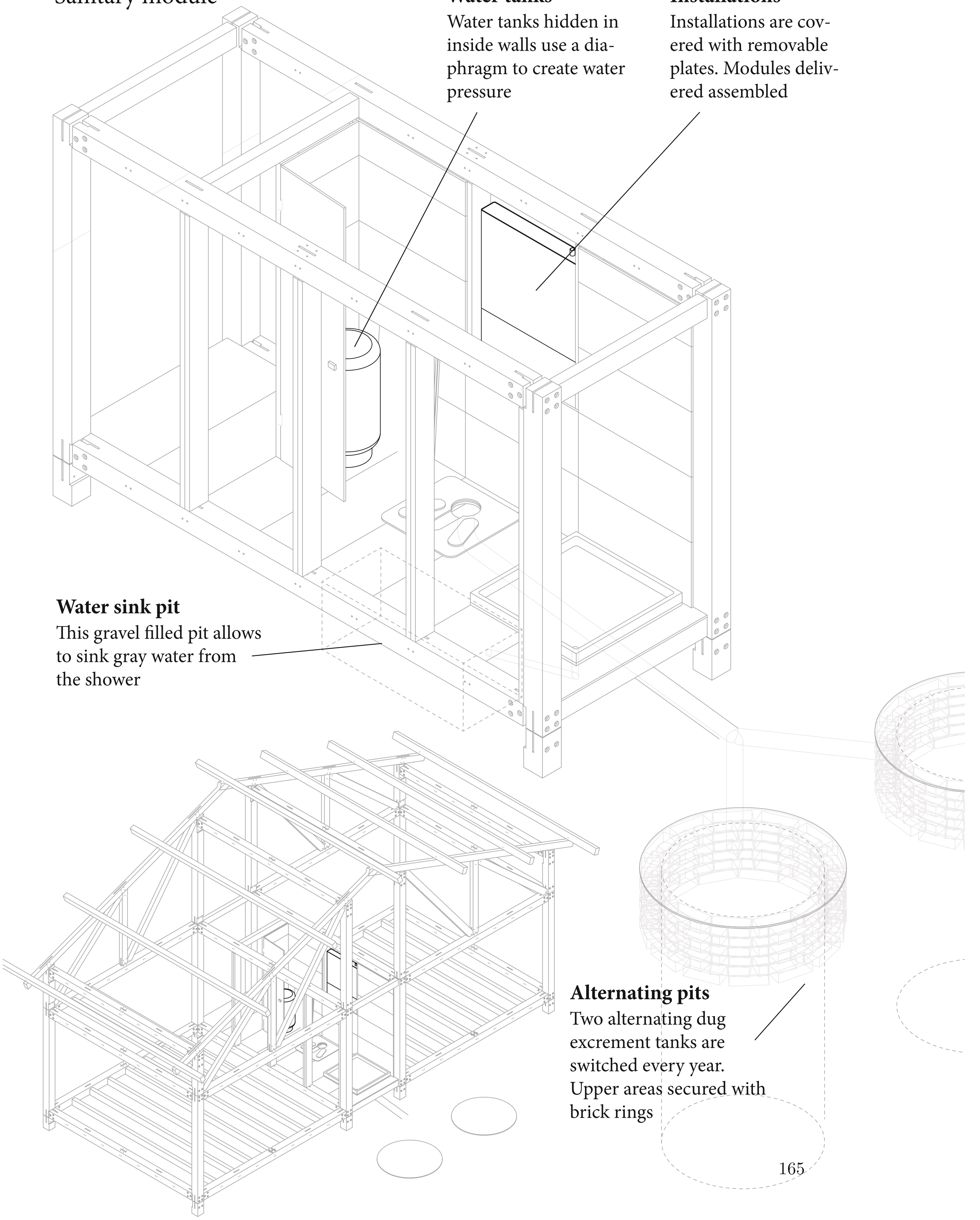
[17] *D-403/2015a Household Toilet and Bathing Unit (Domed Slab, Alternating Pit, Raised Pit)*. UNHCR WASH. 2015. URL: `https://wash.unhcr.org/download/household-toilet-and-bathing-unit-design/` (visited on 20/01/2023).

[18] *Samsung Develops 'reinvented Toilet' with Gates Foundation*. ZDNET. URL: `https://www.zdnet.com/article/samsung-develops-reinvented-toilet-with-gates-foundation/` (visited on 20/01/2023).

Sanitary module

Water tanks
Water tanks hidden in inside walls use a diaphragm to create water pressure

Installations
Installations are covered with removable plates. Modules delivered assembled



Water sink pit
This gravel filled pit allows to sink gray water from the shower

Alternating pits
Two alternating dug excrement tanks are switched every year. Upper areas secured with brick rings

7.6.3 Kitchen

Cooking areas are important spaces in all cultures. Depending on the culture the cooking can happen indoor or outdoor. Also the required placement height of the stove varies depending on the culture.

As fuel source there are multiple options. The most efficient fuel source would be methane which is often not available or too expensive. Methane offers clean combustion with less amounts of fume and a high energy density. If no fuels can be provided inhabitants tend to use existing natural resources like wood, grasses and animal excrement. Those energy sources commonly offer a low energy density and collection creates a huge environmental impact. Especially fire wood collection can lead to local deforestation and tension with the local population over resource exhaustion. Electric stoves are generally not feasible because of the high power consumption and the common lack of good electrical infrastructure.

For cultures where cooking is happening traditionally inside the main living space a prefabricated wall module is provided with this design. In the prefabricated module an efficient stove can be incorporated which outperforms the traditional three stones fires commonly used in developing countries by magnitudes regarding fuel consumption and exposure to fumes. Besides a version with the stove at a height of about 100 cm a lower version at a cooking height of 32 cm was designed. The kitchen module can be combined with other non food items like pods for the inhabitants.

In hot and wet climates cooking is often performed in an external building or hut. With this design a kitchen wall unit can be added to a dedicated external unit serving as kitchen house.

Key aspect besides the actual stove is a reasonable chimney which allows the hazardous combustion fumes to escape. Kitchen smoke related respiratory illnesses are still extremely common in developing countries and affect mainly women and children.[19] The chimney in this design pinches through the roof corrugated galvanised iron modules on the outside of the building. This provides additional horizontal support to the chimney during high wind speeds.

The kitchen module is built from wooden panels and fireclay to withstand the heat of the oven. For climates were insulation is needed fire proof insulation material can be added during the prefabrication process. Detailed designs of energy efficient, low tech stoves are beyond the scope of this work. Several good resources from UNHCR[20] and from the Aprovecho Institute[21] with detailed research exist.

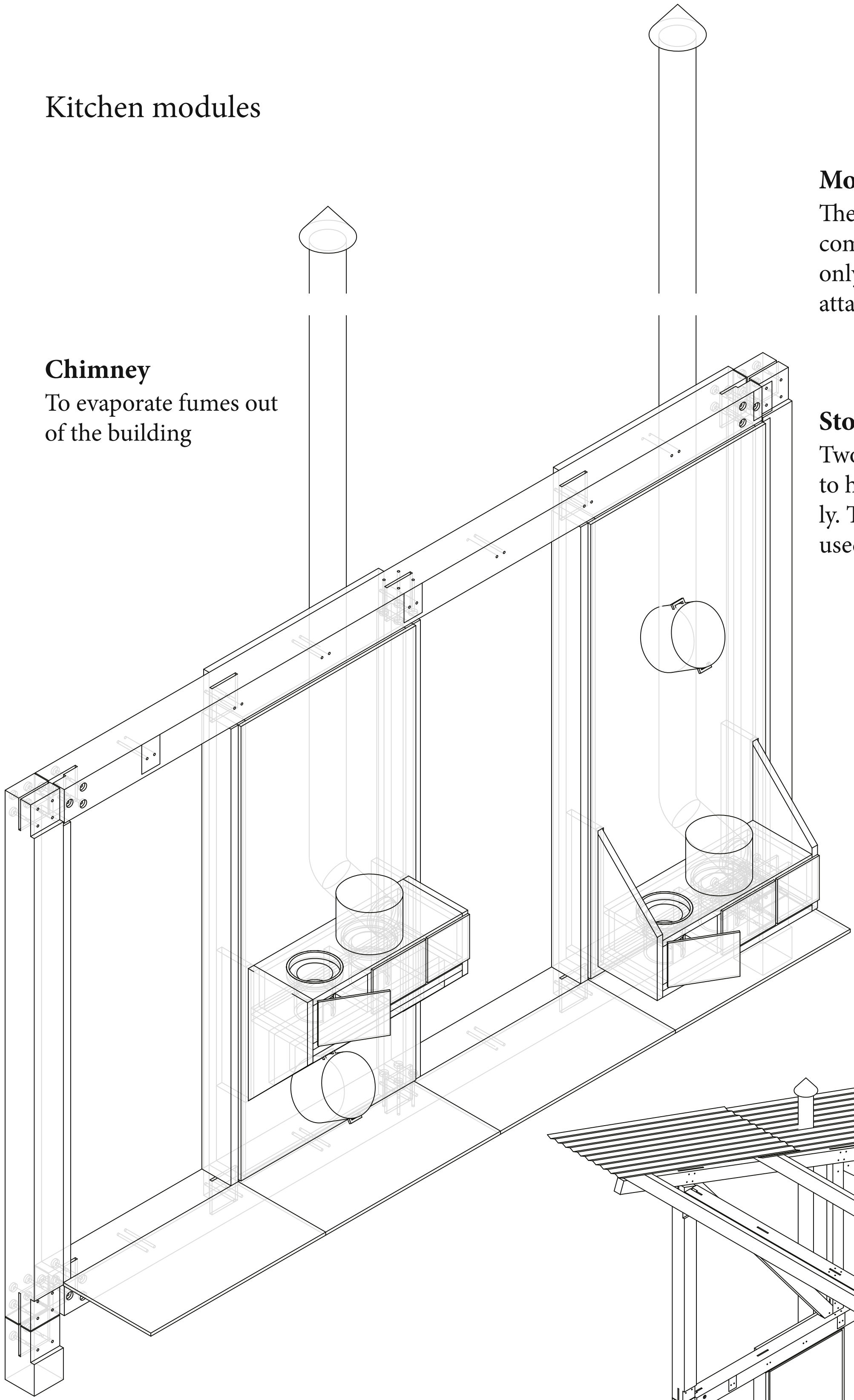
The stove in this kitchen module is also the main heat source during winter times. In combination with wall insulation for cold climates it should create tolerable temperatures.

[19] Hugh Warwick and Alison Doig. *Smoke - the Killer in the Kitchen*. Jan. 2004. ISBN: 1-85339-588-9.

[20] Owen, *Cooking Options in Refugee Situations - A Handbook of Experiences in Energy Conservation and Alternative Fuels*.

[21] Aprovecho Institute. *Fuel Saving Cookstoves*. 1984.

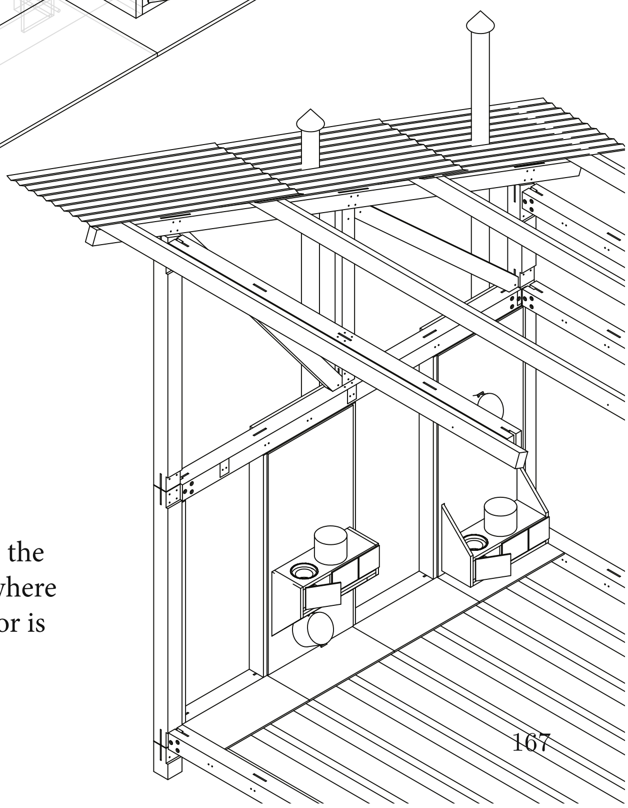
Kitchen modules



Chimney
To evaporate fumes out of the building

Module
The kitchen module comes assembled with only the chimney to be attached later on-site

Stoves
Two efficient stoves allow to heat two pots separately. The stoves can also be used for winter heating



Low variant
A version closer to the floor for cultures where cooking on the floor is preferred.

7.7 Size and configuration

The minimal size is one unit with roughly 4×4 m resulting in 14.7 m^2 of usable space on the ground floor and the same area on a partly usable roof space. This roof space can be used to extend the usable area with a sleeping area in hot and humid climates. Also storage of goods and agricultural products is possible. Putting no ceiling creates a single high space with an increased air volume. With the roof overhang the minimum plot size is at least 34 m^2.

The initial unit can be extended on three sides with another unit forming the second smallest dwelling consisting of two units. With the covered in-between space of 5 m^2 forming between two units the total usable space on each floor is 34.4 m^2. The in-between space exists between all adjacent units. Section 7.6.2 introduces a sanitary module which fits in this space. This space can also be used to create one large room spanning two units and the space in-between.

Extending the high roof side transforms the mono pitched roof to a double pitched roof. An extension on either of the two sides does not change the roof geometry but just stretches the dwelling. Theoretically the dwelling could be extended indefinitely in this direction as each unit is structurally independent. Practically more than three units do not make sense as this design was not designed for community structures. The side with the low roof can not be extended practically as it creates issues with rain water discharge with the resulting v-shaped roof.

As each unit is structurally independent the bracing rules must be applied per unit. See section 7.1.4 on details about the bracing. Wall modules with bracings are shown as blue lines in the layout graphics.

Not all units of a structure need to be closed allowing to create open but covered areas like porches. Covered outside spaces are useful to perform work in wet climates as it shields from rain.

For optional combinability all units should be on the same level. By adjusting the length of the riser corner columns or the height of the screw foundations the ground does not need to be flat.

To allow access to the roof a staircase can be inserted. Structurally the easiest point for putting the staircase is in the in-between space between two units. As the height difference is 250 cm and the length is limited to 384 cm the staircase needs to be steep.

All possible combinations for up to six units are shown on the following pages. The ground floor of each layout is shown with a thick wall version with insulation in the space between the columns. The walls of the upper floor always needs to be light for static reasons. Usable space including the roof area ranges from 14.7 m^2 to 136 m^2. The graphics uses the Sphere minimum space recommendation to calculate the maximum number of people per layout. For details see section 2.3.4.

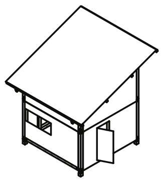
Layouts

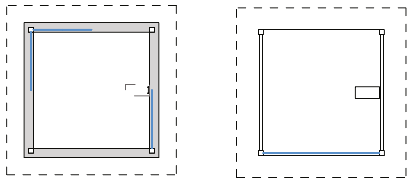
Different possible layouts from 1 to 6 units are shown.
The number of people is assumed for warm climates with the Sphere recommendation of 3.5 m² per person

Bracing
Needed bracing for extra stability is shown in blue

Walls
All layouts are shown with a heavy thick wall on the ground floor and a thin wall on the roof floor

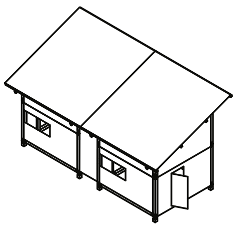
1 unit
14.7m² of usable space
4 people

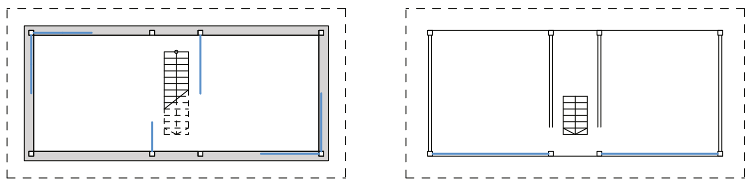




Ground floor Upper floor

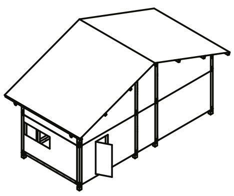
2 units
34.4 m² of usable space
4-8 people

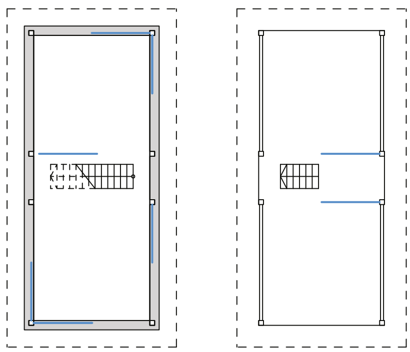




Upper floor
In case the upper floor should be used as regular living space a staircase can be placed in the in-between space of two units

2 units
rotated version (gable roof)
34.4 m² of usable space
4-8 people

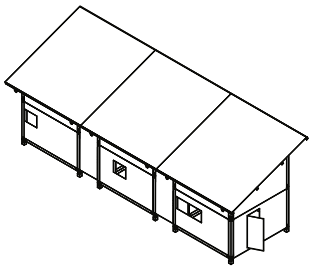


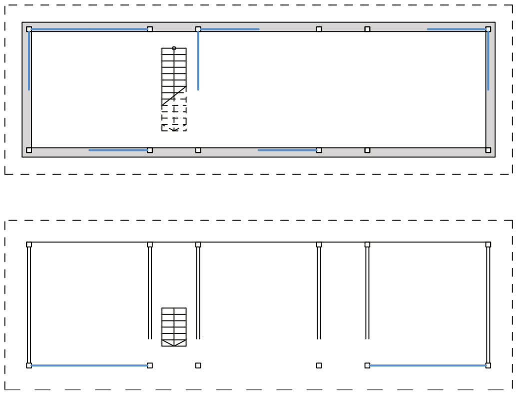


5m

3 units

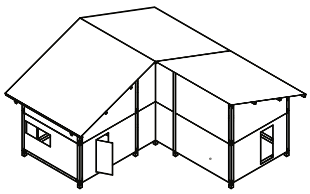
shed roof
54.1 m² of usable space
4-15 people

