Circular
Transitional Housing
for displaced people
in extreme conditions:
the case of Pakistan

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Circular Transitional Housing for displaced people in extreme conditions: the case of Pakistan

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This research addresses two global challenges: the transition of a linear to circular built environment and the provision of shelter to a rising amount of displaced population. Resolving them will not be easy, but every step in this direction brings us closer to a more sustainable and just world. For that, I would like to thank every person spending their time and energy on advocating for circularity or helping people in need.

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Lastly, I would like to thank myself for choosing to work on a topic dear to my heart, believing in myself and doing the hard work.

Abstract

Global displacement has been rapidly increasing over the last decades and is expected to rise even further in the upcoming years due to the negative impacts of climate change and more frequent and severe weather events. This highlights the growing demand for sustainable housing for the displaced. Transitional housing is a structurally sound interim shelter for a maximum duration of about three years, which by essence is designed to be relocated. Though such units have a potential to be partially or fully reused, in reality, high investments, inflexible designs, and negative environmental impacts deem them an undesirable option.

The research aims to integrate circular building principles into the design process of transitional housing units (THUs) to help bring economical value back to the donors, strengthen the community resilience and retain material value. By examining existing transitional housing options and their lifecycle, stakeholder involvement, and circularity principles in the built environment, the thesis develops a suggestive tool for circularity informed design decisions, while introducing a circular transitional housing design proposal for the extreme conditions of upper Sindh province, Pakistan.

The literature review highlights the lack of information on the end-of-life phase of transitional housing units. The most common scenarios, as well as circular alternatives, are mapped out. Circular building principles across the topics of materials, design, manufacturing, and management, are investigated for their ability to be integrated in humanitarian construction. This provides the scientific basis for the development of a recommendation set and a visual evaluation tool for THU planners. The efficacy of the suggestive tool is shown through the design proposal.

The extreme conditions of repeated flooding and high temperatures in upper Sindh necessitate resilient design strategies. Vernacular inspired passive techniques and the use of locally available biobased materials, such as bamboo and hemp, are proposed to mitigate temperature impacts and enhance sustainability. Design principles such as design for disassembly, and adaptability, are implemented as a means to increase the circularity potential of the developed THU. The design proposal portrays the unit as a stock of valuable components, which can be reintroduced in the local economy at the end of the displacement period – a material bank.

Incorporating circularity in transitional housing projects has the potential to foster innovation in the humanitarian sector, which in turn could also be applied to tackling challenges faced by conventional architecture. The findings contribute to the development of circularity practices in the humanitarian sector, thus contributing to the well-known principle of do-no-harm.

Contents

** all pictures and viduals are own unless stated otherwise*

List of Abbreviations

AP	Affected population
AEC	Architecture, Engineering and Construction
BAMB	Buildings as material banks
BB Home	Blooming Bamboo Home
BE	Built Environment
BIM	Building information model
B.R.I.C.	Build Reversible In Conception
CBE	Circular Built Environment
CDP	Center for Disaster Philanthropy
CE	Circular Economy
CTH*1	Circular Tiny House
DfD	Design for Disassembly
DfR	Design for Repair
DP	Displaced population
EMF	Ellen MacArthur Foundation
EoL	End of Life
GHG	Greenhouse gas
HO	Humanitarian Organisation
ICRC	International Committee of the Red Cross
IDP	Internally displaced person
IFRC	The International Federation of Red Cross and Red Crescent Societies
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
NGO	Non-governmental orgnisation
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PDNA	Post-Disaster Neeeds Assesment
RHU	Relief Housing Unit (Better Shelter)
SDGs	Sustainability Development Goals
THU	Transitional Housing Unit
T-shelter	Transitional shelter
UN	United Nations
UNHCR	the UN Refugee Agency

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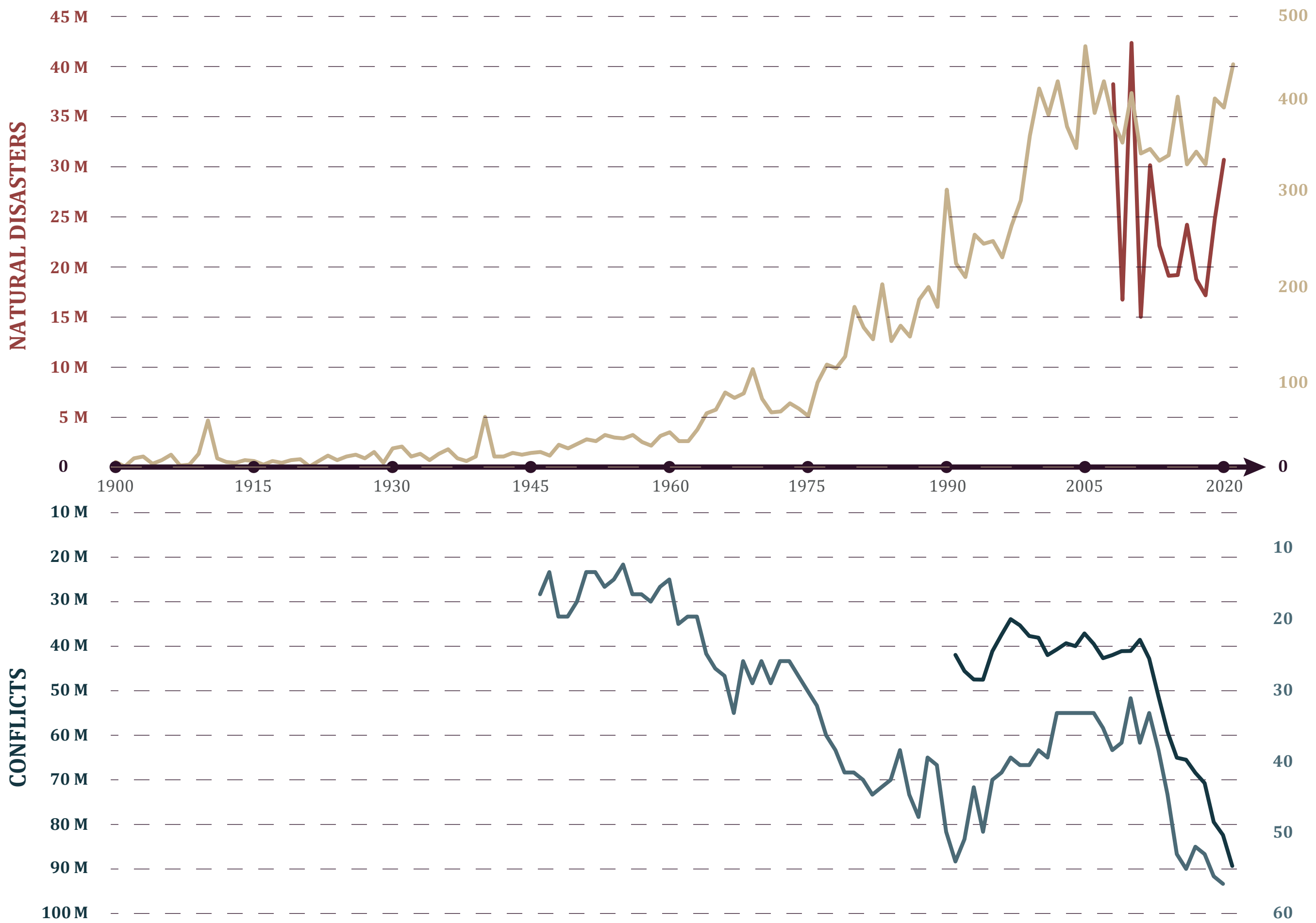
1. Introduction

The general background of the topic will be explored , as well as the outline of the research, which includes problem statement, objectives, research question, expected end products, methodology and relevance.

1.1. Background

Displaced population: causes | The number of people, forced to move due to weather extremes and civil conflicts, is increasing. There is a steady rise throughout the last decade in the amount of displaced population (DP) due to persecution, violence, human rights violation or conflict, accounting to 89.3 million in 2021 and an estimated 103 million in 2022 (Figure 1) (UNHCR, 2022). In addition to that, many are directly or indirectly impacted by natural disasters like floods, draughts, and cyclones, which cause damages to key infrastructure as well as food and water scarcity in the concerned regions. Prevention and emergency plans, better forecast technology, adaptation and mitigation policies and human solidarity have helped to drastically reduce the casualties due to such natural occurrences. However, millions of people, especially those in the low economical brackets, lose their homes and livelihoods. Those crises are further worsened and amplified by climate change.

Figure 1.
Number of events and affected people worldwide by year, shown for natural disasters (up) and conflicts (down)



Number of recorded natural disaster events, All natural disasters, 1900 to 2019
Source: EMDAT (2020): OFDA/CRED International Disaster Database, Université catholique de Louvain – Brussels – Belgium
OurWorldInData.org/natural-disasters • CC BY

Number of active state-based conflicts, World, 1946 to 2020
Source: OWID based on UCDP/PRIO
OurWorldInData.org/war-and-peace • CC BY

People displaced internally by natural disasters, 2008 to 2020
Source: Internal Displacement Monitoring Centre (via World Bank)
OurWorldInData.org/natural-disasters • CC BY

People forcibly displaced worldwide, 1991 to 2021
Source: UNHCR Global Trends 2021

Transitional housing: need | It is estimated that in 2023, one in every 23 people requires humanitarian assistance (OCHA, 2022b). Humanitarian aid has many facets, such as medical help, food security and sanitation, depending on the specific situation and current needs. One essential sector is '*Shelter and Settlement*'. There are different kinds of shelters and shelter support, depending on the emergency phase, expected occupancy duration, location, and overall context. Transitional Housing Units (THUs) are a form of shelter meant to be used for a limited amount of time, which enables beneficiaries to return to their normal daily activities, before they are able to move to a permanent accommodation (Chapter 2). It plays a crucial role in helping people rebuild their life and find stability in the aftermath of a crisis.

Transitional housing: problems | Housing is recognized as a fundamental right in Article 25 of the Universal Declaration of Human Rights and as such should provide the basic human needs like safety, dignity, and privacy. However, the provided post-crisis habitation isn't always adapted to the environmental, climatic, and cultural necessities (Felix et al., 2013; Wimberly, 2021). THUs have a relatively short service life and an often unknown afterlife fate. This can lead to loss of material value and thus result in high initial investment without a big return.

In some cases, reconstruction of the affected areas might take longer than expected due to high expenditures for shelters and thus insufficient capital for permanent housing. As a result, the stay in transitional housing is prolonged. This can negatively impact the DP in the long run. In the 2005 Kashmir earthquake the city of Muzaffarabad (Pakistan) was severely damaged (Figure 2). The housing reconstruction got delayed becouse of limited financial resources among other things. Prefabricated transitional shelters (T-shelters) were donated to beneficaries, but many of them would have picked to receive the monetary value (over US$6000) to invest in a permanent home if given a choice (Mughal et al., 2015). Ten years after the earthquacke half of the provided T-shelters rmained in use and many people, previously homeowners, were still renting property.

Figure 2. *Post-disaster pre-fabricated T-shelters in Muzaffarabad, Pakistan. Shelter cost ca. US$6000;* **2.1.** *Destruction and displacement camp* **2.2.** *T-shelter on the site of a previously 3 storey house, 2008;* **2.3.** *still standing in 2015;* *Source: Mughal et al. (2015)*

Extreme conditions | The biggest challenge humanity must tackle this century is the climate crisis and its known and unknown impacts and risks on ecosystems, biodiversity, natural resources, and human society (IPCC, 2022). The effects of the anthropogenic climate change are complex and intertwined. They can be observed all over the world from arctic permafrost thaw and ocean acidification to extinction of species. Increased frequency, unpredictability and severity of weather and climate lead to extreme conditions, which in return result in heavy precipitation events, fires, and draughts, among other things (IPCC, 2022, p. 9; Eckstein et al., 2021). Such extreme events intensify humanitarian crises by disproportionately affecting the population and delaying recovery.