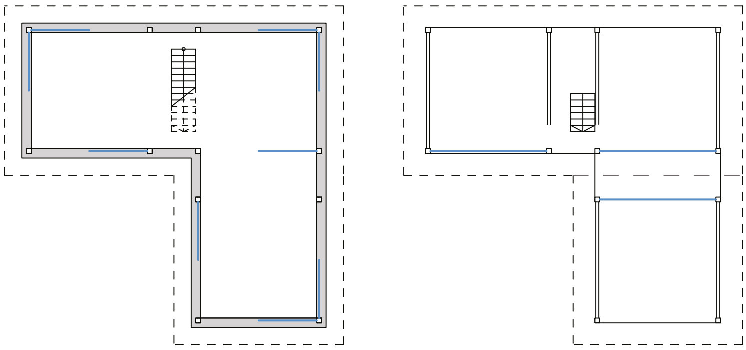




3 units

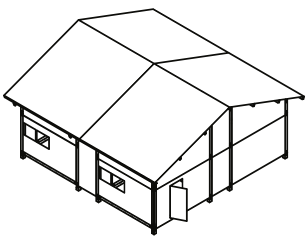
gable roof w. corner
54.1 m² of usable space
4-15 people

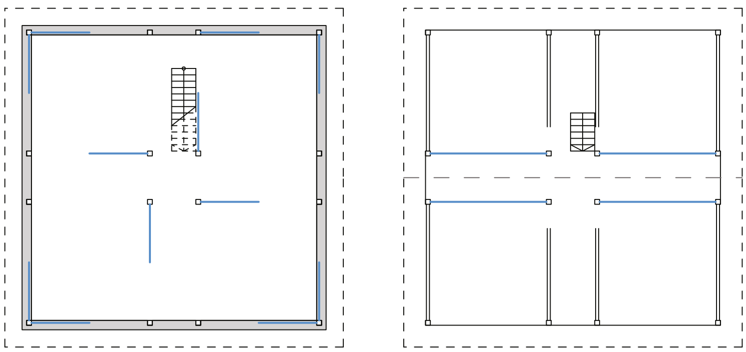




4 units

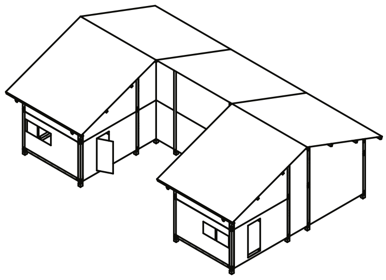
gable roof
80.3 m² of usable space
8-22 people

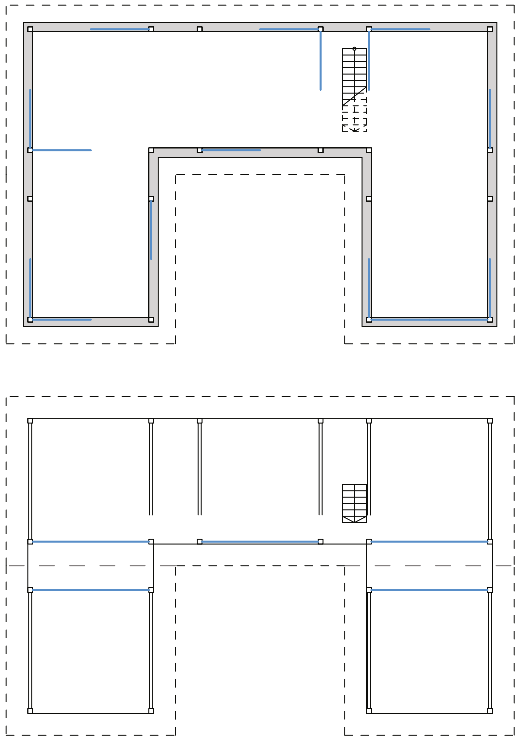




5 units

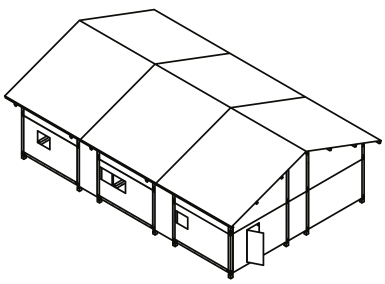
gable roof, patio
93.5 m² of usable space
8-26 people

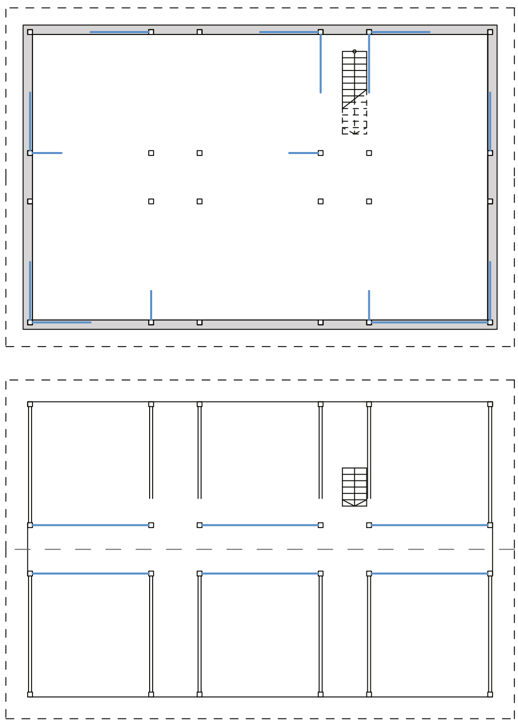




6 units

gable roof
127 m² of usable space
10-36 people





Pouch

One unit can be left open without walls to create a covered poach

5m

7.8 Transportation

Logistics and the ratio of transportation space and weight to unit count are keys factors for emergency relief operations. Depending on the area and country, transportation infrastructure could be of bad quality or damaged after a large disaster. Therefore optimal usage of transportation resources is a necessity.

The kit of this design includes all the needed beams and columns to assemble the whole structure, roof, floor and ceiling support. Additionally all metal connectors, screws, bolts and the metal bracings are included. Also the necessary tools for the assembly like a hammer, wrench and a socket wrench are included in the kit. Depending on the available material on-site galvanized iron sheets as roof cover and OSB plates for the floor should be included.

Depending on the distance and means of transportation available between prefabrication and deployment place the packaging should be decided. It is important to transport all necessary parts of one kit together to avoid incomplete kits on the deployment site causing confusion and delays.

A standard shipping container as packaging is assumed as it can be easily carried by ship, train or truck and is very economic to procure. Load and unload operations and storage can also be handled very fast and efficiently with containers. Also when changing means of transportation during the trip no repackaging is needed.

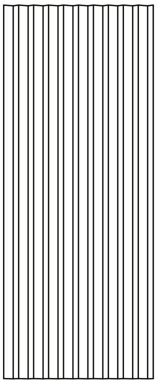
The de facto standard of shipping containers is the twenty-food equivalent unit also known as TEU. Containers exist in single size which correspond to around 20 ft length and double size with exactly 40 ft length. While the length is standardized the height is not but is commonly 2.59 m. Common net cargo weight limits are 25 000 kg for the 20 ft version and 27 600 kg for the 40 ft version. Maximum cargo load varies and depends on the ship lines and other transportation restrictions. Both versions can be transported on container ships. On road transportation it depends on the available truck infrastructure.[22]

It is critical to store the delivered containers on a guarded warehouse space of the camp to protect the content from theft. Also handed out kits must be tracked to avoid handing out kits to unregistered people.

As the wood and the metal connectors roughly weight 1400 kg per kit, a distribution method inside the camp must be planned. One low tech transportation method are hand-carts. Ideally the kits can be dropped at the closest point on the access road near the plot. No part of the design is heavier than the primary beams with 45 kg each, which need to be carried by two people.

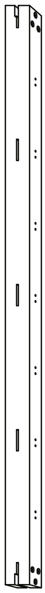
[22] *Containerhandbuch*. GDV. URL: `https://www.containerhandbuch.de/chb/stra/index.html?/chb/stra/stra_03_02_00.html` (visited on 20/01/2023).

Parts

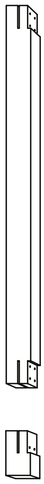


roof sheet
Galvanized iron sheet
100 x 250 cm
2.5 kg

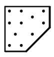
bracing
M10 rod
1 kg



main beam
KVH 160 x 160 mm x 4 m
45 kg



main column
KVH 160 x 160 mm x 2.5 m
30 kg



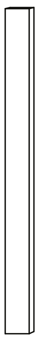
Type I connector
10 mm steel
6 kg

Type II connector
10 mm steel
6 kg

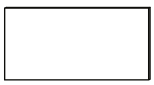
nut w. washer
M10 metal rod
M10 washer
M10 nut

secondary roof beam
timber
80 x 160 mm x 5.44 m
32.7 kg

floor / ceiling beam
timber
80 x 160 mm x 3.8 m
23 kg

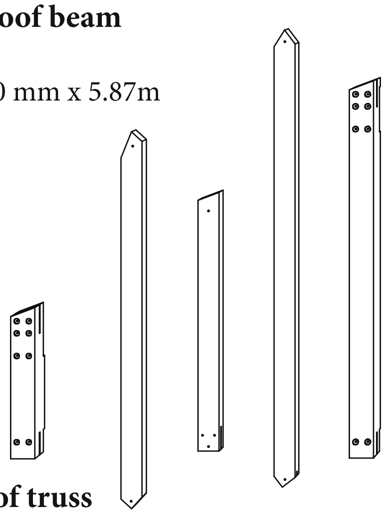


module frame
timber
160 x 40 mm x 2.2 m
6.5 kg

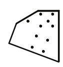


OSB plate
96 x 48 cm x 1.5 cm
4 kg

main roof beam
timber
80 x 160 mm x 5.87m
34 kg



roof truss
timber
5 beams
76 kg total



Type III connector
10 mm steel
6 kg

Type V/IV connector
steel

7.9 Self-empowerment

To fabricate and build one unit three different types of manuals with two different viewer scopes are needed during the whole process.

The first manual is about the preproduction and the necessary steps to create a shippable unit of the design. This includes all the technical drawings of the design and all instructions how to create the drill templates. This manual can be rather technical as the audience can be expected to have some wood and metal working background. It is expected that the manual is studied and applied by a skilled foremen who breaks it down for the less qualified workers at the prefabrication facility. Even though the foreman is expected to have some knowledge about wood and metal work the manual contains suggestions how to create and manufacture the holes and slots in the wood and metal pieces. As some metal connectors require welding, the practical knowledge of this process is also expected to be already existing. Ideally the manual is translate to all the needed languages.

The other two manuals target the future inhabitants of the structure. The first part of the manual is the core building manual and is the same for all deployments focusing on the structural frame and how to erect it on different soil conditions. A section about the specific foundation concept for the site should be appended to the manual before deployment. No specific prior skills are required to erect the kit so this manual focuses on very entry level drawings and pictures. The informations must be conveyed in a precise, explicit way and should also potentially work for illiterate people. As some mistakes like missing bracing or missing screws could cause later damage during high wind loads it is expected that there is support and oversight provided by a qualified person.

Depending on the area and local climate adapted building techniques of the affected population a third manual should be created which targets the wall and roof construction using local material. This manual can be created by international relief organisations together with craftsmen from the affected population. As design patterns and materials repeat it should be easier to create new versions after some initial versions have been created and built. It is also crucial to include maintenance advices and intervals to ensure that the wooden parts stay dry and are not affected by rodents or insects.

7.10 Materials

This sections goes into detail about all the major materials used in this design for the unit kit. Also needed tools for the prefabrication are included in this section. According to the manifest low tech prefabrication methods and globally available materials are used as much as possible.

7.10.1 Timber

Structural timber is used for all columns and beams of the primary and secondary structure. The metal connectors require that slots and holes are created in the timber beams and columns.

For creating the slots a professional slot mortising machine like the SG 500 from Mafell can be used. [23] As alternative a custom self-build with a mounted chainsaw can be used. The required slots with a width of 11 mm can be created with one cut. Double wide slots with 22 mm can be created by repeating the cut. Slots can also be manually created with a chisel and repeated drills but own experiments showed that this approach is very time intense and does not yield accurate results.

Almost all precise slots which need to fit the metal connectors are located at the endings of the timbers. To create those slots a band saw can be used to perform two cuts and drill a hole at the end to create a slot fast.

To create the holes for the screws a carpentry drilling machine like the ZB 400 E from Mafell with an auger drilling bit 10 mm can be used. Those machines are easily moveable and allow to drill in place.

For creating the wider holes to submerge the nuts a 35 mm forstner bit is needed. Moving the washers and nuts into the timber level protects the nuts and allows to create a flat surface outside and inside.

Biggest issue for the timber constructions is the precision. While the metal parts can easily be built machine assisted the wooden parts are commonly built by trained craftsmen. All cuts and holes must be created very precisely because the bolts only fit through the metal plates and the timber beams if they match exactly. Templates should be used to accurately mark the locations for the holes.

For this design softwood with quality of C24 according to EN 338 was assumed. In Austria spruce with around 420 kg/m^3 is commonly used for building purposes.[24] Also hardwoods can be used for this design but the potential higher weight needs to be factored in for calculating the units per container ratio. Hardwoods are generally more resistant to humid conditions and have a higher lifespan in outside usage. Bamboo as building material while being cheap, fast growing and widely available suffers from relative low lifespan and is easily attacked by insects. Also the compression strength is not sufficient for the long beams in our design. For the above reasons it is not recommended for the primary or secondary structure.[25]

7.10.2 Metal

Steel is used for every wood to wood connection in this design to allow for safe assembly and disassembly if needed.

If no plasma cutting machine for cutting out the metal connectors from the raw 10 mm steel plates is available it should be considered to ship the already cut connectors instead of the raw metal plates. If possible the holes in the metal plate connectors should be also drilled machine assisted to achieve a high accuracy.

A welding device and skilled labour is needed to create the angled Type II and Type IV connector at the prefabrication site. Welding the connectors on the prefabrication site

[23] `https://produkte.mafell.de/fraesen/schlitzgeraet/schlitzgeraet-sg-500`
[24] *ÖNORM EN 338:2016*. Austrian Standards, 1st June 2016.
[25] Roland Stulz and Kiran Mukerji. *Appropriate Building Materials : A Catalogue of Potential Solutions*. 1981.

allows for much more space efficient transportation of raw steel plates to the prefabrication facility. See section 7.1.3 for details on the connectors.

All bolts, washers and nuts are made from steel to ensure high durability. Also common metric norms are used to allow to procure them at a commercial scale.[26] Especially corrosion must be avoided as it prevents the disassembly of the nuts from the bolts. Steel quality 4.8 according to DIN EN ISO 898-1 is deemed sufficient and also widely available. A steel quality of 4.8 means a tear strength of $400\,\mathrm{N/mm^2}$ (4×100) and a yield strength of $320\,\mathrm{N/mm^2}$ $(4 \times 8 \times 100)$. For deployment locations close to the ocean with increased corrosion a higher steel quality should be considered.

The M10 metal rods forming the diagonal bracing must take high tensile forces during high wind loads or seismic events. The same metal rods are also used as bolts. For cutting the 2 m long M10 threaded rods to the needed length during prefabrication a steel saw or a chop saw is needed. With a chop saw production speed for one cut is down to a second. See section 7.1.4 for details on the bracing.

7.10.3 Corrugated galvanised iron sheets

As roof cover commonly corrugated galvanised iron sheets are used. The reason is the good availability even in developing countries and the durability. Especially the water resistance and lower maintenance effort in comparison to traditional hatch roofs are commonly appreciated. Lifespan heavily depends on the coating thickness and the climate. It can range from over 50 years in dry or cold regions to less than 2 years in tropical regions with high air pollution.[27]

Corrugated galvanised iron sheets lead to higher inside room temperatures as traditional thatch roofs and also create louder noises during rainfall. Because of rust and developing structural weaknesses badly maintained corrugated galvanised iron sheets can get loose and become a threat during storms. Especially in coastal areas the salty air leads to fast corrosion of cheap corrugated galvanised iron sheets.[28]

7.10.4 OSB

Oriented strand boards are used in this design to form flat surfaces for the floor and the ceiling. Depending on the country the common size is around 250×125 cm with common thicknesses from 12 to 25 mm. In this design the torsion forces can be partly absorbed by using structural OSB floor plates.

As shown in some reference designs the boards can also be used to create shear resistant walls very quickly. Especially designs with limited bracings benefit a lot from the extra stiffness introduced by structural OSB/3 or OSB/4 boards.

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[26] *ISO 1502*. Feb. 1996. URL: `https://www.iso.org/standard/6092.html` (visited on 19/01/2023).

[27] Emeline Decoray. *How to Build Safe Roofs with Corrugated Galvanized Iron (CGI) Sheeting*. 2017. URL: `https://www.humanitarianlibrary.org/resource/how-build-safe-roofs-corrugated-galvanized-iron-cgi-sheeting` (visited on 20/01/2023), p.45.

[28] Enrique Sevillano Gutiérrez, Eugénie Crété and Cecilia Braedt. *Detailed Shelter Response Profile: Bangladesh*. Sept. 2018. URL: `https://sheltercluster.org/bangladesh/documents/detailed-shelter-response-profile-bangladesh` (visited on 04/12/2022), p.21.

Cuts needs to be aligned with the few common sizes to reduce waste. OSB plates can be cut very efficiently with hand-held circular saws.

7.11 Adaptability

When multiple units are combined only the columns of the primary structure are fixed. All internal partitions can be created depending on the actual needs of the inhabitants without restrictions.

It is also up to the inhabitants if the roof space should be used as dedicated floor or if the air volume of the ground level should be increased by not installing a ceiling between ground and upper floor.

In this design the walls and openings are entirely created by the inhabitants and can be customized according to their needs. Only the bracing rules from section 7.1.4 must be respected. Besides for the main structure this design does not force any particular material or construction.

By creating a significant portion of the shelter locally by the inhabitants it is expected that the resulting structures are visually distinct. The negative aspects of handling inhabitants like numbers in identical military-efficient buildings were discussed in particular in section 3.3.1 and section 3.3.2. Distinct shelters allow for individuality and also make orientation in settlements easier.

7.12 License

The license of a design is a key aspect as it controls how widely and easy the design can be produced, shared and adapted.

One possible license type are copy left licenses purposely giving away some of the owners exclusive rights. Copy left licenses originate from software where the General Public License written by Richard Stallman was the first one. The idea of copy left licenses is to grant certain rights to the users and also force the same rights to be preserved from derived work. This allows other users to improve the design and force them to make their changes available for other people as well.

While classic copy left licenses mainly target software artifacts the creative commons licenses target all other creative work. The license of all design files of this project is inspired by the wikihouse project.[29] Like this project all files of this work are licensed under the creative commons BY-SA 4.0 license. This creative commons license allows everybody to share meaning *"copy and redistribute the material in any medium or format"* and to adapt meaning *"remix, transform, and build upon the material for any purpose, even commercially"* the design.

This ensures that this work is available free of charge and can also be commercially produced. But all modifications need to be given back to a community forming around the project. A vivid community allows to adapt the design over time to improve the existing revisions step by step.

[29] *WikiHouse - Design Guide.*

7.13 Prices

Only the price for the kit which includes the structure, metal connectors, OSB plates as floor and corrugated galvanised iron sheets as roof cover is calculated. The final price depends on the chosen materials for the walls as well. Chapter 8 about Jordan, chapter 10 about Ukraine and chapter 9 about Bangladesh will try to give a price estimate for a full usable unit.