> *Increased frequency, unpredictability and severity of weather and climate lead to **extreme conditions,** which in return result in heavy precipitation events, fires, and draughts, among other things. Such extreme events intensify humanitarian crises by disproportionately affecting the population and delaying recovery.*

Even though the number of affected people can fluctuate from year to year, it is expected to go further up as more people move towards urban areas, where poor living conditions expose them to greater risks. The global population surpassed 8 billion in November 2022 and is expected to exceed 10 billion by mid-century before reaching a plateau (Roser et al., 2013). Those two trends make communities more vulnerable to crises (Kuittinen, 2016). Thus, it is more likely that when a disaster strikes, even more people will be affected and in need of assistance (Wimberly, 2021). Some of them get displaced internally or even across borders for an often-unknown period of time.

Displaced population: vulnerabilities | Displaced people are usually considered the most vulnerable group of the affected population (AP), because there is a lot of uncertainty involved in their situation. They were forced or have decided to leave their original home and are temporarily in a location where they are not willing to or are unable to remain (Global Shelter Cluster, 2014). It is possible that they have legal issues with authorities and that they need to move several times. In many cases, they also have limited access to services, and are disconnected from their social network. DP could also face phenomena of discrimination.

Besides the displaced population, non-displaced people are also directly affected by any given crisis. They are people who have the capacity and willingness to remain in the location they are for the long term. This could be their original residence if they are property- or landowners or a new place, where they wish to resettle. The category of the affected people isn't fixed and can change as their circumstances and the development of the situation evolve (Global Shelter Cluster, 2014). Furthermore, each affected person, family or community has varying and diverse needs, for which different types of assistance in the short, mid, and long term is required. Some depend upon more support during the initial emergency response while others require assistance later-on during the early recovery or reconstruction phases. A country, where people have been repeatedly affected and displaced by crises, is Pakistan.

The case of Pakistan | Pakistan has experienced a lot of extreme events (flash floods, earthquakes, high temperatures) in the past decades, reoccurring in Germanwatch's 10 countries most affected by climate change (Echstein et al., 2021). In the summer of 2022 heavy monsoon rains caused devastating floods all over the country. Of the 33 million affected people, about 8 million got internally displaced. There is a partial or full destruction of over 2 million houses. The crisis is labelled as the worst so far, even more devastating than the floods of 2010 (CDP, 2023). Several months after the disaster some areas remained under water, leaving many in need of a more stable housing, especially with the drop of temperatures below zero in certain regions. A big part of the provided shelter aid is focused on emergency tents and tarpaulins in order to reach as many of the AP as possible, but those items are hardly enough to respond to the beneficiaries' needs until they can rebuild their homes (Figure 3). Neither is there a clear concept for what will happen with those materials once the disaster is over.

Figure 3.

3.1. *Emergency shelters, border of Eastern Balochistan and North Sindh provinces, October 2022. Source: MSF*

3.2. *Makeshift shelters. Photo: Saadeqa Khan*

3.3. *Emergency shelters, Matli, Sindh province, 29 September 2022. Photo: Xinhua*

3.4. *Emergency shelters, Sindh province, Photo: Asif Hassan/AFP*

Potential of circularity for transitional housing | Sourcing, production, transportation, and waste of items in the humanitarian sector can have a considerable impact on the local and global environment. This topic has been raising more friction among humanitarian organisations (HO), as awareness of the produced waste and emissions during humanitarian actions has been growing. The *do-no-harm* guiding principle is therefore valid also for protecting the environment and not making disaster- or war-hit areas more vulnerable to future extreme climate events.

Providing THUs is a common mid-term relief strategy, yet it has been often criticised for being expensive and environmentally damaging. This could be due to a lack of understanding of the afterlife scenarios of the units and the potential of their components. Circularity is examined for its capacity to close resource loops and thus retain material value. By incorporating circularity principles in the design of THUs, the negative impacts of transitional housing could be reduced, while increasing the benefits.

Linking Circular Economy and Building Technology in the dynamic and uncertain humanitarian context can therefore be beneficial for innovation in humanitarian as well as conventional architecture. A rethinking of the shelter design process and supply chains of HO can contribute to the United Nation's Sustainable Development Goals (SDGs) and a transition towards a more circular humanitarian approach.

> *By incorporating circularity principles in the design of THUs, the negative impacts of transitional housing could be reduced, while increasing the benefits.*

Figure 4.
Circular Transitional Housing

1.2. Problem statement

Growing demand for Transitional Housing options | The number of displaced people worldwide due to conflict or natural disaster is at an all-time high and is expected to rise even further in the upcoming years. The average duration of displacement has been continuously increasing as well, lasting years or decades (Sphere, 2018). Furthermore, climate change, more frequent and severe weather events, growing urbanisation and global population numbers increase the vulnerability of communities to humanitarian crises. All these reasons highlight the growing need of housing options for displaced population (Kuittinen, 2016, p. 13; Perrucci et al., 2020).

After a crisis, anthropogenic or natural, people are often scared, vulnerable and traumatized. Before they can return home or move somewhere else safe, many displaced people are relocated in a temporary accommodation. This can be an emergency shelter, THU, self-built shack, a rental or shared place or DP get hosted by other family members or friends. THUs, in particular, are seen as a structurally sound interim shelter for a maximum duration of about 3 years, which by essence is designed to be relocated.

It seems that, if planned for, THUs have a great potential to be reused fully or partially, refurbished, extended, or incorporated in reconstruction of permanent structures. This accommodation should still give people security and comfort, for them to heal, return to daily activities and participate in their community (Felix et al., 2013). On the other side, the lack of transitional housing design plans as part of disaster preparedness can lead to high cost, inefficient results and damage to beneficiaries mental health, which in turn can cause a prolonged recovery period (Perrucci et al., 2020). Consequently, *there is a rising demand for sustainable, adequate and context sensitive transitional housing.*

Lack of circular transitional housing options | There are many different transitional housing designs, which use a variety of materials. Some HO import prefabricated components from abroad, others use a more grassroot approach utilising local materials and workforce. This can lead to very big differences in the performance and environmental impact of the units. Resource efficiency and conservation, adaptability of the design to changing needs and accountability of the supply chain are still underexplored in the humanitarian construction, where the urgency of the disaster aftermath holds grip. *Integration of circular building principles in the planning of THUs can help bring economical value back to the donors, strengthen the community resilience and keep the materials in the technical and biological loop.* Researchers such as Perrucci et al. (2020) have identified the need for further research of the implementation of circularity principles in THU design, as well as sustainability evaluation systems.

1.3. Research objective

Main objective | The main objective of this research is to investigate how circular building principles can be integrated in the planning of humanitarian transitional housing units and thus reduce the negative impacts THUs may have.

Sub objectives

SO1 | To identify the existing transitional housing design approaches and understand what happens at their end-of-life.

SO2 | To understand what the potential of applying circular building principles in humanitarian construction and in particular transitional housing is.

SO3 | To identify the main stakeholders in the supply chain of transitional housing.

SO4 | To identify the extreme climatic conditions of Sindh province in Pakistan and how these affect the built environment.

SO5 | To develop a circular THU design for Sindh, Pakistan, following recommendations for circularity informed design decisions.

Scope | Providing adequate help to people, affected by natural disasters or conflicts, is extremely important but also very complex. The humanitarian sector has a lot of aspects, various stakeholders and faces big challenges. This thesis focuses on the topic of *Shelter* and particularly on *Transitional Housing*. For a shelter project to be successful, many elements need to be considered besides the physical structure, such as policies, economy, tenure, politics and more. The scope of this research is limited to:

1. | *Transitional housing: detached units*. There are multiple ways to provide accommodation to people in need. This thesis focuses specifically on newly developed detached units, located on a temporary available site.

2. | *Focus on the physical structure of THUs.* Services like electricity and water supply are essential for the daily activities of occupants. The availability of those resources is highly dependent on the settlement location and the connected infrastructure and therefore will not be examined in detail.

3. | *An economic analysis is not included.* Cost usually plays a big role in the design process, however, this thesis investigates the possible integration of circularity principles in humanitarian architecture. Since economic value can vary in time, availability, and location, it is not considered in detail.

1.4. Research question

Main question | How can transitional housing for displaced people in the extreme conditions of upper Sindh province in Pakistan be made using circular building principles?

Sub questions

SQ1 | What are the existing transitional housing options and their end-of-life scenarios?

SQ2 | Which principles of circularity can be applied? How can they inform design decisions about transitional housing?

SQ3 | Who are the existing stakeholders? How are they currently entangled in the management?

SQ4 | How do the extreme conditions of repeated flooding and high temperature in upper Sindh, Pakistan affect the design of transitional housing?

SQ5 | How can THU planners be assisted in taking circularity informed design decisions?

1.5. Expected end products

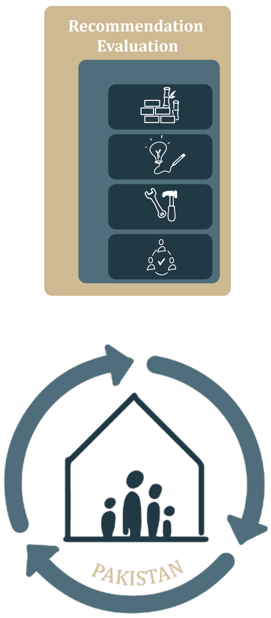


Figure 5.
End products

| *Recommendation set and visual evaluation tool for circularity informed design decisions*

The recommendation set is a compilation of circularity principles which can be used as a guideline for the design of circular transitional housing units. The recommendation set can be used by HO project team members, THU manufacturers or local initiatives. A visual evaluation of the circularity potential of existing design propositions is further proposed.

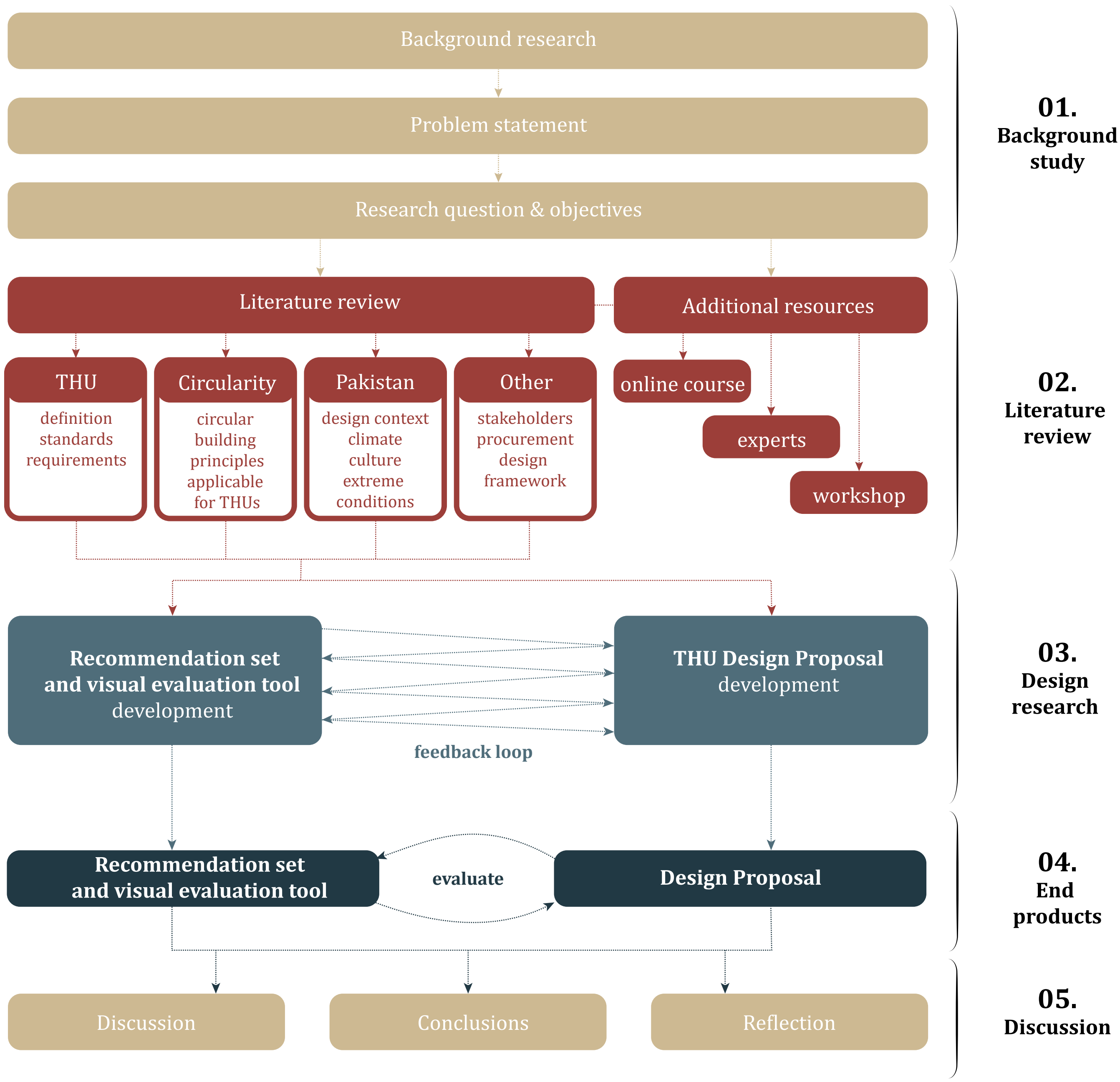
| *Design proposal for a circular THU in Sindh, Pakistan*