Two per kit prices were calculated: The first one takes prices for a low number of units with all elements procured in Austria available for individuals at construction markets or the internet. This price can be seen as a 1:1 prototype price with privately organized transportation.

The second calculation takes wholesale prices from mainly Chinese manufactures for huge quantities. While this price is much lower other factors like transportation costs etc. must be added to get the final unit cost at the destination area. This price tries to give an estimate of the costs when many kits are procured by international relief organisations or governments to assist in a crisis. Prices for local transportation are much harder to estimate and strongly depend on the scale of the crisis and the state of the infrastructure available at the destination country.

Transportation prices are hard to estimate even for international shipping. Because of current supply chain issues the shipping price per container from Asia is fluctuating greatly. Local transportation costs on trucks highly depend, not only on the country and area, but also on the damages and availability after a disaster. Under these unclear constraints not even a price range can be given.

The labour prices needed for the prefabrication are hard to estimate because hourly rates and skill level varies substantially around the world. Also with higher volumes of produced kits processes get more automated and thus faster and cheaper. It needs to be noted that creating a 1:1 prototype of one corner with inadequate tools took around one full day for three people.

Final wholesale price for one unit including a corrugated galvanised iron roof and floors but without a foundation is around 900 €. With the two floors and the $29.4\,m^2$ of usable space this results in $31\,€/m^2$. This does not include labour cost for the pre-fabrication and no transportation costs. Also costs for local materials for the wall construction are not factored in but are expected to be low. In comparison to the references in chapter 3 this places this design exactly at the median. It is certainly more expensive than most emergency shelters built from only local materials but is substantially cheaper than more durable shelters with long lasting structures.

Wood

Name	Dimension	Times	Austria Unit price	Austria Total AUT	Bulk (China) Unit price	Bulk (China) Total bulk	
Main column	250 cm	4	€ 43.68	€ 174.74	€ 19.20	€ 76.80	1), 2)
Main beam	384 cm	10	€ 67.19	€ 671.87	€ 28.59	€ 280.59	
Roof truss			€ 55.15	€ 110.30			
Main roof beam	587 cm	2	€ 45.03	€ 90.06			
Sec. roof beam	544 cm	4	€ 53.20	€ 212.80			
Floor / ceiling beams	384 cm	14	€ 29.89	€ 418.46	€ 12.90	€ 180.63	3), 2)
OSB floor plate			€ 20.76	€ 299.77	€ 4.17	€ 60.17	

Galvanized Iron

roof sheets		32 m²	€ 15.00	€ 480.00	€ 3.85	€ 123.20	3), 2)

Steel parts / connectors

Threaded M10 rod	16 cm	192	€ 0.32	€ 61.44	€ 0.02	€ 3.07	3), 2)
Washer M10		192	€ 0.05	€ 9.45	€ 0.01	€ 1.92	
Nuts M10		192	€ 0.09	€ 17.57	€ 0.02	€ 3.84	
Type I		10	€ 88.00	€ 880.00	€ 4.00	€ 40.00	4), 2)
Type II		10	€ 88.00	€ 880.00	€ 4.00	€ 40.00	
Type III		6	€ 60.00	€ 360.00	€ 3.00	€ 18.00	
Type IV		28	€ 2.12	€ 59.36	€ 0.50	€ 14.00	3), 2)

Sum

Sum				€ 4.882,86		€ 900

1) Wood prices requested from Burger Sägewerk und Holzhandel and Holz-Marberger
2) bulk prices from various vendors from Alibaba.com
3) prices from hornbach.at
4) metallparadies.de

Part III

Showcases


Bulgaria
Russian Federation
Georgia
Armenia
Türkiye
Iran
Greece
Cyprus
Syria
Lebanon
Damaskus
Iraq
Zaatari refugee camp
Amman
Palestine
Israel
Jordan
Kuwait
Egypt
Saudi Arabia
Hala'Ib Triangle
Sudan
Bir Tawil (Disputed Territory)

Chapter 8

Jordan

8.1 Refugee situation

With a civil war raging since 2011 UNHCR states that in 2021 around 6.8 million people were under its mandate with an additional 7 million people being internally displaced in Syria. Of the 6.8 million refugees who fled the country it is still estimated that 300 000 are living in refugee camps. While the biggest share of the people found refugee in Turkey and Lebanon also Jordan is hosting around 700 000 people. This work will focus on Jordan because it shares a similar climate and multiple planned refugee camps are still operating.[1]

8.2 Camp Za'atari

Founded in 2012 this refugee camp is still operating and home to roughly 80 000 displaced. The camp is located 12 km away from the Syrian border covering an area of around 5 km^2. Al Mafraq is the next bigger Jordan city with a road distance of 15 km. Each year around 2000 babies are born in the camp resulting in half of the camp population being children. Over 1200 staff from over 30 organisations is working in the camp.[2]

A lot of the initially deployed UNHCR family tents have been replaced with 25 000 prefabricated metal structures. While this shelter was not analyzed in detail it is very similar to the analyzed T-Shelter for the Azraq camp, Jordan in section 3.3.7. After delivery of the container shelters the emergency tents were reused as extension to the new containers. Later additional containers replaced the tents altogether. After ten years with the harsh climate most of the shelters are currently in the need for repair and considered sub standard. A pipe-water connection to each shelter was established over the years. Electricity is mainly generated using solar panels and provided around 9 hours per day.[3]

[1] *Situation Syria Regional Refugee Response.* UNHCR. 31st Oct. 2022. URL: `https://data.unhcr.org/en/situations/syria` (visited on 03/11/2022).

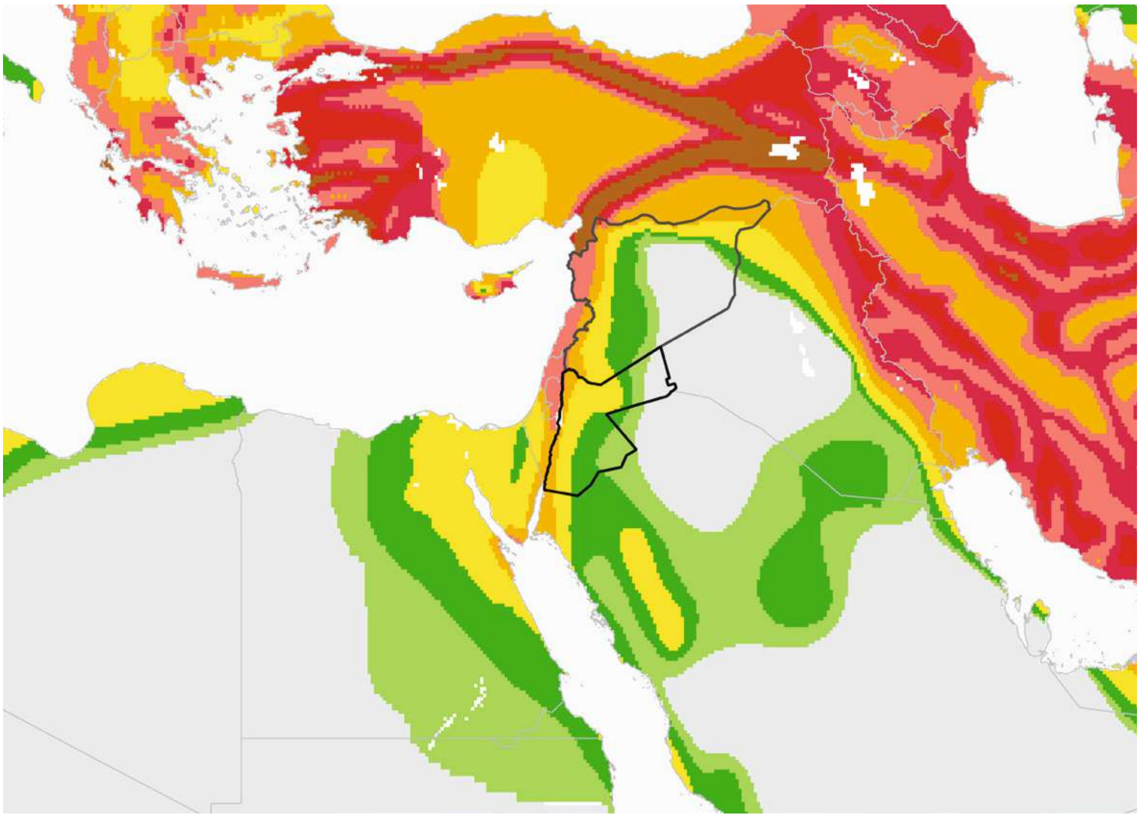
[2] Lilly Carlisle. *Jordan's Za'atari Refugee Camp: 10 Facts at 10 Years.* UNHCR. 29th July 2022. URL: `https://www.unhcr.org/news/stories/2022/7/62e2a95d4/jordans-zaatari-refugee-camp-10-facts-10-years.html` (visited on 03/11/2022).

[3] Ayham Dalal. *From Shelters to Dwellings - The Zaatari Refugee Camp.* Bielefeld: transcript-Verlag, 2022. 223 pp. ISBN: 978-3-8394-5838-9.

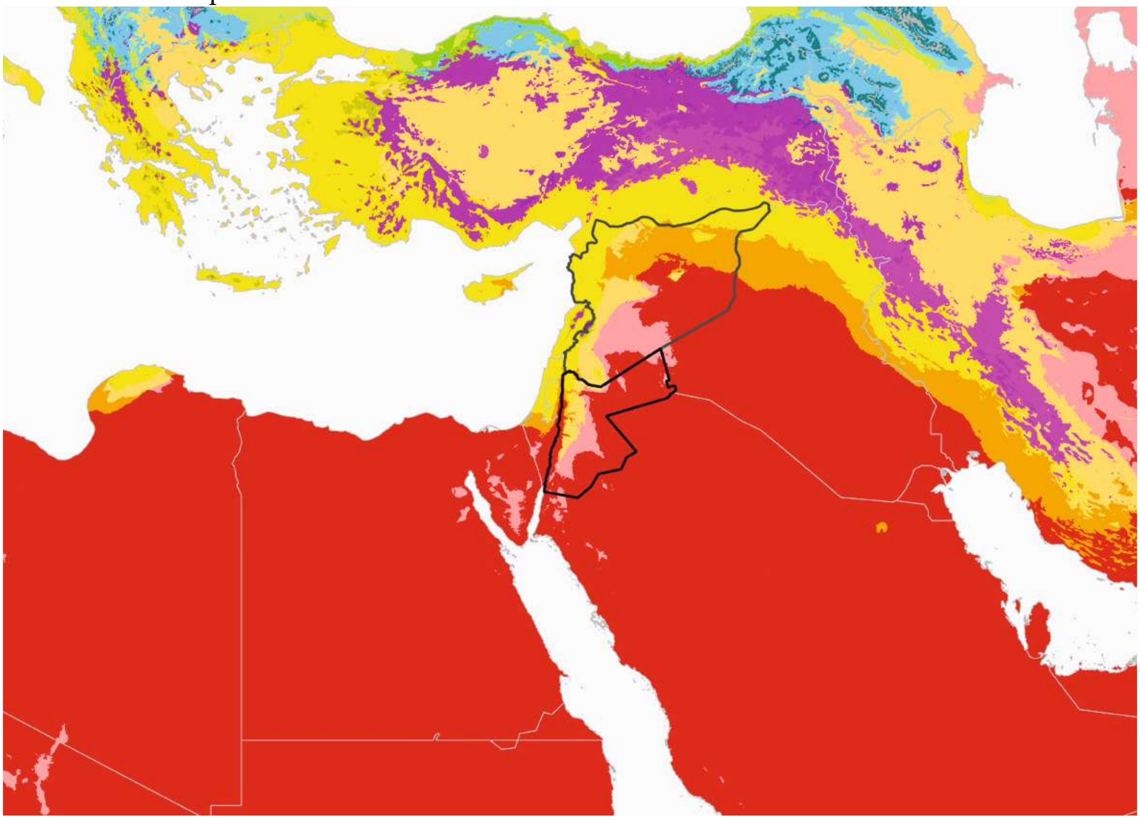
The camp is according to the Köppen-Geiger climate classification system in a BWk zone meaning the climate is arid, desertic and cold. For details about the climate classifications see section 2.6. The camp is elevated 640 m above mean sea level resulting in major day-night temperature swings. The annual precipitation happens mostly from December to March with around 35 mm per month during wet season. Flooding originating from rain water from a 1750 m high mountain ridge was reported during the wet season. Due to the clayey soil infiltration of the rain water does not occur.[4]

[4]Cedrick Gijsbertsen, Maarten Kuiper and Lucas Borst. *Water Management and Irrigation near Za'atari Refugee Camp, Jordam.* 8th May 2017, p.10f.

Earthquake risk map



Climatic zone map



8.3 Climate & Tradition

Jordan and Syria do have very similar climatic zones. Based on the common Köppen-Geiger climate classification Syria and Jordan mainly belong to the dry (arid and semi-arid) and the temperate/mesothermal climate zones (coastal zones). Over 70 % percent of the whole country is classified as arid zones with precipitations of less than 350 mm/y in 90 % percent of the country. More specifically the subcategory for the dry areas are BWh (arid, desertic and hot climate), BWk (arid, desertic and cold climate), BSk (semi-arid cold) and BSh (semi-arid hot). The climate on the Mediterranean coast is classified as CSa which is temperate with a dry and hot summer. For details about the climate classifications see section 2.6.

While the building types in Syria and Jordan are not the same, investigating the building traditions of Syria with its identical climate gives insights into climate adapted layouts and construction techniques. Although many traditional dwelling types are not common anymore they provide a good starting point for low-tech climate adapted constructions.

There are different traditional dwelling types in Syria like the Riwaq houses, Iwan houses, rectangular houses, dome houses and also courtyard houses. The Riwaq house is taken as example in this showcase as it commonly has a moderate size, is well adapted to the climate and is still in use.[5]

The Riwaq housing type is a rectangular house with all rooms orientated to an arcade gallery. This gallery is called Riwaq and is the characteristic element of the house allowing to regulate the attached room temperature. The Riwaq keeps the intensive high summer sun out while allowing the winter sun to warm up the rooms. It can consist of one or two stories with traditionally an outside staircase for access of the upper floor or roof area depending on the number of stories. Most prominently the house can be found in village centers and mountain environments. While the origins of the type are not exactly known the type got common during the late 19th century. The house covers 50 to 100 m^2 which usually makes up for half of the entire plot size. The main room is central with rooms used for sleeping and cooking attached on both sides.[6] It was found that the houses are still inhabited with regular maintenance performed.[7]

The construction consists commonly of masonry load bearing walls which are 40 to 60 cm thick while the floor and roof are constructed from wooden battens. Traditionally the walls were plastered with lime but recently the more durable concrete is preferred. As foundation compacted earth is common.[8]

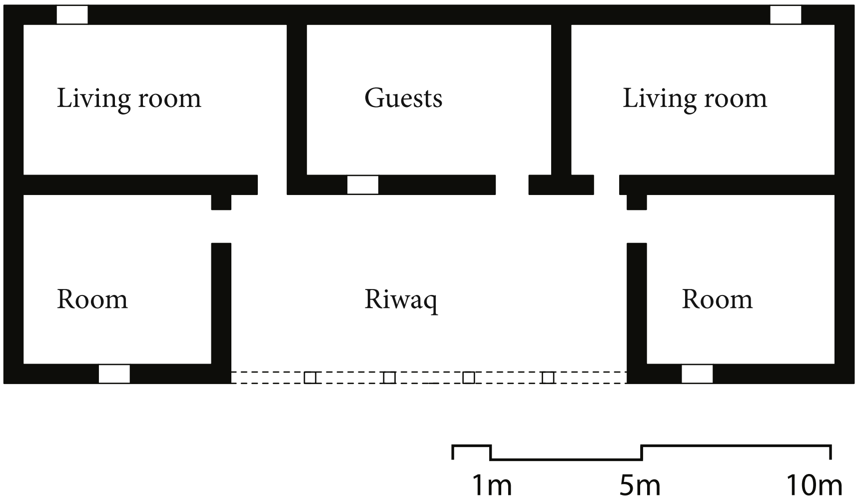
[5]Mühlbauer and Shretah, *Flüchtlingsbauten*, p.24ff.

[6]Karin Pütt. *Zelte, Kuppeln Und Hallenhäuser : Wohnen Und Bauen Im Ländlichen Syrien*. Petersberg: Michael Imhof Verlag, 2005. 280 pp. ISBN: 3-937251-75-8, p.25.

[7]*"Traditional Mediterranean Architecture - Rural House with Court, Syria"*. In: CORPUS, Euromed Heritage, 2013. URL: http://www.meda-corpus.net/arb/fitxes/F1/eng/sy_t01.pdf (visited on 01/03/2022), p.1ff.

[8]Ibid., p.3f.

Traditional Riwaq house
1:200



Pütt, 2005

8.4 Local design

To adapt to the climate in this particular region the following designs for walls and roof are incorporated.

Domestic timber production is low as only 1 % of the country is covered with forests. For this design timber must be imported.[9] Jordan does have limited agriculture with wheat being prominent in northern and central areas on higher altitudes. Straw remaining from the wheat production can be used for the light-loam walls in this showcase.[10]

8.4.1 Walls

Because of the arid cold climate at the location of the refugee camp it is important to have sufficient thermal insulation and thermal mass. Thermal insulation is necessary because during the wet months and winter sub-zero degrees can occur. During these few wet months the walls need to be protected from the annual precipitation. The thermal mass is needed because of the major day/night temperature swings.

To companion for these requirements the walls of the ground floor will be filled with light loam which is a mix of loam and insulating materials. As the wall module structure is bearing the loads of windows and other openings the light loam does not have any load bearing function. All loads from the roof and the floor are handled by the primary structure.

To protect the wall from rain a clay plaster is added with additional water protection provided by the extended roof. As the whole construction is elevated by 30 cm no moisture from the ground can move up into the walls. With regular maintenance the loam is protecting the wood by draining moisture resulting in construction examples lasting for centuries.[11]

The loam is mixed on-site with straw or any other insulating material and water. It is then directly applied into the wall modules. For the placement of the wet light loam moving form boards are utilized. The moving form boards are attached and slide alongside the planks of the module system. To create a frictional connection between the loam and the vertical planks of the module system additional narrow planks need to be added.[12]

The outside of the wall is protected by a 3 cm layer of clay plaster. This plaster layer is necessary to achieve airtightness for the light loam to reduce heat losses. It also adds to the thermal mass needed for temperature buffering. Also the columns and beams of the primary construction of the ground floor need to be covered with clay plaster to protect them from the sun and rain. Reed fabric is added to the primary construction as plaster base to allow the clay to stick better. The structural elements of the main frame in the roof area are protected with a clay slay base paint for durability and to increases the fire

[9] *United Nations Statistics Division - Environment Statistics*. 2010. URL: `https://unstats.un.org/unsd/environment/forestarea.htm` (visited on 22/01/2023).

[10] Helen Metz. *Jordan: A Country Study - AGRICULTURE*. Washington: Library of Congress, 1989. URL: `https://countrystudies.us/jordan/51.htm` (visited on 16/03/2023).

[11] Franz Volhard. *Bauen Mit Leichtlehm*. 8th ed. Basel: Birkhäuser, 2016. ISBN: 978-3-0356-0619-5, p.211.

[12] Ibid., p.87.

resistance of the structure.[13]

On the inside a 1.5 cm clay plaster adds to the ability of regulating moisture and room climate. Additionally it creates a consistent smooth surface and can also be colored for increased individuality.[14]

The heat transmission coefficient λ of light loam depends on the bulk density. Everything less than 1200 kg/m^3 is generally considered light loam. Light loam with a density of 300 kg/m^3 has a λ of 0.1 W/(m K) and a straw content of around 70 %. The resulting dead load of this wall construction is 2.8 kN/m which is below the load assumptions. This mix is only possible if very fatty loam and straw is locally available.[15] The whole construction of the wall with very fat loam and straw creates a U-value of around 0.64 W/(m^2 K) and a phase shift of 9.2 h. The heat storage capacity is 57 kJ/(m^2 K) which is comparable to a two layer brick wall.[16]

Although the soil is reported to be clay rich in the area the actual quality for construction of the local loam in the refugee camp can not be assumed remotely. In case the loam is unusable an alternative would be compressed or stabilized earth blocks to fill the walls. Also fired bricks can be used if available and affordable. Fired bricks can usually not be produced on-site and require industrial processes and transportation. Agricultural production is also low in Jordan due the mostly arid climate. If straw is not available an alternative is expanded clay as insulation in the light loam walls.[17]

Wooden planks with a thickness of 1.5 cm form the walls in the unheated roof area. This reduces the center of gravity and the weight of the overall structure improving resistance against seismic events. See section 8.4.4 for details on the airflow concept.

8.4.2 Roof

The standard roof of this project is a corrugated galvanised iron sheet based roof. Although this roof type is not traditional it is very durable and thus often preferred by the inhabitants.

The extending roof shadows the windows and walls from direct sunlight during summer and allows for solar energy to arrive during cold winter months. It also protects the loam plaster and walls from driving rain.

The roof is not insulated to reduce the weight which is especially important in this seismic active zone. Instead the insulation is directly placed on the ceiling of the ground floor to create a thermal buffering zone between the ceiling of the ground floor and the roof. All available insulation materials can be used because the height is not limited.

As straw is not available well in Jordan an alternative is imported wood fiber insulation plates which come in thicknesses of 30 to 240 mm. The λ is 0.036 W/(m K) and the bulk density is 60 kg/m^3. The resulting U-value for the 240 mm thick version is

[13] Ibid., p.160ff.
[14] Ibid., p.170f.
[15] Ibid., p.200.
[16] Ralf Plag. *U-Wert-Rechner*. URL: `https://www.ubakus.de/u-wert-rechner/` (visited on 04/12/2022).
[17] Gijsbertsen, Kuiper and Borst, *Water Management and Irrigation near Za'atari Refugee Camp, Jordam*, p.11.

0.15 W/(m^2 K).[18] It creates a dead load of 0.14 kN/m^2 which is well within load limits.

During summer this buffer zone can be used to sleep as it cools down faster than the ground floor. As the corrugated galvanised iron sheets are generally very water tight and durable, storage of belongings and goods can happen in this unheated roof space.

8.4.3 Floors

The raised ground floor consists of wooden beams of the secondary structure with OSB plates on top. The space in-between these wooden beams can be insulated. This space allows for an insulation thickness of up to 16 cm. As insulation material wooden fiber insulation boards with a thickness of 16 cm or below can be used. With this thickness the wooden fiber boards have an U-value of 0.26 W/(m^2 K). Metal brackets secure the plates to the secondary structure.[19]

8.4.4 Airflow

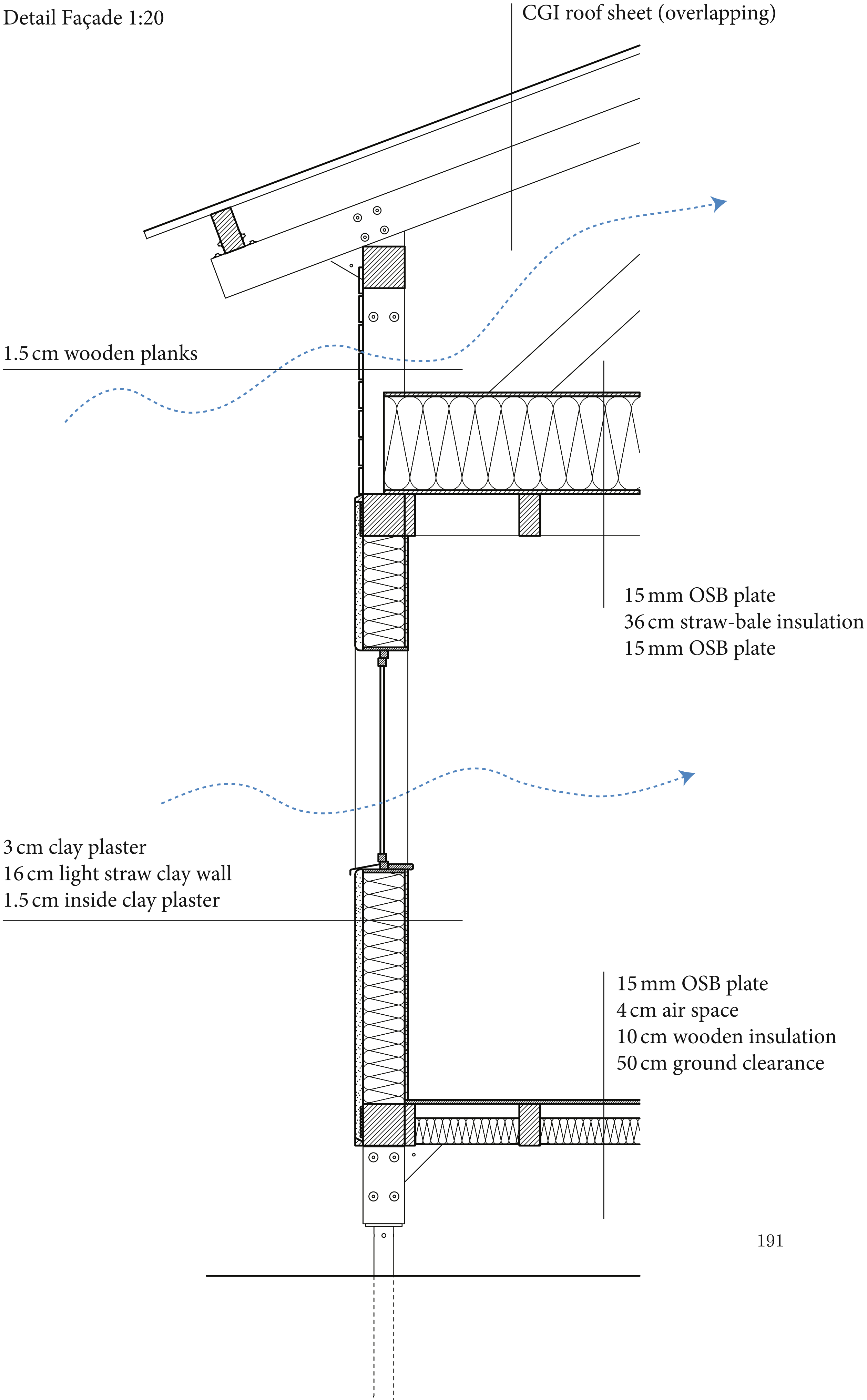
The ventilation concept of this design is to have an increased airflow through the thermal buffer zone in the roof space to cool down the building during the day and to shield the ceiling of the ground floor from direct sun exposure.

The walls of the roof area are not plastered with light loam but with wooden planks which do not having any insulating or buffering effect. This lowers the center of mass and reduces the overall weight of the upper floor. During the hot summer months this roof area allows for good sleeping conditions because of the increased airflow. It also cools down quicker as it does not have a high thermal mass. In winter the space can be used to store dry goods.

During the hot summer days the small windows of the main living area should be closed and only opened at night for ventilation. During the cold period the small windows can minimize the heat losses. Also windows should be facing the covered and shaded Riwaq as much as possible to benefit from this buffering area. The core living area on the ground floor offers good thermal mass to keep the building warm during night time and cool during the day. It is also the only area which can be heated because insulating material is present on all sides.

[18] *STEICOflex 036*. STEICO. URL: https://www.steico.com/de/produkte/daemmung/gefachdaemmung/flexible-daemmmatten/steicoflex-036 (visited on 22/01/2023).
[19] Ibid.

Detail Façade 1:20



8.4.5 Foundation

Because of the clayey soil and the lack of existing concrete foundations earth screws are the best option. If the soil is too clay heavy, mechanical equipment might be needed to insert the screws deep enough into the ground.

Local concrete point foundations would be possible but generally concrete foundations are considered more durable which can create resistance of the local population.

See section 7.1.5 for details about the common foundation types available.

8.4.6 Price

The materials of the kit need to be procured and shipped internationally because Jordan does not have a lot of timber. Nevertheless the drilling and prefabrication of the kit can happen in Jordan.

From the materials needed to finish the walls only the clay can be gathered directly on-site. It is assumed that the needed straw for the light loam walls can be procured domestically.

As foundation ground screws were selected. The screws are 65 € per screw and at least four per unit are needed. See details in section 7.1.5. Also the wood fiber boards used for insulation in the ceiling and the floor need to be procured from abroad. The price for procuring them in Austria are 20 to 35 €/m^2.[20]

The shipping of all the materials required results in around a quarter of a TEU container. The only international port of Jordan is port Aqaba in the Red Sea which makes it unfavourable for shipments from Europe. For a similar route going from West India to the region one TEU was estimated with 2800 € and a delivery time of around 19 days. This results in around 700 € per kit of transportation costs including the truck to the destination. It shall be noted that only one offer was displayed and that shipping prices and durations can vary greatly.[21]

The total price for one unit is calculated as follows:

Item	Unit price	Quantity	Total
Kit	900	1	900 €
Clay	0	1.2 m^3	0
Straw	?	4 m^3	?
Façade planks	20	18 m^2	360 €
Ground screws	65	4	260 €
Wood fiber boards 100 mm	20	14 m^2	280 €
Wood fiber boards 240 mm	35	16 m^2	560 €
Transportation			700 €
Total			3060 €

[20] *STEICOflex 036*.

[21] *Searates Nhava Sheva to Al-Mafraq, Jordan*. Searates. URL: https://www.searates.com (visited on 22/01/2022).

8.4.7 Design

The design shown here is the final extension phase with the maximum size of six units combined together. It is not necessarily the most likely design in this context but it was chosen to show the possibilities with the maximum number of units combined.

The inside area on the ground floor without the space for the Riwaq is 114 m^2 and allows to accommodate an extended family with more than 10 members well. It tries to resemble the idea of a thermal buffer zone from the traditional Riwaq house type with this design. The resulting covered area with around 141 m^2 is slightly larger than a traditional Riwaq house. The space for this construction in the camp is only available when the initial high density is reduced by extending the camp and relocating some of the inhabitants. This is commonly done after the emergency phase.

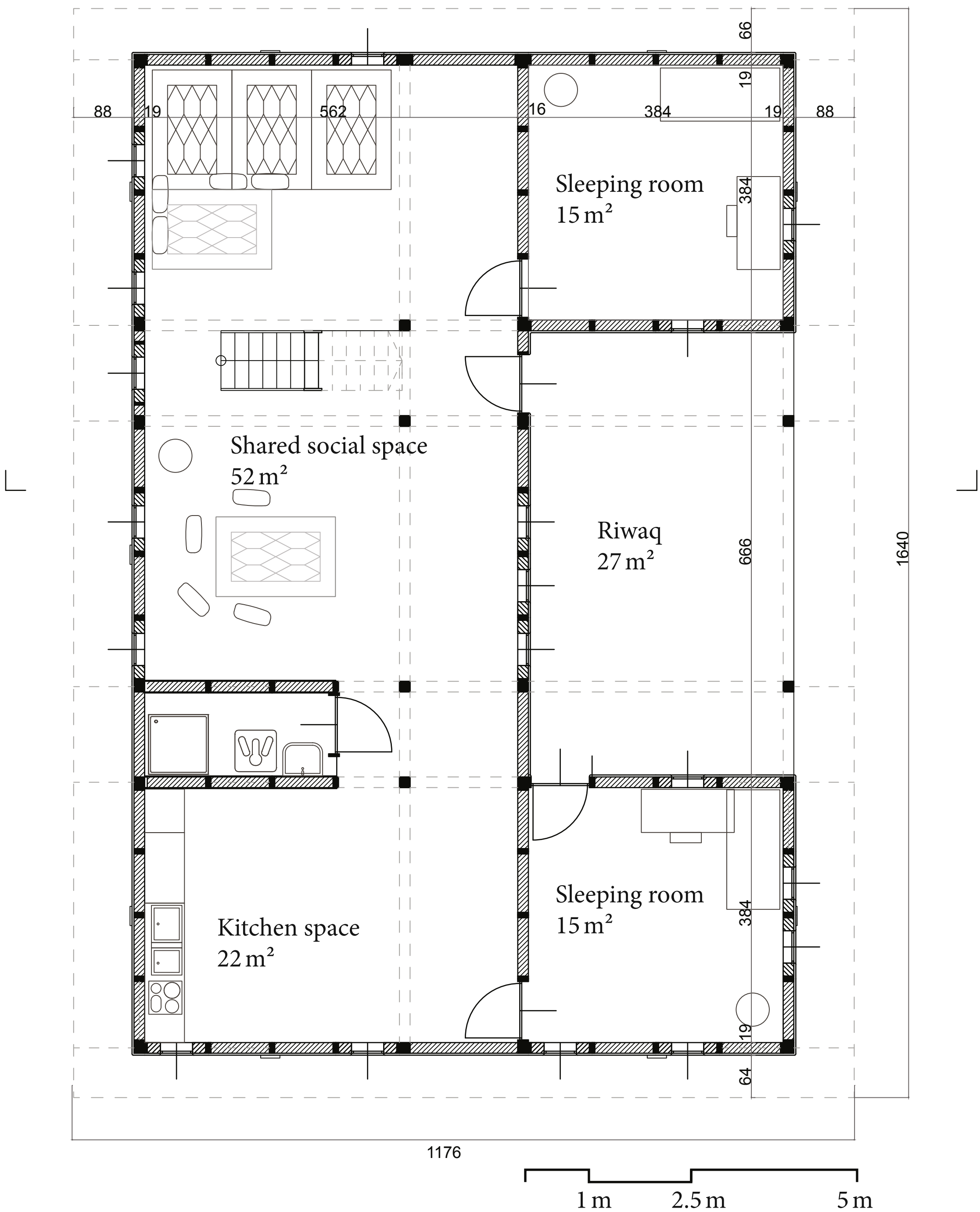
The Riwaq allows to meet up in this semi private space which also provides shading through the covering roof. It also allows for ventilation of the rooms which open up to this Riwaq. In a traditional house the Riwaq is taking up the full length of the building. In this adaption the Riwaq was reduced to just half of the building length. Reasons is that outside walls must be placed on beams of the primary frame in this design.

This shelter consisting of six units can easily accommodate two whole families like the core family and the family of a son. The design features two dedicated sleeping rooms and one big shared social space. During summer the upper floor connected with a staircase can be used for sleeping. The upper floor can be used as storage all year long.

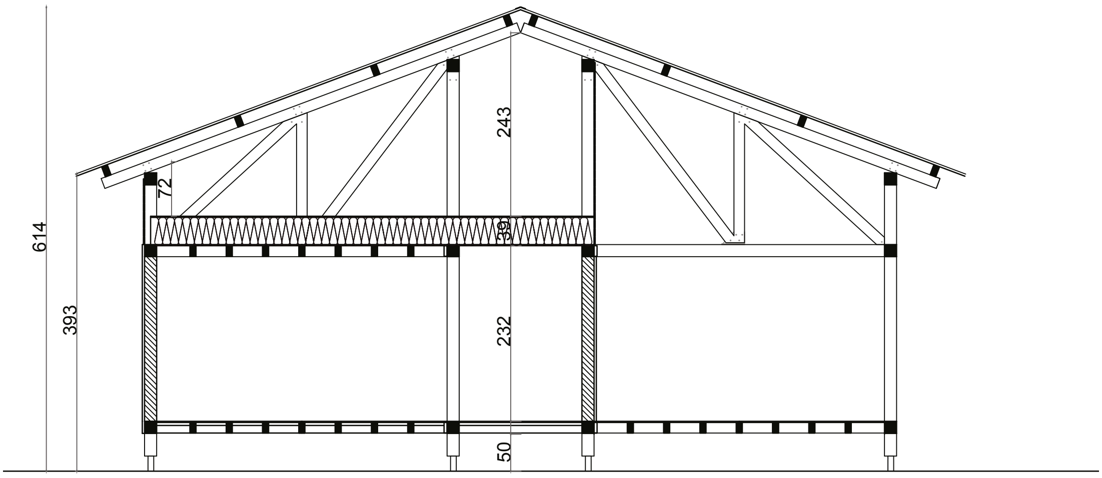
The in-between space between two units is used to place a sanitary module including shower and toilet with a septic tank underneath. See section 7.6 for details. The sanitary module of this design is a huge upgrade because as of 2015 only 14.4 % of the inhabitants had access to a private toilet.[22]

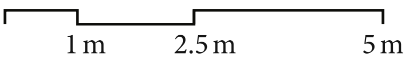
[22] *Jordan - Al Za'atari Refugee Camp, Access to Suitable Private Toilet - December 2015 - Jordan — ReliefWeb*. 25th Feb. 2016. URL: https://reliefweb.int/map/jordan/jordan-al-zaatari-refugee-camp-access-suitable-private-toilet-december-2015 (visited on 16/03/2023).