The design proposal is a circular transitional housing unit for the particular extreme conditions of upper Sindh province in Pakistan. It will be shaped following the recommendation set and evaluated through the visual evaluation tool. This design proposal is an example of how the recommendation set can be implemented in a certain location.

1.6. Methodology

The thesis has two main parts: scientific research and design. A five step approach is followed: *background research, literature review, design research, end products* and *discussion.* The methodology scheme can be seen in Figure 6 and is further explained in more detail on the following page.

Figure 6.
Methodology



Background research Background research is done to gain more clarity on the topic of humanitarian shelters and set the context for the thesis work. The information is used to define the problem statement, research objectives and research question.

Literature review The literature review focuses on four main topics, namely: *transitional housing, circularity, extreme conditions* (such as flooding and high temperatures) *in Pakistan* and *others* (stakeholders, procurement). The chapters 2-4 will address each of the first three topics separately. Transitional housing research is conducted in order to provide an understanding of this shelter form and its requirements, problems and oppurtunities. Circularity is investigated as a means to identify circular building principles relevant for the humanitarian construction and in particular for transitional housing. Existing stakeholders will be mapped out in the interest of identifying potentials for a more circular business model.

For the purpose of the research, the upper part of Sindh province in Pakistan has been chosen as a case study for extreme conditions. Such extreme conditions include climatic and economic parameters, as well as occurance and impact of natural disasters and vulnerability to climate change.

The search engines Scopus and Google Scholar were used with key words including: *transitional housing, shelter, temporary housing, post-disaster housing, THU (transitional housing unit), refugee, displaced population, circularity*. Furthermore, there were additional sources such as an online course from the Global Shelter Cluster on the topic '*More Than Just a Roof – Introduction to shelter and settlement*' and conversations with experts on the topic.

Design research For the design of the circular THU additional topics were researched. Those include information aboult materials (bamboo and hempcrete), construction methods and Sindhi culture. The suggestive tool for circularity informed design decisions and the design proposal will develop simultaneously in a feedback loop. Based on the knowledge gained from the literature review a recommendation set is developed, which is used to inform the design of the transitional housing unit. The design process will give indication for improvements to the tool.

End products The final visual evaluation tool will be used to evaluate the circularity potential of the design proposal. While the design proposal will adhere to the specific requirements of the chosen location, the recommendation set can be implemented anywhere.

Discussion The final step includes discussion, conclusions and reflection. The connection between innovation, circularity and the humanitarian construction will be examined. The benefits and limitations of the end products will be discussed as well. Finally, there is a suggestion for further research and a reflection on the process.

1.7. Relevance

Societal Relevance

Humanitarian aid is vital for the survival of millions of people every year. With the projected increase of the severity and frequency of natural extreme events and the upward trend of people affected by conflict, it is ever so important to find ways to help the affected and vulnerable population in a way that doesn't contribute to the environmental crisis. Over 350 humanitarian organisations on local, national, and international level commit to *The Climate and Environment Charter for Humanitarian Organizations* and aim to reduce greenhouse gas emissions, increase focus on climate change adaptation and strengthen environmental action among other things. Even though sustainable and circular building approaches are being developed, the humanitarian architecture is still an underexplored field due to the complexity and uniqueness of crises. Furthermore, different political, cultural and climatic circumstances situations around the world call for flexible and adaptable concepts. This research aims to contribute to the development of more sustainable practices in the humanitarian sector while keeping the human being in the focus.

Scientific Relevance

The interest in and information on circularity in the built environment has been steadily growing in the recent years as a means to reduce the high emissions of the industry and building technology plays an important role in this transition from a linear throwaway economy towards a circular one. Transitional housing for displaced people presents an interesting context for the exploration of this innovative field due to the technical, social, environmental and economic aspects in combination with a temporary nature of humanitarian architecture.

THUs are notorious for high resource consumption and waste generation. By proposing a recommendation set to make circularity informed design decisions for transitional housing units, this research tries to identify potentials to keep material value and to map possible roles of stakeholders following a more circular business model. The added complexity of extreme conditions aims to investigate the influence of possible climate related events on the decision making.

2. Transitional Housing

This chapter will give an understanding of what transitional housing is, what are the officially recognised standards and requirements, what are the common materials used in the design process and which are the most common end-of-life scenarios. The main stakeholders and procurement approaches are discussed as well.

2.1. Introduction to humanitarian shelter

Importance of shelter | Having a shelter is crucial for displaced people after a crisis strikes, because it allows them to start rebuilding their lives. Besides protection from the elements, it provides safety, privacy, health, and dignity (Figure 7) (Sphere, 2018; Global Shelter Cluster, 2021). Furthermore, a shelter can provide a sense of identity and stability. Several ways to help people get habitation are available, besides direct construction, such as rental assistance, accommodation by the host population or monetary assistance to buy building materials.