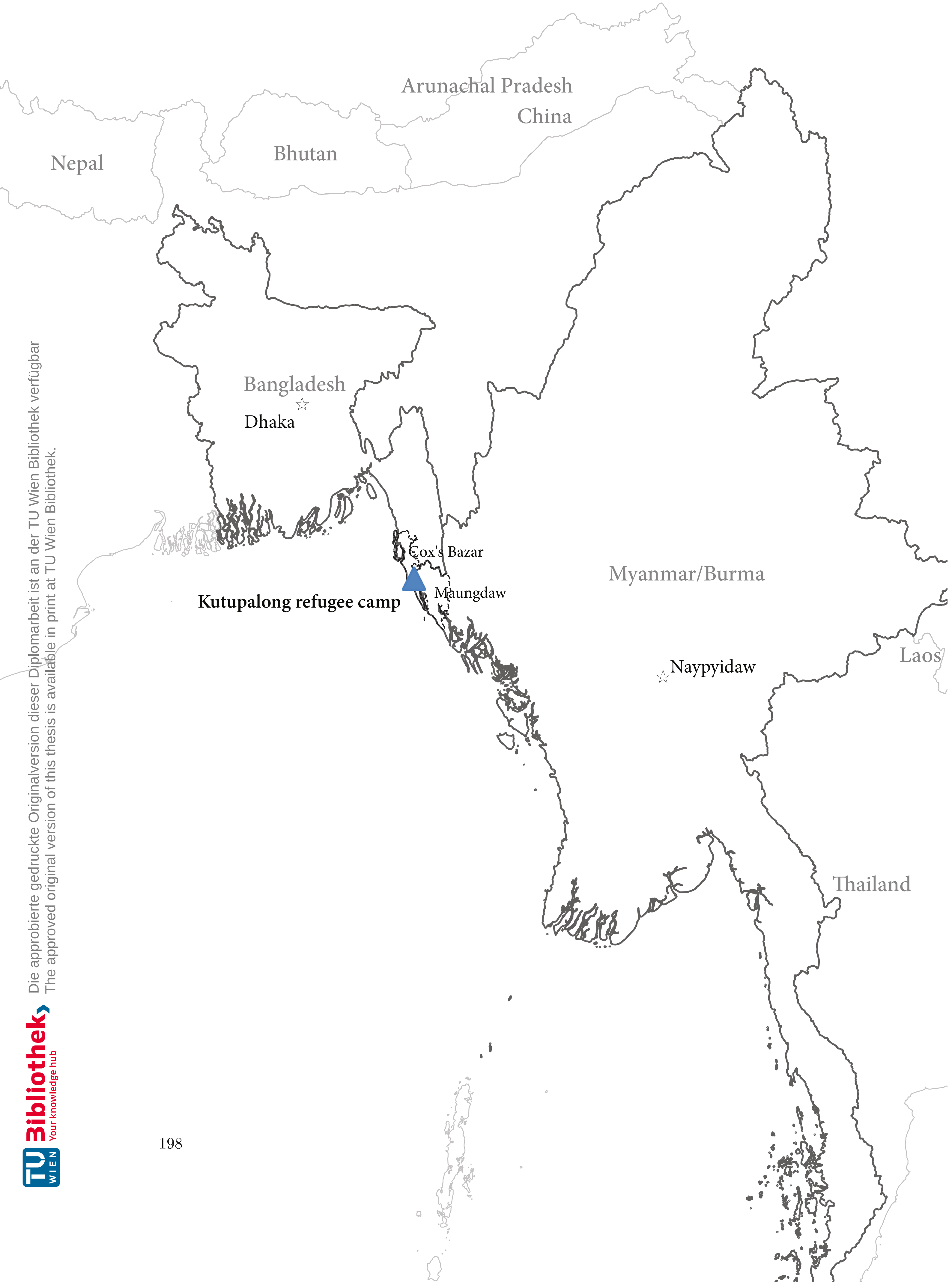
Detail Plan 1:100



Section 1:100






Arunachal Pradesh
China
Nepal
Bhutan
Bangladesh
Dhaka
Cox's Bazar
Maungdaw
Kutupalong refugee camp
Myanmar/Burma
Naypyidaw
Laos
Thailand

Chapter 9

Bangladesh

9.1 Refugee situation

Since the year 1990 members of the Rohingya muslim minority in Myanmar are displaced systematically by the military to Bangladesh.

Between 25th August, 2017 and 1st of October an influx of more than 509 000 Rohingya refugees from Myanmar to Bangladesh has been reported. On the shelter side it was pointed out that the local supply chain can not provide that much bamboo and that other options must be evaluated to reduce environmental effects like deforestation.[1]

The most recent displacement wave started on 25th July, 2022 resulting in a displacement of more than 742 000 within the first three months.[2] According to UNHCR more than 900 000 people fled Myanmar to Bangladesh in total. The current focus in the shelter sector is to maintain and upgrade existing shelters. In some areas new shelter deployments adjacent of the camps still remains a priority.[3]

9.2 Kutupalong refugee camp

The Kutupalong refugee camp managed by UNHCR is the largest refugee camp in the world covering over 14 km^2. It is located in Cox's Bazaar district, Chittagong Division, Bangladesh and houses over 610 000 displaced in around 22 camps. Because of the sloped terrain construction of dwellings and infrastructure is difficult. The area is subjected to heavy rainfalls during the wet season.[4]

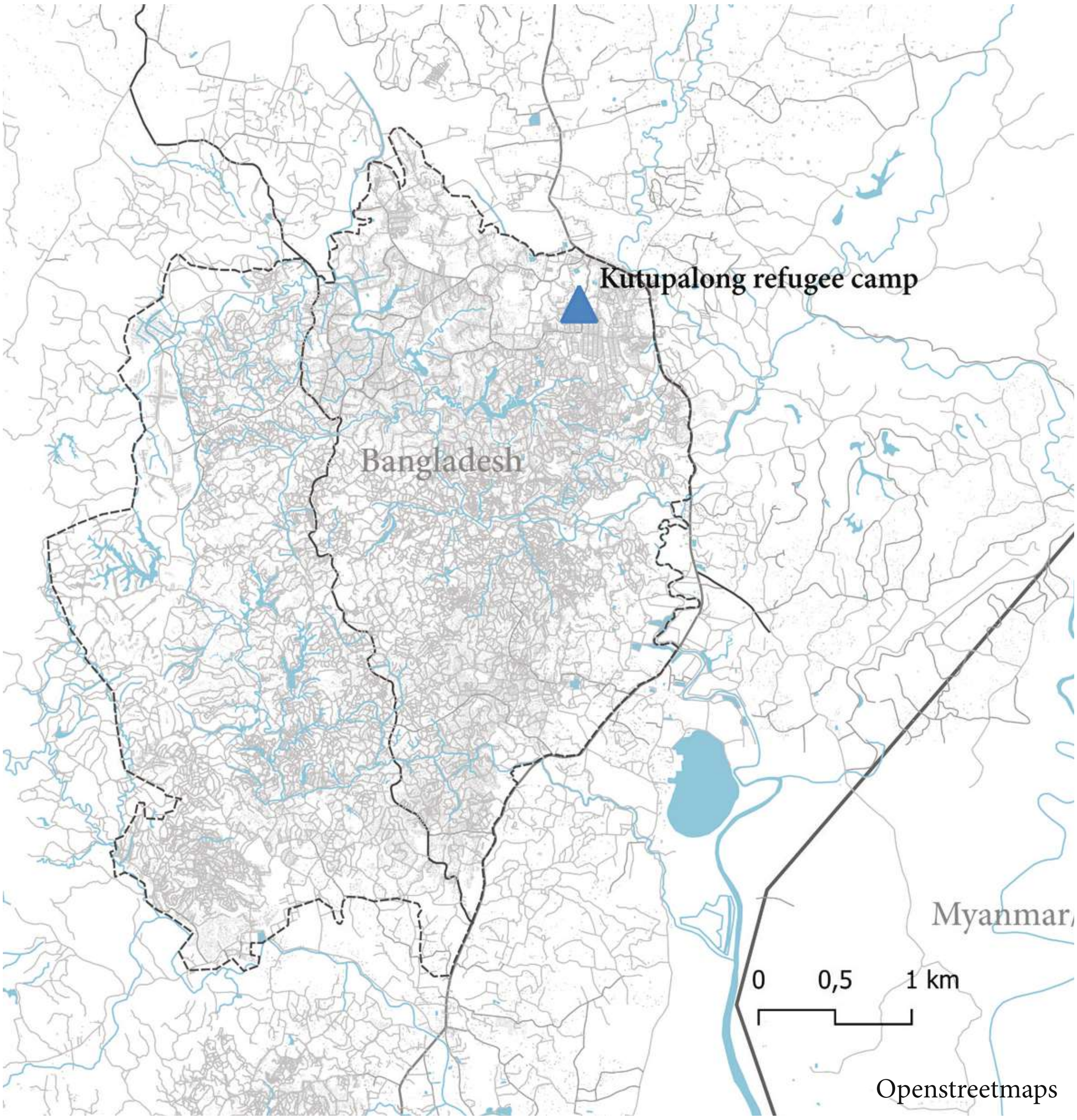
[1] *Bangladesh: Humanitarian Response Plan - September 2017 / February 2018 - Rohingya Refugee Crisis.* Inter Sector Coordination Group, 3rd Oct. 2017. URL: `https://reliefweb.int/report/bangladesh/bangladesh-humanitarian-response-plan-september-2017-february-2018-rohingya` (visited on 26/01/2023).

[2] *Rohingya Emergency.* UNHCR. URL: `https://www.unhcr.org/rohingya-emergency.html` (visited on 04/11/2022).

[3] *2022 Joint Response Plan: Rohingya Humanitarian Crisis (January - December 2022) - Bangladesh.* UN OCHA, 29th Mar. 2022. URL: `https://reliefweb.int/report/bangladesh/2022-joint-response-plan-rohingya-humanitarian-crisis-january-december-2022` (visited on 26/01/2023), p.27.

[4] *Joint Government of Bangladesh - UNHCR Population Map as of 31 May 2022.* UNHCR Operational Data Portal (ODP). 31st May 2022. URL: `https://data.unhcr.org/en/documents/details/93465` (visited on 04/11/2022).

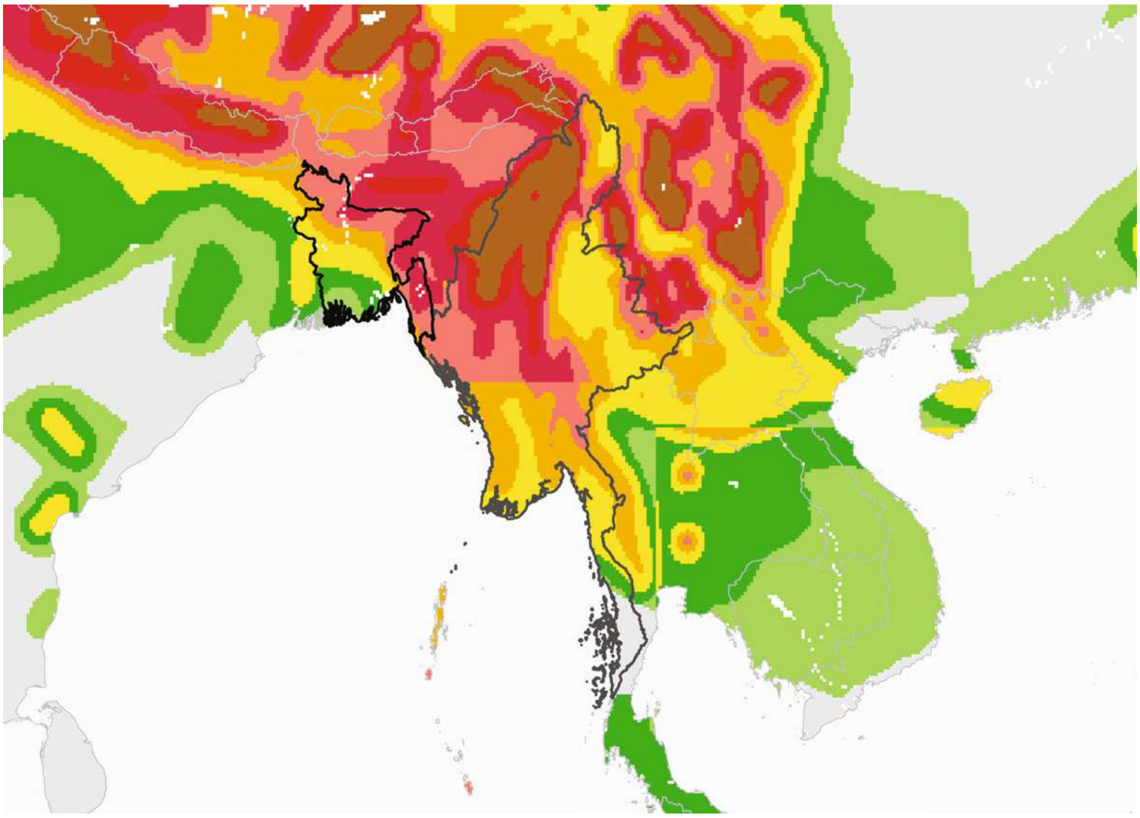
Because of poor infrastructure and flood protection the camp is subjected to threats from water, wind, fire and diseases. Heavy monsoon rains in 2019 led to the destruction of 6000 shelters in the camp and the displacement of 20 000 refugees. During another occasion in 2021 a fire destroyed more than 9500 shelters rendering 45 000 refugees homeless.[5]
During the existence of the camp multiple projects to upgrade and educate for better shelter structures have been performed. The UN Central Emergency Response Fund published a picture guide on shelter placement and techniques to make the structure stronger. The guide visually shows the importance of hill slide drainages, plinths, spacing between units and secure bamboo connections.[6]



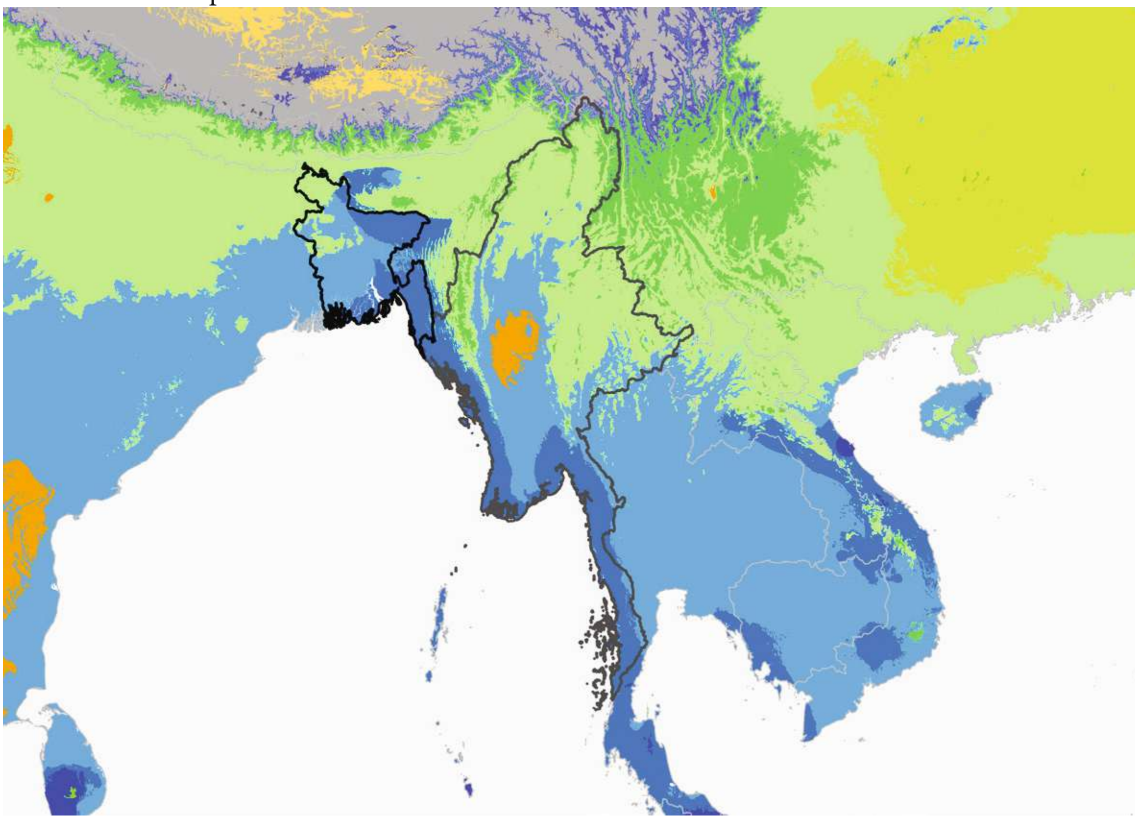
[5]Christian Dela Cruz. *Sheltering in Camps: Kutupalong and Balukhali Camps, Bangladesh*. Better-Shelter. 18th Apr. 2022. URL: `https://bettershelter.org/sheltering-in-camps-kutupalong-and-balukhali-camps-bangladesh/` (visited on 04/12/2022).

[6]*Basic Guidance on Shelter Upgrading*. UN CERF, 12th Sept. 2018. URL: `https://sheltercluster.org/coxs-bazar-crisis/documents/basic-guidance-shelter-upgrading` (visited on 04/12/2022).

Earthquake risk map



Climatic zone map



9.3 Climate & Tradition

The climate in the coastal area of Myanmar and Bangladesh is according to Köppen-Geiger a tropical monsoon climate (Am). This climate zone has an average temperature above 18 °C during every month and a dedicated wet season. Most of Bangladesh is receiving more than 2000 mm of annual precipitation. The Rohingya population is mostly living in the Maungdaw district of the Rakhine state of Myanmar. Mostly members of this group were displaced to the Chittagong division in Bangladesh.[7]

Bangladesh is prone to floods and landslides which happen annually and affect over 60 % of the country. Coastal areas can also be effected by strong cyclones on average every three years. Earthquakes are not common in the south eastern areas close the Myanmar which are the areas of interest for this work.[8]

Traditional architecture layouts in Bangladesh consists of separate houses oriented towards an interior courtyard (Uthan) and dedicated to functions elevated on mounds to prevent flooding. Gender and privacy separation are of utter importance. All the structures together with external sanitary infrastructure form the homestead. As in many developing countries there is a big rural exodus to the cities. This is generally driven by the lack of work but also by more modern building standards in the cities, mostly consisting of higher concrete block apartment buildings.[9]

Global influence created a trend to move to newer Pucca houses made from brick with concrete roofs. These houses do not perform well in the wet and humid climate.[10] Still as many as 75 % of the rural population is living in simple Kutcha houses which are mainly built from natural resources like earth, bamboo and timber. Those houses are traditionally covered with thatch but recently replaced with corrugated galvanised iron sheets. The Kutcha houses were choose as example for this showcase as they are climate adapted and often constructed by the inhabitants themself. Using known building techniques like bamboo walls allow the inhabitants to perform maintenance tasks independently.

The size of the buildings varies from 3.6×3 m to 7.3×4.5 m resulting in useable sizes from around 11 to 33 m^2. Houses can have two stories where the upper level is commonly used for sleeping and storage. Traditionally bamboo and timber is used as main materials for the structural frames. Stabilized earth is commonly used to create 30 cm high plinths where the buildings are sitting on.[11]

In the Chittagong division in Bangladesh, mostly hosting refugees from Myanmar because of its proximity, earth plinths are not common because of the hilly terrain. Mostly light materials like bamboo, timber form the frame of the raised buildings. Bamboo structures commonly suffer damages from high wind speeds. Walls are covered with thatch and roofs commonly with corrugated galvanised iron sheets or thatch. Inside furniture is often elevated to create extra distance to potential flood water.[12]

[7] Sevillano Gutiérrez, Crété and Braedt, *Detailed Shelter Response Profile: Bangladesh*, p.10f.