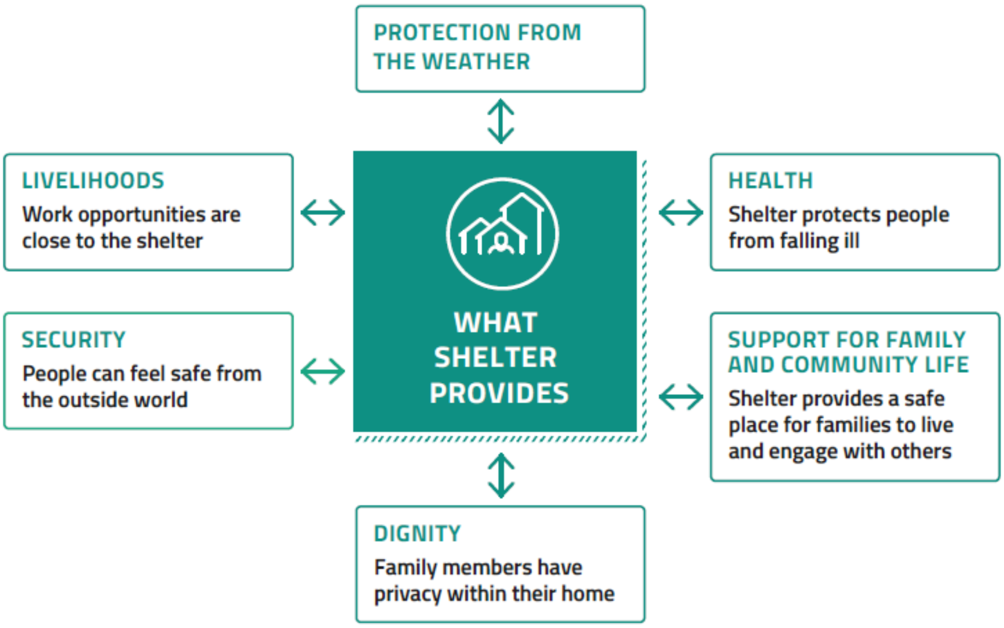
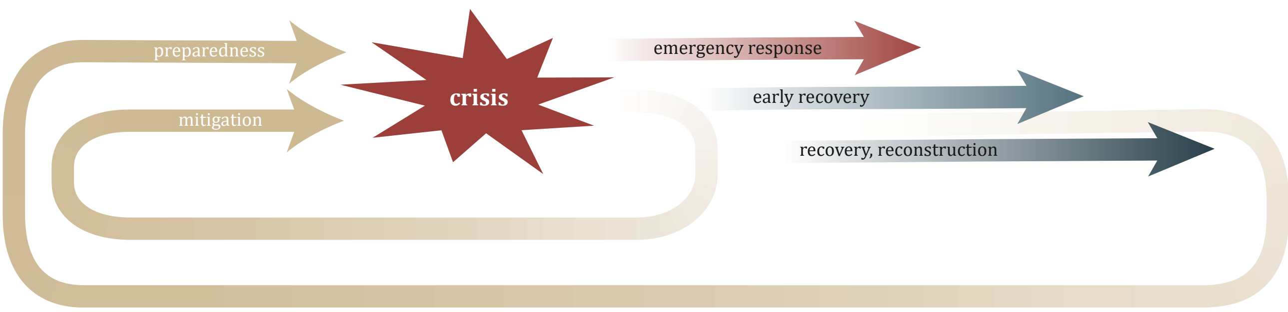


Figure 7.
Shelter functions; Source: Sphere (2018)

Immediately after a natural disaster, communities and affected households are usually active in addressing their own shelter needs by repairing their homes or using salvaged materials to build a temporary shelter (IFRC, 2011; Felix et al., 2013; Global Shelter Cluster, 2014). Such activities are encouraged and supported by Shelter and Settlement Response teams through provision of tools, parts, and technical know-how. 'Shelter' is being widely recognised as a *process* rather than a product, meaning that the response should be tailored to the beneficiaries' individual needs and capacities (IFRC, 2011). Those needs and capacities can change with time and the transition of emergency phases (Figure 8).

Figure 8.
Emergency phases



Types of shelter | There are different, sometimes overlapping, shelter terminologies in use in the humanitarian sector. They vary depending on the expected service life of the structure but also depend a lot on the context in which they are built (Figure 9)(IFRC, 2013; Antonini et al., 2020). In general, emergency or temporary shelters are provided immediately after the onset of a crisis (emergency response) as a life-saving support. Very often those are public shelters, tents, or a basic kit of materials like a plastic tarpaulin and framing parts. Those shelters are foreseen only for a limited time and can be expensive, bulky, and not climate appropriate.