[8] Ibid., p.12.

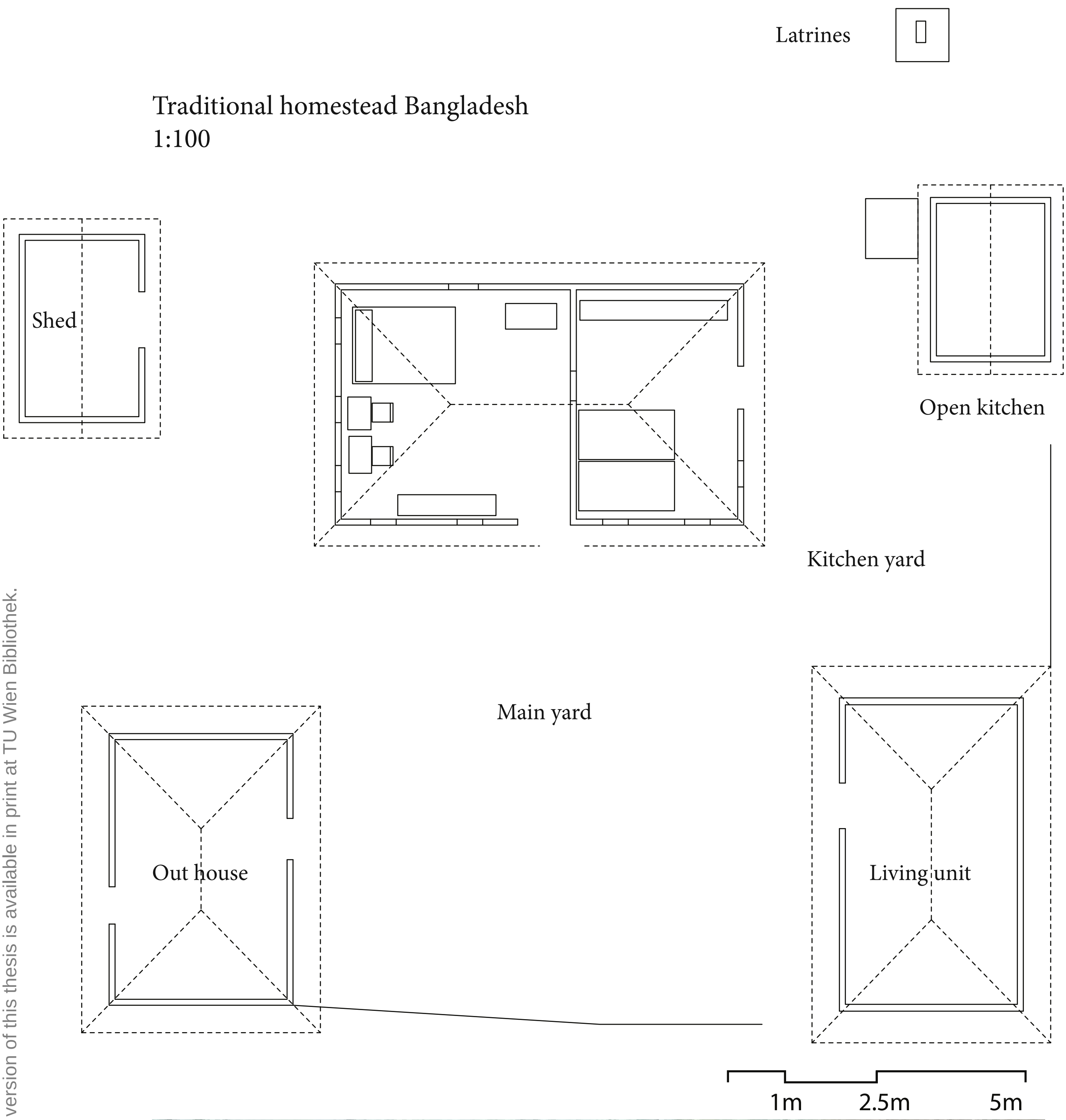
[9] Dewan Hasan. *"A Study of Traditional House Forms in Bangladesh"*. MA thesis. Bangladesh University of Engineering and Technology, 1985; Iftekhar Ahmed. *"The Courtyard in Rural Homesteads of Bangladesh"*. In: *Vernacular Architecture* 43.1 (Oct. 2012), pp. 47–57. ISSN: 0305-5477.

[10] Sevillano Gutiérrez, Crété and Braedt, *Detailed Shelter Response Profile: Bangladesh*, p.22ff.

[11] Ibid.

[12] Ibid., p.29f.

Traditional homestead Bangladesh
1:100



Hasan 1985

9.4 Local design

In the local climate where temperatures never drop below zero no thermal insulation is required. Also thermal mass is not beneficial as the temperature does not swing much during day and night. Because of the high humidity a good ventilation concept mainly focusing on an increased airflow is necessary. See section 2.6 for climate adapted construction priorities.

The wet climate can also negatively affect the timber beams of the core structure requiring chemical treatment. Elevating the structure on metal ground screws reduces the termite risk. If water damage happens to the main structure the lower separate parts of the four main columns can be easily replaced.

Only 11 % of land-use in Bangladesh is forests for timber production. Timber in Bangladesh is mostly hardwood like Teak (Tectona grandis) and Sal (Shorea robusta). Both have a similar compression strength compared to spruce but have a higher density of around 680 kg/m^3 for Teak and 800 kg/m^3 for Sal. Sal wood is generally better available and cheaper than the slow growing Teak. Other wood types available are Eucalyptus and Acacia, planted because of their fast growing speeds. There is a significant amount of timber imported from Myanmar. This design was not calculated for Eucalyptus but initial research showed that Eucalyptus is stronger than the spruce the calculation was done with. Calculating the structure for the use with Sal and Eucalyptus is left open for further work.[13]

Materials like bamboo and reed are commonly available directly on-site. Because of the size of the refugee camp dangers of local deforestation must be paid attention to.

9.4.1 Walls

Traditionally walls are made from perforated bamboo or reed mats which allow for plenty ventilation and light. Sometimes the lower areas of the wall are built with earth.[14]

Commonly the density of the material is varied throughout the height of the wall. Upper areas have less material to allow for a better ventilation by increasing the porosity. The middle area is often more dense as it provides more visual privacy.[15]

In newer buildings also corrugated galvanised iron sheets are used as walls. Because of the high price commonly only the lower sections of the walls are made with corrugated galvanised iron sheets. The sheets stop humidity from moving upwards.[16]

For this location this work suggest a bamboo façade for the walls of the lower and upper floor. The module frame helps to create a substructure from bamboo rods holding the bamboo mats. Bamboo is commonly available on-site and the bamboo mats are also a local product which does not require complex machinery during production. Because the whole structure is already elevated no moisture from the ground can move up the bamboo

[13] A Awal, Md Rahman and A Adham. *"Properties of Some Selected Timbers in Bangladesh"*. In: *Bangladesh Journal of Agricultural Engineering* 11 (1st Jan. 2000), pp. 59–65.
[14] Sevillano Gutiérrez, Crété and Braedt, *Detailed Shelter Response Profile: Bangladesh*, p.29.
[15] Ibid., p.44.
[16] Ibid., p.44.

mats. Although the bamboo mats are not extremely durable they can be easily replaced during regular maintenance.

There are multiple bamboo connection options available, each with different strengths, complexity and durability. For this showcase pegs and ropes are chosen because they offer a good compromise between strength and low-tech. They do require pre-drilled holes which can happen directly on-site.[17]

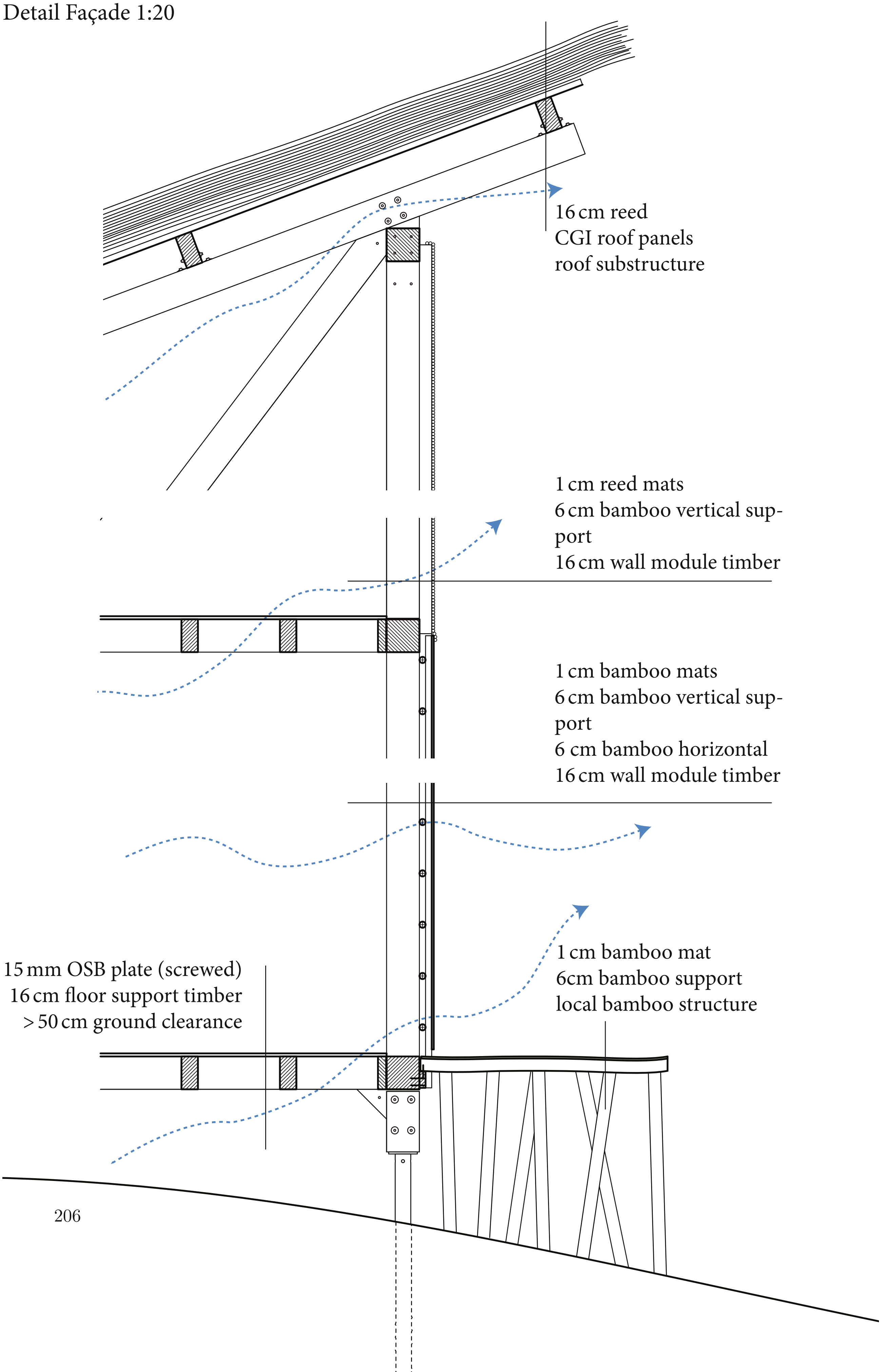
Termites and borers attack bamboo frequently which is commonly used as construction material in Bangladesh. Bamboo can be treated by soaking it in muddy water or smoking it over fire. Untreated bamboo in contact with soil and without covering lasts only for one to three years. Treated bamboo can last up to 20 years even when deployed in humid areas. Common chemical treatments include soaking in diesel and mixtures of solutions based on copper and chrome.[18] By elevating the whole structure using metal screws the termite risk can be reduced.

Because of the high wind risks metal rod bracing must be applied to at least three wall modules on different sides.

[17]Dave Hodgkin. *Humanitarian Bamboo Guidelines.* 2018, p.149.

[18]Iftekhar Ahmed. *Handbook on Design and Construction of Housing for Flood-Prone Rural Areas of Bangladesh.* Asian Disaster Preparedness Center, Jan. 2005. 93 pp. ISBN: 984-32-2163-X. URL: `https://sheltercluster.org/bangladesh/documents/handbook-design-and-construction-housing-flood-prone-rural-areas-bangladesh` (visited on 04/12/2022), p.36ff.

Detail Façade 1:20



9.4.2 Roof

There are two common roof types in Bangladesh. Traditional roofs are made from reed and newer roofs mainly from corrugated galvanised iron sheets.

For corrugated galvanised iron sheets the corrugation process can happen locally in the country but prices for good quality sheets are considered high for rural populations. For detail see section 7.10.3.

Thatch roofs made out of palm leaves, reed and grasses are the most common traditional type of roof covers. They provide good insulation and ventilation with very low cost and resource usage. Because of the higher maintenance effort they lost popularity. Thatched roofs are prone to be attacked by termites and can be a hideout for mosquitoes.[19]

One way to combine corrugated galvanised iron sheets and thatched roofs is to place the thatch on top of the corrugated galvanised iron sheets. By doing so the noise of rain is reduced and the heat up caused by the direct sun exposure is limited. Even when the thatched roof becomes penetrable as a result of low maintenance the shelter stays dry because of the underlying corrugated galvanised iron sheets.[20]

The main structural frame can not take wind force during strong cyclones because of the size of the roof area. A tropical storm can reach sustained wind speeds of 177 km/h or higher.[21] To protect the structure and material in case a strong cyclone is predicted the corrugated galvanised iron sheets should be detached and stored on the floor of the roof level to avoid wind-uplift and damages. During the cyclone the stored panels should be additionally covered with plastic tarpaulin to prevent water damage to the main living area.

The roof space can be used as separate room for storage or sleeping or it could provide additional volume to the main room. In case no ceiling and OSB boards are put additional horizontal steel bracings need to be placed if the specific area is prone to high wind loads. For details about bracing options see section 7.1.4.

9.4.3 Floors

The floor can be formed of OSB plates or bamboo mats if available. For bamboo mats a bamboo rod substructure needs to be constructed. The OSB plates give shear resistance to the floor but might degrade because of the high humidity. Below heavy furniture the floor should be reinforced with OSB plates.

As there is no need for a floor insulation or thermal mass the space between the floor structure can be left empty.

9.4.4 Airflow

To allow for a good airflow walls and floor are both made of porous materials like bamboo mats. This allows the wind to penetrate the building. Additionally hot air moves up and

[19] Sevillano Gutiérrez, Crété and Braedt, *Detailed Shelter Response Profile: Bangladesh*, p.45.
[20] Ibid., p.44.
[21] *Tropical Cyclone Climatology*. National Hurricane Center. URL: `https://www.nhc.noaa.gov/climo/?text` (visited on 20/03/2023).

is guided by the mono pitched roof to the highest point where it escapes. When two units are combined such that a double pitched roof is formed, rain proof outlets must be placed close to the ridge to allow hot air to escape.

In case the roof area is used as dedicated space with a ceiling between ground and roof area, porous material should be used for the floor to allow hot air to move up.

Windows allow to regulate the airflow and allow to reduce it at night time during the colder dry season.

9.4.5 Foundation

Traditionally the timber columns lifting the building up are directly in contact with the ground resulting in the degradation of the wood. With the better availability of concrete the columns are nowadays placed on individual concrete foundations called Katla.[22]

For this location this work suggest to utilize metal ground screws as foundation if available. Long ground screws help to erect the shelter in this hilly terrain. The raised building also provides a better flood protection. Details about the foundation are given in section 7.1.5. Ground screws of the G-pro series from GSPillar can be extended by units of 1 m with their modular system. Without extensions the longest screws available are around 3 m of length.[23] Additional measurements like building and maintaining water drainages are required to protect the structure against landslides.

With light walls cladded with bamboo mats the ground pressure is low. Also no insulation or heavy materials for thermal mass add to the ground pressure.

9.4.6 Price

The market price for timber is hard to determine because most of the wood is grown in home gardens and used locally. We assume the normal unit kit price with wholesale wood prices from India. India and Bangladesh share a land border allowing for truck transportation of the wood.

As foundation ground screws were selected. The screws are 65 € per screw and at least four are needed. See details in section 7.1.5.

The walls are covered with local bamboo mats which can be produced directly on-site by the inhabitants. Also the sub structure for the floor can be created from local bamboo rods.

The total price for one unit is calculated as follows:

[22] Sevillano Gutiérrez, Crété and Braedt, *Detailed Shelter Response Profile: Bangladesh*, p.29.
[23] *GSPillar G-PRO 89 EXTENSION x 3.5 Mm.* Groundscrews.shop. URL: `https://groundscrews.shop/product/g-pro-extension/` (visited on 04/12/2022).

Item	Unit price	Quantity	Total
Kit	900	1	900 €
Bamboo rods	0	?	0
Bamboo mats	0	18 m^2	0
Ground screws	65	4	260 €
Transportation			?
Total			1160 €

9.4.7 Design

The design was inspired from the traditional homesteads by separating different functions to different units. Only the main building consists of two units combined together. One of the reasons is that with difficult hilly terrain it is harder to create one large structure than multiple small ones. Using multiple dedicated units an inside courtyard is formed naturally providing another layer of privacy which is important for the local Muslim culture. Multiple smaller units also help to maximise the airflow through the buildings.

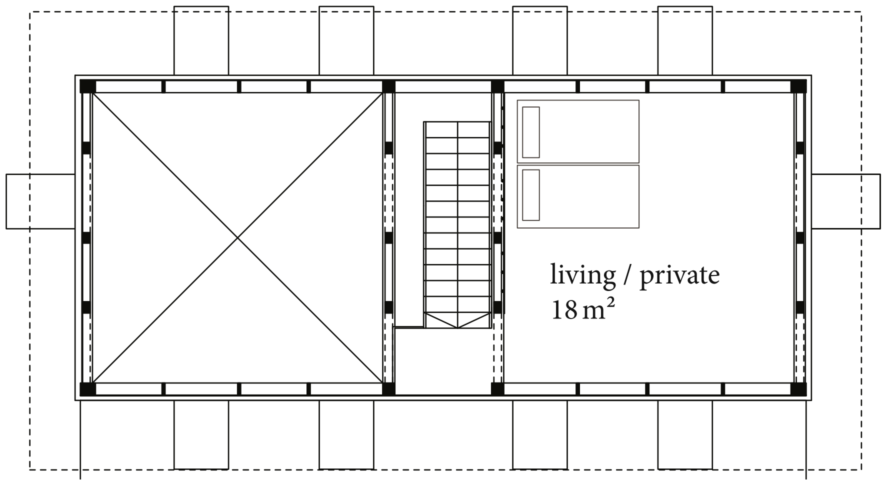
The resulting design offers 79 m^2 of living space. Half of the space of the main unit has a dedicated second floor. With two separated bedrooms two family branches like the family of the son and the parents can live together in this structure. A covered but open kitchen unit with 14.7 m^2 allows to cook in this space during summer and winter months. An additional guest unit allows for relatives to stay over or to have gatherings with non-family members.

A bathing module is placed in the in-between space between the two units of the main building. The toilet is commonly located in a dedicated shed on the edge of the homestead with a septic tank bellow. If possible the tank should be lower to not contaminate the soil and water around the main living unit. Dry toilets like in this design require very short distances to the septic tank. With an existing waste water network an internal toilet can be placed in the sanitary module.

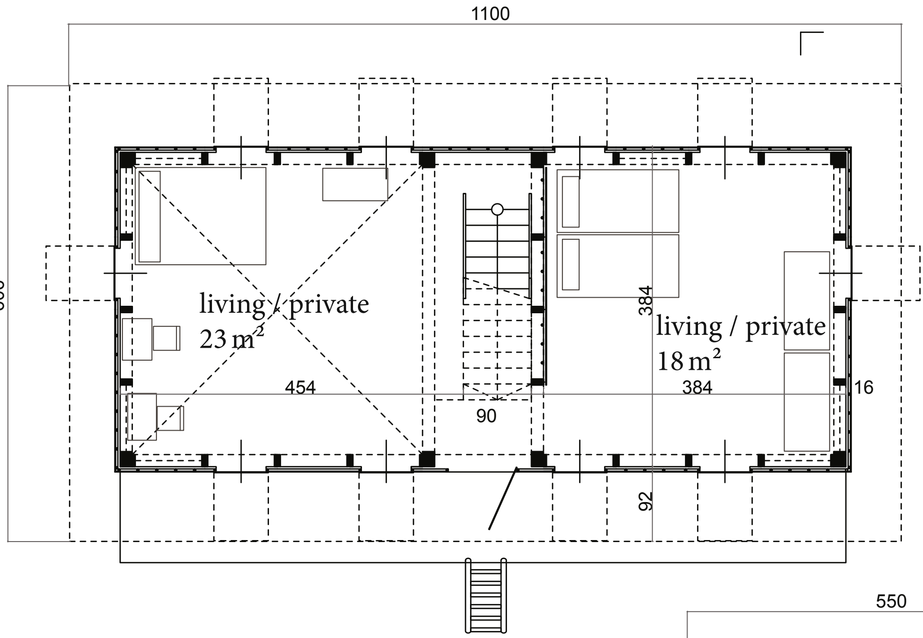
The main living unit features a terrace on the front facing the courtyard. During the monsoon season the earth can be quite muddy and an elevated terrace allows to perform outside work in a dry environment. The terrace is built entirely from local bamboo. It gives an additional of 10 m^2 of usable space. If this partially covered working space is not sufficient a dedicated terrace unit without walls can be added.

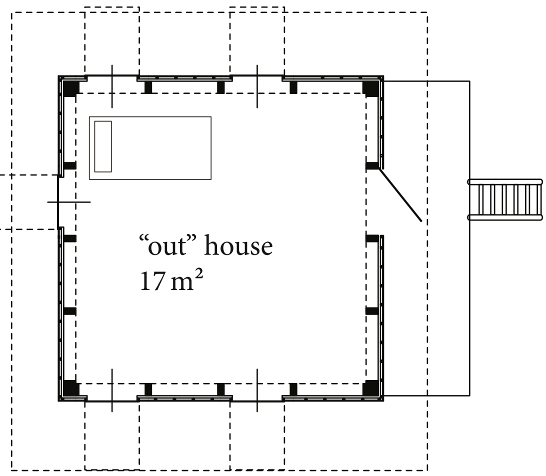
Detail Plan 1:50

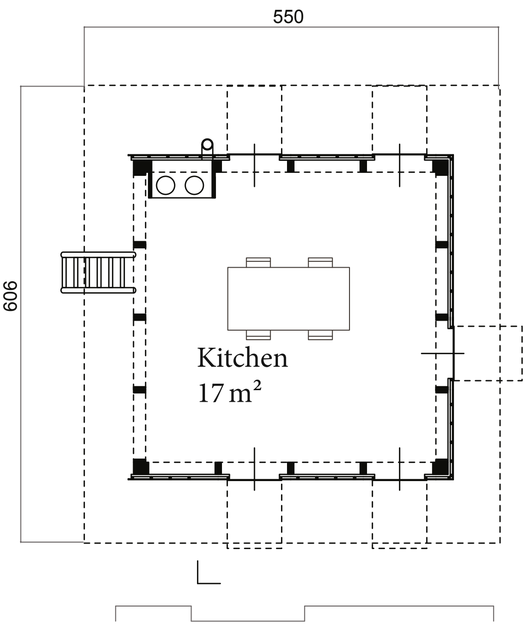
upper floor



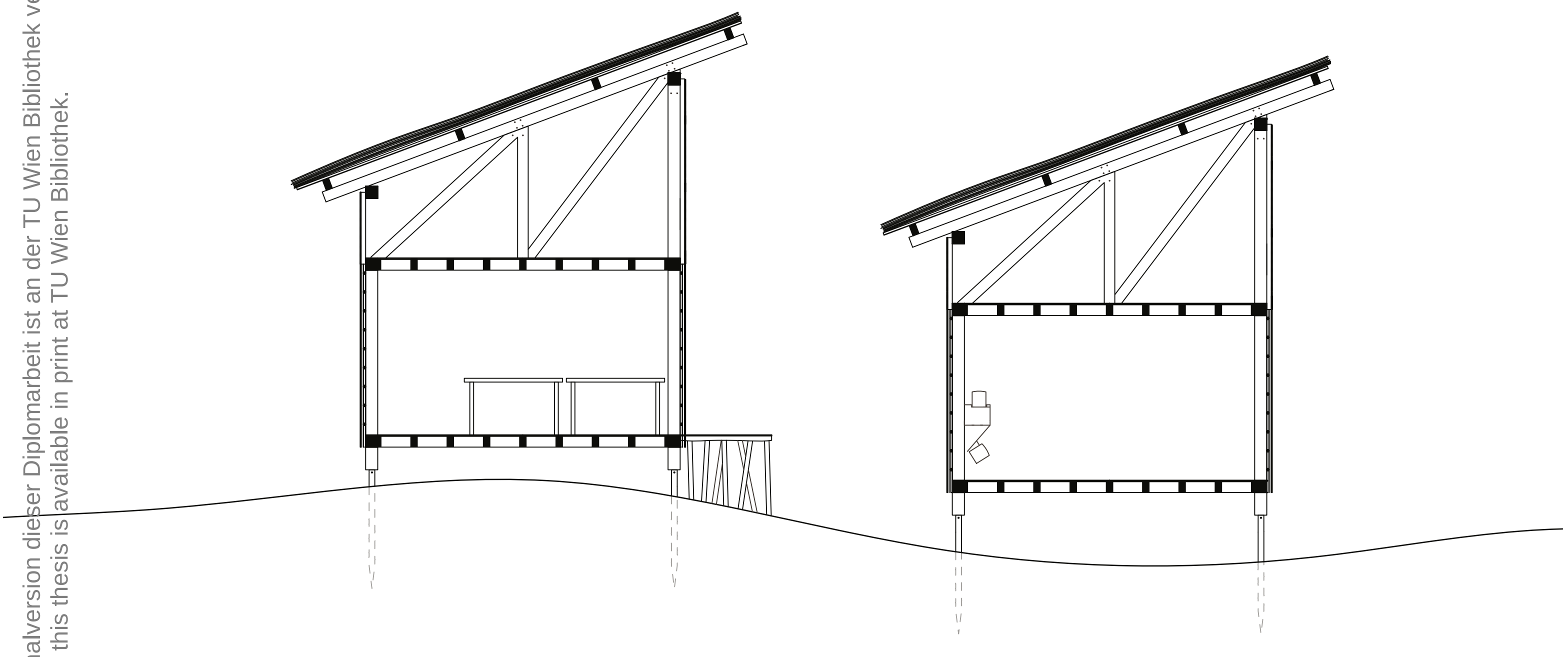
ground floor

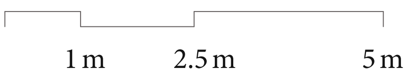






Section 1:50






Estonia
Latvia
Lithuania
Belarus
Russian Federation
Poland
Kyiv
Ukraine
Slovakia
Hungary
Moldova
Romania
Bosnia and Herzegovina
Serbia
Montenegro
Bulgaria
Georg
North Macedonia
Albania
Greece
Türkiye

Chapter 10

Ukraine

10.1 Refugee situation

As of beginning of 2023 UNHCR reports a total of five million refugees who have fled Ukraine to mostly neighbouring countries with Poland alone counting 1.5 million refugees.[1]

The UNHCR delivery update from 28th Dec. 2022 estimates the number of internally displaced people with 5.91 million. While in total UNHCR reached around 4 million people only around 150 000 received shelter support for damaged homes. Delivery of shelter kits is mainly conducted with trucks as the road infrastructure is still intact.[2]

Even before the recent invasion of Russia to Ukraine in 2022 the conflict in the Donbas region was leading to internally displaced people since 2014. No big refugee camps are operated in Ukraine and the local Caritas sections provide support for people in need of shelter. Also it is assumed that many internally displaced can rely on family coping mechanisms by finding shelter at the houses of relatives distant from the conflict zones.[3]

UNHCR is operating its *multi-purpose cash assistance for conflict-affected population* program in Ukraine supporting single headed families and elderly from regions directly affected by the conflict. Also people returning home to the mentioned areas are subjected to 135 € per household member per month.[4]

[1] *Ukraine Refugee Situation.*

[2] *Ukraine Emergency: Operational Response and Delivery Updates.* Global Focus. 28th Dec. 2022. URL: https://reporting.unhcr.org/document/3941 (visited on 03/02/2023).

[3] *List of Organizations Ready to Provide Shelter.* UNHCR Ukraine. URL: https://help.unhcr.org/ukraine/list-of-organizations-ready-to-provide-shelter/ (visited on 03/02/2023).

[4] *Multi-Purpose Cash Assistance for Conflict-Affected Population.* UNHCR Ukraine. URL: https://help.unhcr.org/ukraine/multi-purpose-cash-assistance-programme-for-idps/ (visited on 03/02/2023).

10.2 Climate & Tradition

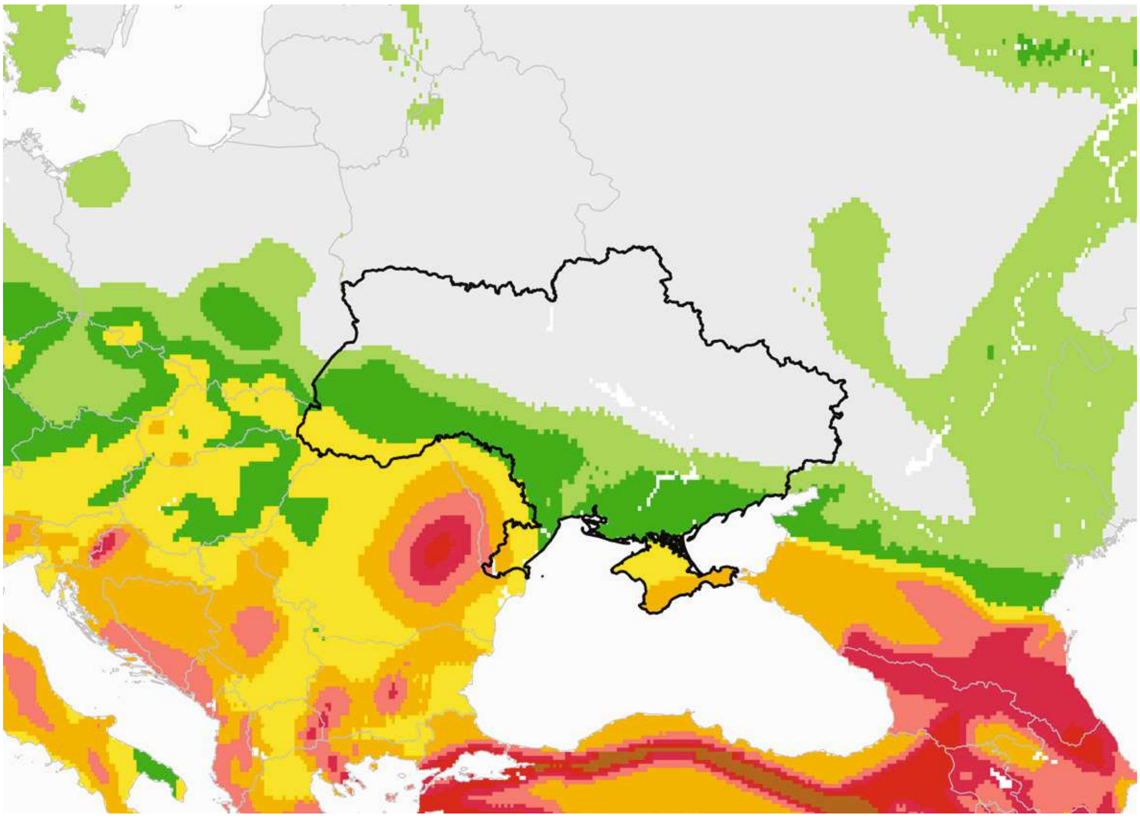
The climate in Ukraine is mostly cold, without a dedicated dry season and with warm summers (Dfb). At eastern areas bordering with Russia the climate is similar but with hot summers (Dfa). The Krim and around belongs to a cold arid step climate (BSk). Parts of the country covered with the Carpathian Mountains in the very west feature an all-year cold climate (Dfc). See section 2.6 for details.

Except for the Krim and areas bordering with Romania Ukraine is in a zone with low earthquake risks. Earthquake classifications and implications are give in section 2.7.

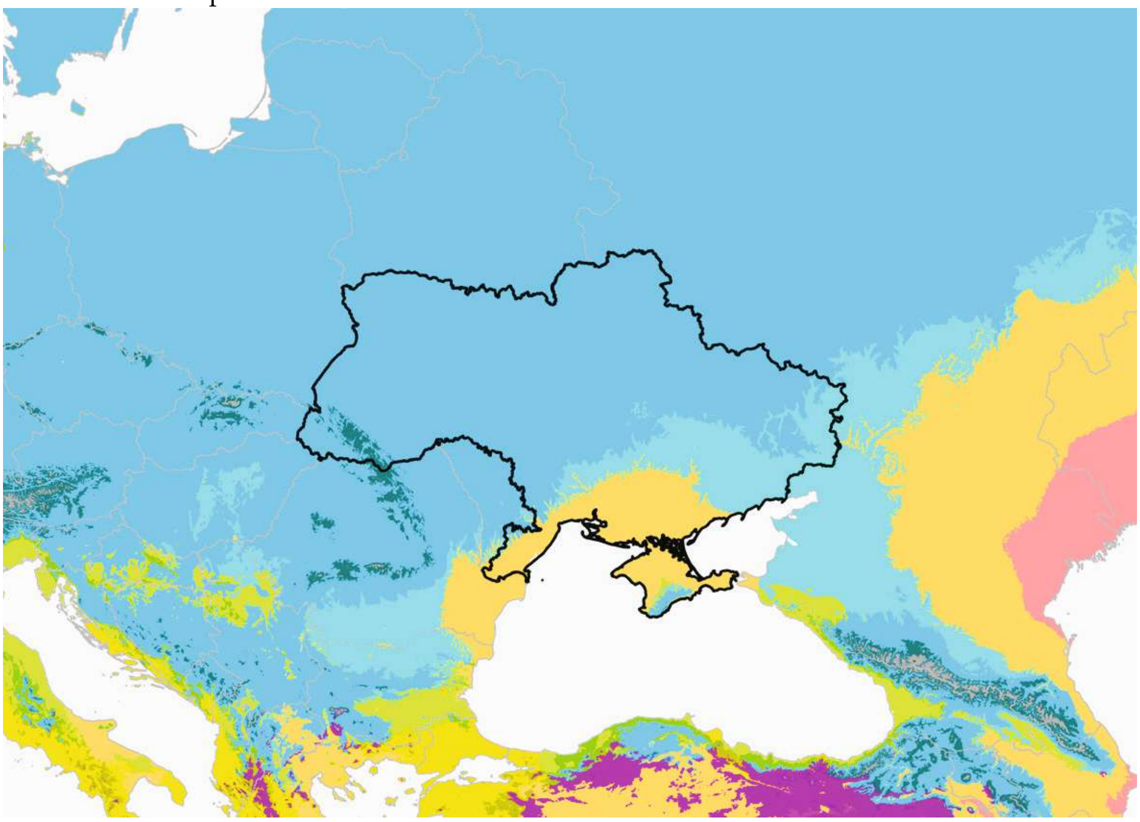
Traditional countryside architecture is reported to be houses built with lumber and covered with shingles for the wood rich areas in the mountains in the west. The southern step regions consist of houses built with clay mixed with straw and thatched with reed or straw. In all Ukraine the vernacular houses were divided into two rooms, one for living, one for storage and a central hallway connecting them.[5] A picture research on war damaged Ukrainian rural houses in the southern regions showed that small single story houses built from brick are prevalent. Common roof material is corrugated galvanised iron sheets. In depth publications about this mostly anonymous rural architecture are only available in Ukrainian language.

[5]Volodymyr Hodys and Bohdan Kravtsiv. *Folk Architecture*. 1984. URL: http://www.encyclopediaofukraine.com/display.asp?linkpath=pages%5CF%5CO%5CFolkarchitecture.htm (visited on 03/02/2023).

Earthquake risk map



Climatic zone map



10.3 Local design

In this climate with cold winters good thermal insulation is a necessity. Thermal mass is not critical as the day-night temperature cycles are not major. Because of the wet months the structural timber of the frame needs to be protected from surface water.

With more than 8 million m^3 of logs produced Ukraine is a major lumber exporter.[6] Also Ukraine hosts a major steel industry and straw for insulation is available commonly as Ukraine is ranked as the seventh biggest global wheat producer.[7] This offers to build this design entirely locally.

10.3.1 Walls

For this deployment a straw block insulation is used. As the straw blocks commonly come in thicknesses exceeding the 16 cm space between the main structure the insulation is added outside. This brings extra usable space, simplifies the construction and avoids thermal bridges in the ceiling area.

The bracing to stiffen the frame is done with structural OSB plates retaining the straw insulation. For exposed local deployments additional bracing rods can be applied easily as the bracing layer is free from insulation. The 16 cm space between the modules can also be filled with rubble increasing the thermal mass and deformation resistance.