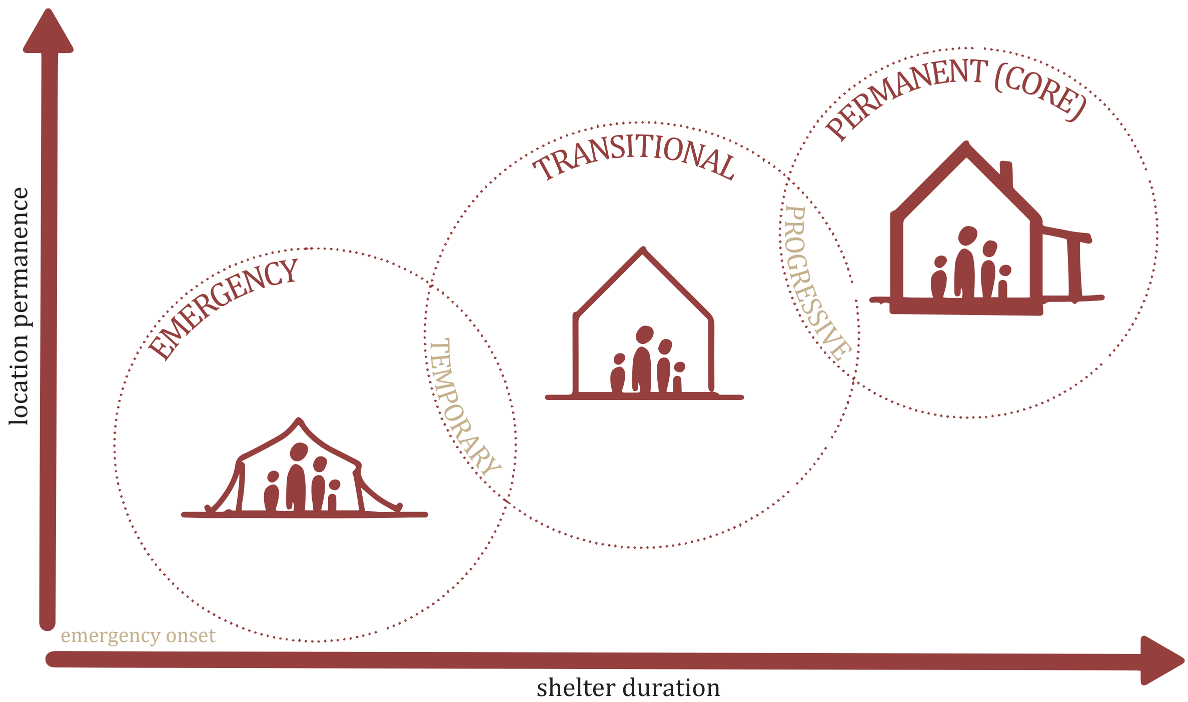


Figure 9.
Shelter terminology; adapted from IFRC (2013)

Transitional housing is meant to bridge the time gap between the emergency relief and the completion of a more permanent accommodation (IFRC, 2013; Abulnour, 2014; Perrucci et al., 2020). The expected service life is between 6 months and 3 years and it should enable people to return to their normal daily activities like work, school and socializing (Felix et al., 2013; Antonini et al., 2020; Perrucci et al., 2020). This added security and comfort can allow AP and communities to plan a more sustainable and resilient reconstruction. An inefficient design and management of the transitional housing therefore influences the ability of beneficiaries to recover (Perrucci et al., 2020). Transitional housing units are often prefabricated and designed in a way that can be relocated or reused in a later stage.

Progressive or Core shelters are (semi-) permanent structures and are placed on locations where people are allowed to stay. For multiple reasons like budget, construction speed and equity those housing units contain only the main part of the house, which the beneficiaries can later-on extend themselves (IFRC, 2013).

AP do not necessarily pass through all these types of shelters. Depending on their situation and capabilities, some might go straight from an emergency tent to a permanent accommodation (skipping the transitional housing) or may remain in their own house if only minor repairs are needed (Global Shelter Cluster, 2014; Abulnour, 2014). Shelters, independent of their type, are always part of a bigger network – a *settlement*.

Importance of settlement | It is important to note that any shelter provision plan should be planned in accordance and consideration of the settlement (IFRC, 2013; Sphere, 2018). AP have multiple needs including and not limited to access to employment and infrastructure, proximity to family and friends, access to healthcare and education. If those elements are not provided nor easily reachable, people will refuse or leave housing units provided to them (Lizarralde et al., 2010). A good location of the settlement is important for reducing people's vulnerability to hazards. It should be in a safe and secure area with enough space available (Sphere, 2018). The securing of available land, preferably connected to existing infrastructure, essential services and close to livelihood oppurtunities, is therefore essential for the success of any shelter project.

The settlement context may vary and be formal or informal (Figure 10). Site planning should be based on urban design principles. It must include roads, public space and acess points. Privacy of the separate units should be maintained and requirements of different social groups (based on gender, age, religion, disability) should be taken into account. Services and facilities such as sanitation, healthcare, places of worship, waste disposal and livestock accommodation should be present as well.

Figure 10. *Setllement options for displaced populations; Source: Shelter Centre (2012)*

Option 1	**Host families**	**Definition:** local families shelter the displaced population within their households or on their properties.
Option 2	**Urban self-settlement**	**Definition:** unclaimed urban properties, or land unaffected by the disaster, are used informally by displaced populations.
Option 3	**Rural self-settlement**	**Definition:** displaced populations create a settlement on collectively owned rural land.
Option 4	**Collective centres settlement**	**Definition:** existing large structures, such as schools, can serve as collective shelters.
Option 5	**Self-settled camps**	**Definition:** independent from government or international organisation support, camps are formed by the displaced population.
Option 6	**Planned camps**	**Definition:** government or aid organisations plan camps, including infrastructure, to house displaced populations.

2.2. Challenges and opportunities of transitional housing

Transitional housing: essence | As explained in *subchapter 2.1.*, transitional housing provides a *home* for people, whose house has been severely damaged or who have been temporarily displaced. A place, which allows them to resume daily activities, until a permanent accommodation is available. There are many different options, from cargo containers and prefabricated units to self-built shelters or staying with other family members. Essentially, transitional housing should be affordable for the occupation duration and provide enough comfort for the family to live without compromising the long-term full reconstruction and recovery (Lizarralde et al., 2010, p 71).

Usually, THUs are built in settlements, on a temporary available land, either clustered in a camp or individually dispersed in proximity to the property of the beneficiaries. The units can be detached, be part of a row-house or of a low-rise block (Figure 11). Facilities like kitchen and bathroom can also either be available per unit or communal. There are, however, several aspects of transitional housing that pose big challenges to the design process.

Figure 11.
11.1. Detached units; Azraq Refugee Camp, Jordan; Photo: Adel Sarkozi/ CARE
11.2. Rowhouse units; ooden Prefabricated Temporary Housing, Kumamoto Earthquake, Japan. Photo: Hiroyuki Hirai
11.3. Block; Container Temporary Housing 2011, Onagawa, Japan; Shigeru Ban; Photo: Hiroyuki Hirai

Short service life | In the case of humanitarian construction, and in particular transitional housing, the service life is drastically reduced in comparison to conventional buildings. Usually, THUs have an expected occupancy between 6 months and 3 years. Even with a short timeframe in mind, materials like steel, plastic tarpaulin or concrete are common as they are relatively cheap and easy to handle. They do outlive the THU and, if not disposed properly, can contribute to site pollution once the settlement is dismantled. In other cases, refugees end up staying in transitional housing for way longer than initially planned. This might be due to a general lack of affordable housing alternatives, prolonged conflicts or legal issues. DP may remain in formal or informal settlements for years or even decades. The THUs, which are not meant to become (semi-)permanent, can start to decay and inflexible designs cannot accommodate the changing needs people may have (Askar et al., 2019).