The outside of the straw bales is plastered with clay to create a uniform surface protecting the straw from water. On the inside the OSB plates can be kept or a plaster can be applied.

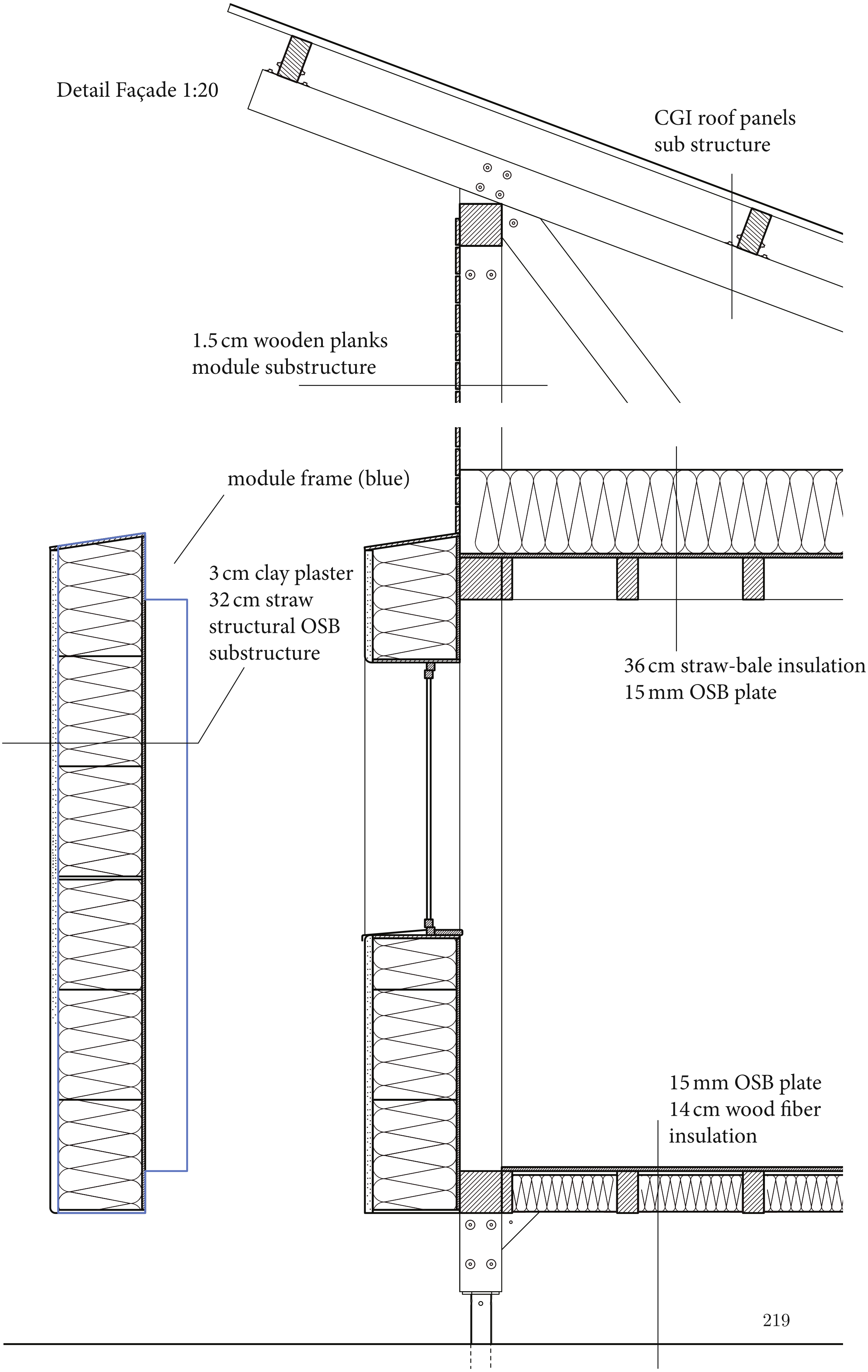
The straw bales can be inserted into the wall modules on the ground and then lifted up and fixed to the main frame. The plaster is added when the modules have been mounted. This wall construction results in a dead load of 2.1 kN/m which is well within the limits.

Wooden planks form the walls in the unheated roof area.

10.3.2 Roof

Compressed straw blocks can be placed on the ceiling for insulation to the unheated roof space. Thickness of 36 cm and a width of 48 cm are common measurements for straw bales. The certified BauStroh achieves a λ value of 0.049 W/(m K) resulting in an overall U-value of the roof insulation layer of 0.14 $W/(m^2 K)$. With a density of around 100 kg/m^3 the overall load on the ceiling is just 0.36 kN/m^2. For improved fire safety the straw bales can be plastered with mud.[8]

[6] *Forests - Country Overview Ukraine.* UN WCMC, May 2020. URL: https://ec.europa.eu/environment/forests/pdf/Country%20overview%20Ukraine%20_17.05.2020.pdf (visited on 03/02/2023).
[7] *Ukraine Agricultural Production and Trade.* U.S Department of Agriculture, Apr. 2022. URL: https://www.fas.usda.gov/sites/default/files/2022-04/Ukraine-Factsheet-April2022.pdf (visited on 03/02/2023).
[8] Benedikt Kaesberg and Dirk Scharmer. *Strohbaurichtlinie SBR-2019.* 26th Oct. 2019. URL: https://baustroh.de/pdf/SBR_2019.pdf (visited on 04/12/2022).


Detail Façade 1:20
CGI roof panels
sub structure
1.5 cm wooden planks
module substructure
module frame (blue)
3 cm clay plaster
32 cm straw
structural OSB
substructure
36 cm straw-bale insulation
15 mm OSB plate
15 mm OSB plate
14 cm wood fiber
insulation

10.3.3 Floors

Compressed straw blocks are only available in thicknesses exceeding 28 cm not allowing the installation in the 16 cm space between the substructure of the floor. As alternative the floor can be insulated with 16 cm thick wooden fiber insulation boards. For details about this material see section 8.4.3.

10.3.4 Airflow

The airflow concept is similar to the showcase in Jordan. The roof space is unheated and permeable to air allowing to store belongings and goods all year long. In this climate and culture it is not expected that the roof area is used as sleeping space at any time of the year. The main living space can be ventilated using the windows. See section 8.4.4 for details.

10.3.5 Foundation

As the focus in this crisis is mainly the reconstruction of existing houses with build back better in mind the foundations do not need to be temporal. Although it must be noted that the construction of ground screw foundations can happen much faster than casting reinforced concrete foundation points. Ground screws can be subjected to soil liquefaction during seismic events but in most of Ukraine the risk of seismic events is considered low. For clay rich soils heavy mechanical equipment can be trucked in. With the straw insulated walls the ground pressure is low and only one screw per corner point needs to be constructed. Details about possible foundations is given in section 7.1.5.

10.3.6 Price

The price level for timber is expected to be similar to the wholesale prices calculated for China therefore we assume the same kit price. Straw is expected to be available as a by product from agricultural production for a low price or for free. Also clay used as plaster is expected to be available locally on-site for free. Transportation is assumed by 20 t truck from Kyiv to Kherson with around 600 km of distance taking 10 h. Truck prices are estimated at around 2 €/km for one TEU container.[9] It is expected that in practise existing planks from the damaged structure can be used to cover the upper floor façade lowering the price. Windows and doors are expected to be partially salvageable as well.

The total price for one unit is calculated as follows:

Item	Unit price	Quantity	Total
Kit	900	1	900 €
Clay	0	1.2 m^3	0
Straw	0	0 m^3	0
Façade planks	20	18 m^2	360 €
Ground screws	65	4	260 €
Wood fiber boards 100 mm	20	14 m^2	280 €
Transportation			300 €
Total			2100 €

10.3.7 Design

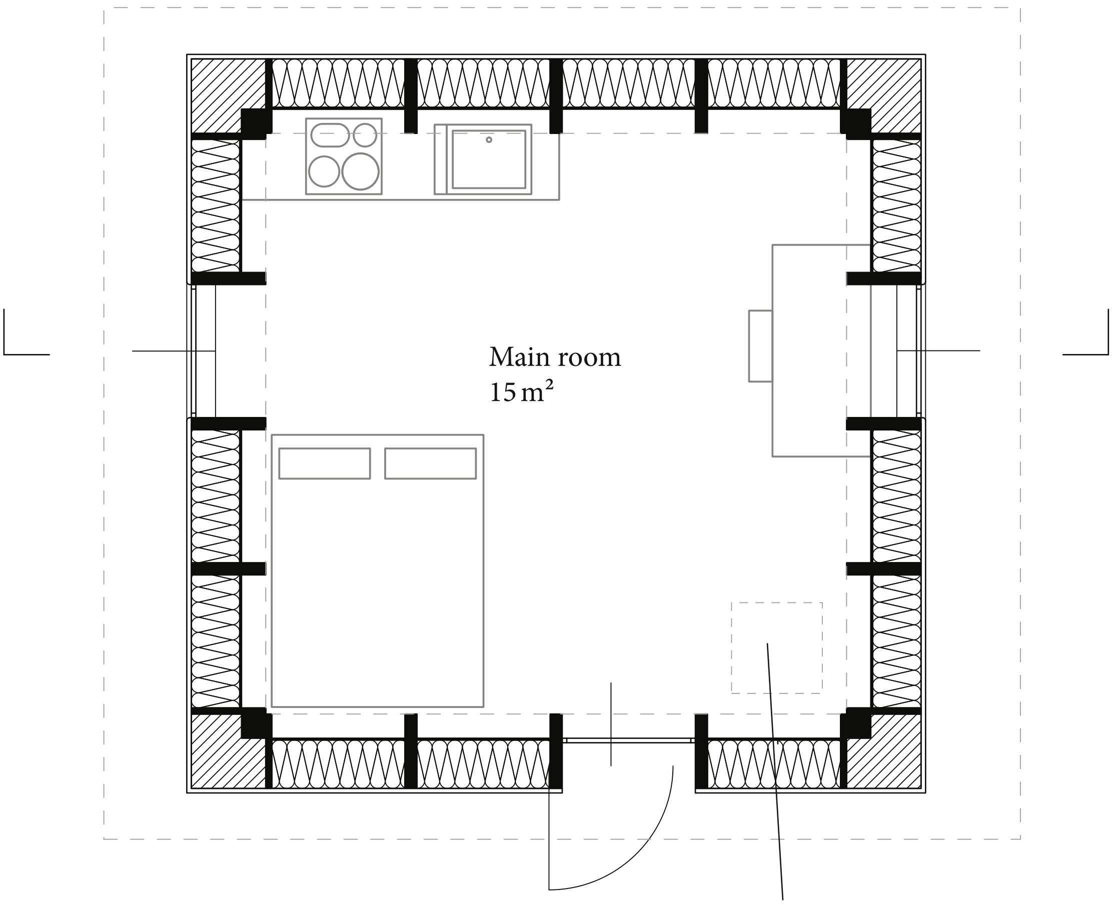
The design uses the minimal size of one unit to provide a basic room which can be heated in winter. Dry storage is available in the roof area. This shelter can be built next to damaged existing structures and later be connected to them.

With this configuration the shelter is suitable for a maximum of two people. As young people left the conflict zone because of their greater flexibility and mobility the author imagines the kit for the elderly remaining on-site. Construction must be assisted by volunteers in this case.

Toilets are commonly available already in dedicated outside cabins.

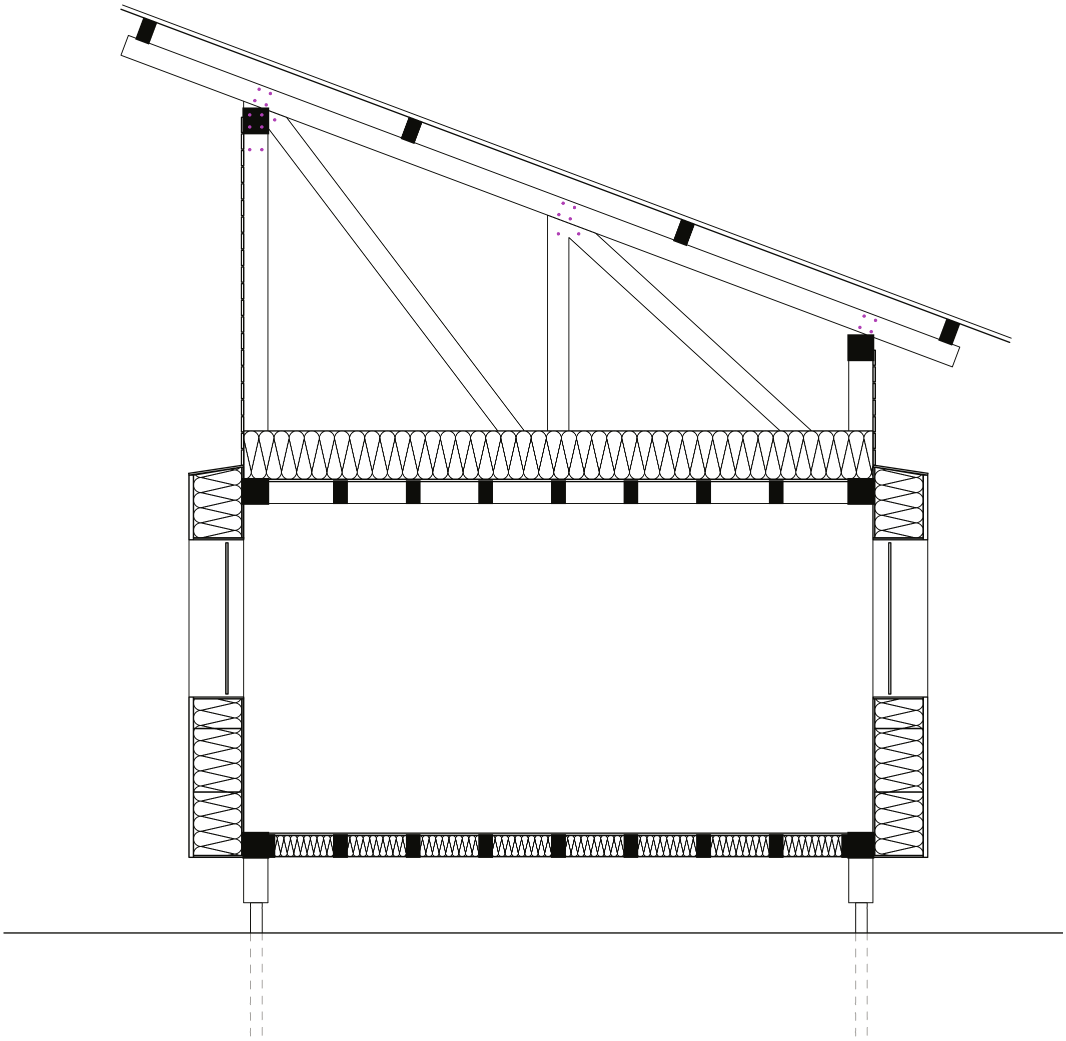
[9] *Della - Transportation Prices*. Della. URL: `https://della.eu/price/local/` (visited on 03/02/2023).

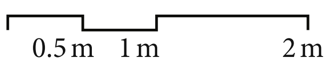
Plan 1:50



Roof access
The roof area used for storage can be accessed using a ladder and a hatch

Section 1:50





Chapter 11

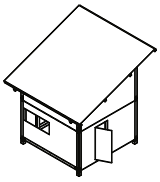
Summary

This thesis introduces a novel transitional shelter design. After defining the relevant theoretical basis current shelter responses were analyzed according to their construction qualities. Most common issue found was insecure joints resulting in instabilities during high wind speeds and a negligence of surface water protection. Shelter responses of international organizations were mostly pre-fabricated abroad using high tech but climate unfit materials and were often not expandable. Local shelter responses were commonly very low tech resulting in structural deficits and short lifespans.

With the discovered issues a manifest summarizing the important aspects of an improved transitional shelter response was created. Based on this manifest this work introduced a novel design combining partial pre-fabrication and good engineering practices with local sustainable materials collected on-site to reduce transportation costs. The resulting design comes as a kit consisting of a robust wooden frame connected with steel connectors and is shipped together with corrugated galvanised iron roof sheets. It offers $16\,m^2$ of usable covered space on each of the two floors. All walls are created by the inhabitants using locally available materials with a climatic appropriate construction. This allows to add insulation and thermal mass according to the climate of the deployment. The design also features an easy way of expanding the shelter by adding units forming additional covered spaces between the adjacent units. This space can be used to install a sanitary module. The generic climate agnostic kit design was showcased with specific local wall designs in three different climate scenarios including Jordan, Bangladesh and Ukraine. Attention to the climate adapted, locally known building techniques was taken.

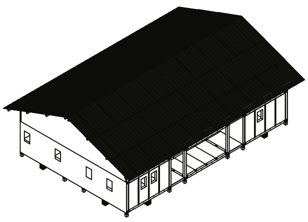
The design showed that a wooden structural frame can be locally pre-fabricated and easily adapted to different climates while retaining an acceptable transportation efficiency and a comparable price to existing shelter responses. With only low tech machinery needed during the prefabrication and a later simple assembly on-site fabrication can assist local economies. To this point the structure has not been built entirely as 1:1 prototype so critical information about the practical usability is missing and subject for future work.

Generic kit



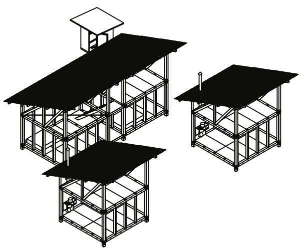
Phase	trans+	Climate	-	Earthquake	-
Area m²	15+15	Price/m² €	40	Lifespan	10 years
Plotsize m²	34	Weight kg	1400	Labour	1/3
Room height	218 cm	no per TEU	6	Build time	2d
Local Material	both	Flood safe	yes	Extendable	yes

Jordan



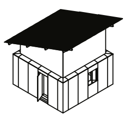
Phase	trans+	Climate	BWk	Earthquake	moderate
Area m²	112+112	Price/m² €	110	Lifespan	10 years
Plotsize m²	200	Weight kg	8400	Labour	1/3
Room height	218 cm	no per TEU	1	Build time	12d
Local Material	both	Flood safe	yes	Extendable	yes

Bangladesh



Phase	trans+	Climate	Am	Earthquake	high
Area m²	64+44	Price/m² €	54	Lifespan	10 years
Plotsize m²	134	Weight kg	5600	Labour	1/3
Room height	218/310	no per TEU	1.5	Build time	8d
Local Material	both	Flood safe	yes	Extendable	yes

Ukraine



Phase	trans+	Climate	Dfb	Earthquake	low
Area m²	15+15	Price/m² €	93	Lifespan	10 years
Plotsize m²	34	Weight kg	1400	Labour	1/3
Room height	218 cm	no per TEU	6	Build time	2d
Local Material	yes	Flood safe	yes	Extendable	yes

* Price per m² calculated including 50% of roof area

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