Unmet environmental needs | The environmental, social, cultural, and economic performance of THUs is often scrutinised as described by Hosseini et al. (2021) and Felix et al. (2013). The critiques arise from the overall lifecycle of the THUs. Often the units are prefabricated in a location other than where they need to be deployed. The components can be directly shipped to the site and get quickly assembled. However, the primary energy demand and the greenhouse gas (GHG) emissions of the production, transportation and construction and their possible effects on the local and global environment are rarely taken into consideration.

The end-of-life scenarios for THUs are underexplored as the ownership of the units is not always clear and there is no plan for that stage. Usually, after they get deconstructed, some parts can get donated, sold for scrap or end at the landfill, which leads to the loss of a lot of raw materials (Felix et al., 2013; Perrucci et al., 2020). Pollution of settlement sites is also a problem as foundation, garbage and other remains don't always get cleaned up (Felix et al., 2013). This can have major consequences on the local community and surroundings. Environmental degradation can influence livelihoods, worsen social relationships and increase the chance of a flood or landslide (Global Shelter Cluster, 2021).

Unmet economic needs | Massproduced, industrialised units can have a very high cost, especially compared to local permanent reconstruction (Lizarralde et al., 2010). Besides the production and transportation cost of the units themselves, there are additional expenses connected to the infrastructure of temporary settlements. The maintenance of the units and the clearance of the site have yet an additional cost. As described by Felix et al. (2013) the price of a THU can accumulate to more than a permanent one, which in turn can delay the reconstruction phase and limit the number of beneficiaries. This perceived double construction can result in people staying in transitional housing longer than initially planned.

Usually, THUs are provided, and thus financed, by governments and NGOs. Funds are then often raised through donations. HO rely on donors and sometimes must fulfil certain expectations set by them, which have an influence on the budget decisions along the way. Nevertheless, the unit design and material choice have a huge influence on the production and maintenance cost. The overall investment in transitional housing, and thus the design of THUs, should be in consideration with an overall recovery and reconstruction strategy, as this can help better determine the expected occupancy period and quality needed (Lizarralde et al., 2010, p. 82).

The overall investment in transitional housing, and thus the design of THUs, should be in consideration with an overall recovery and reconstruction strategy, as this can help better determine the expected occupancy period and quality needed.

Uncertain context | *Uncertainty* is yet another challenge. It is difficult to predict how many people will be affected and in need of a THU before a natural disaster or conflict strikes. This can lead to challenges in material procurement. Furthermore, in many cases a crisis is not an isolated event. Cascading hazards, so one situation shortly following another one, could pose additional challenges for shelter and settlement planning and construction (Simons et al., 2020). THUs should therefore be resilient to existing and expected dangers and a hazard preparedness plan should be included in the design process.

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Unmet cultural needs | Prefabricated and standardised THUs often follow a top-down approach and are planed with little consideration or participation of the end user due to monetary and manufacturing time restrictions. A culturally unfit shelter can have a negative impact on the psychological health of residents (Perrucci et al., 2020). In those cases, people may abandon or try to modify the units by themselves (Askar et al., 2019). This is not always done in a safe manner due to lack of knowledge and tools. Such modifications can lead to damages of the materials, potential health risks and even less resilience towards future disasters (Felix et al., 2013).

The provision of transitional housing to beneficiaries can sometimes take a long time, extending their stay in emergency shelters. The sooner THUs are available for DP, the better it is for their self-resilience and psychological well-being. Delays can be caused by many factors, including securing of land, providing of infrastructure, procurement agreements with suppliers, information gathering. Many of these issues can be avoided if a strategic plan is drafted as preparation even before a disaster strikes (Lizarralde et al., 2010). Such preparedness plan can already include data about culture, material availability, safe temporary settlement locations with infrastructure, hazard evaluation etc.

Transitional housing: a necessity | Even though the need of transitional housing at all is being questioned by some experts, due to the described challenges, Cassidy Johnson highlights that the long waiting period till a permanent accommodation is completed (up to several years) inevitably makes THUs a necessity (Lizarralde et al., 2010, p. 74). Even when there are many ways to support DP, transitional housing remains one of the valuable mid-term options. In the long term, it can even prove to be a rather cost effective approach as the livelihood opportunities reduce the beneficiaries' reliance on external assistance (Shelter Centre, 2012). A problem arises when the transitional nature of THUs turns into a permanent state, as it has happened before (Lizarralde et al., 2010, p. 75; Askar et al., 2019).

This does raise the question of what is temporary and at what point does *temporariness* become *permanence*? Long-term strategies for a secondary use of the unit and its components thus become extremely important. At best transitional housing designs allow units to be relocated, repaired, and partially or fully integrated in permanent reconstruction. This additionally allows funding from the recovery phase to remain with the beneficiaries (IFRC, 2011). At worst they get abandoned, burned, or end up at a landfill where the material value is lost.

2.3. Lifecycle and end-of-life scenarios of transitional housing units

A common criticism towards THUs is that they are uneconomical due to the high production investment for a relatively short lifespan. The quality of the materials used in a given THU project is often dependent on the anticipated service life. In some cases, when the expected occupancy is short, cheaper materials are prioritised. In other cases, better quality is preferred, as it allows beneficiaries to reuse those elements in permanent reconstruction. A consideration of the end-of-life (EoL) scenarios during the initial planning phase of a project can help retain the material value, not only for the duration of the displacement, but also after the units are no longer needed as such. This subchapter analyses the most common EoL scenarios for THUs.

Lifecycle of transitional housing | The lifecycle of THUs differs in each particular situation, based on location, material quality, availability and more. It mainly follows a linear take-make-waste approach. Components are often produced far away and imported from abroad. After being transported to the building site, the THUs get assembled and distributed to beneficiaries. The people live there for the duration of the displacement. Modifications and upgrades are often made to the units in order to meet the needs of the DP. After the service life of the units, following EoL scenarios are most common:

No action | If the THU are designed without a consideration of the local context and culture they might get rejected by the DP and abandoned, leaving the units to decay and thus resources go to waste. In other cases, people remain living in a transitional settlement for way longer than initially planned due to ongoing conflicts, financial difficulties or lack of alternatives. Units unfit for such prolonged period of time deteriorate or get unsupervised modifications. Such settlements might turn into a slum, creating health risks for the inhabitants (Askar et al., 2019).

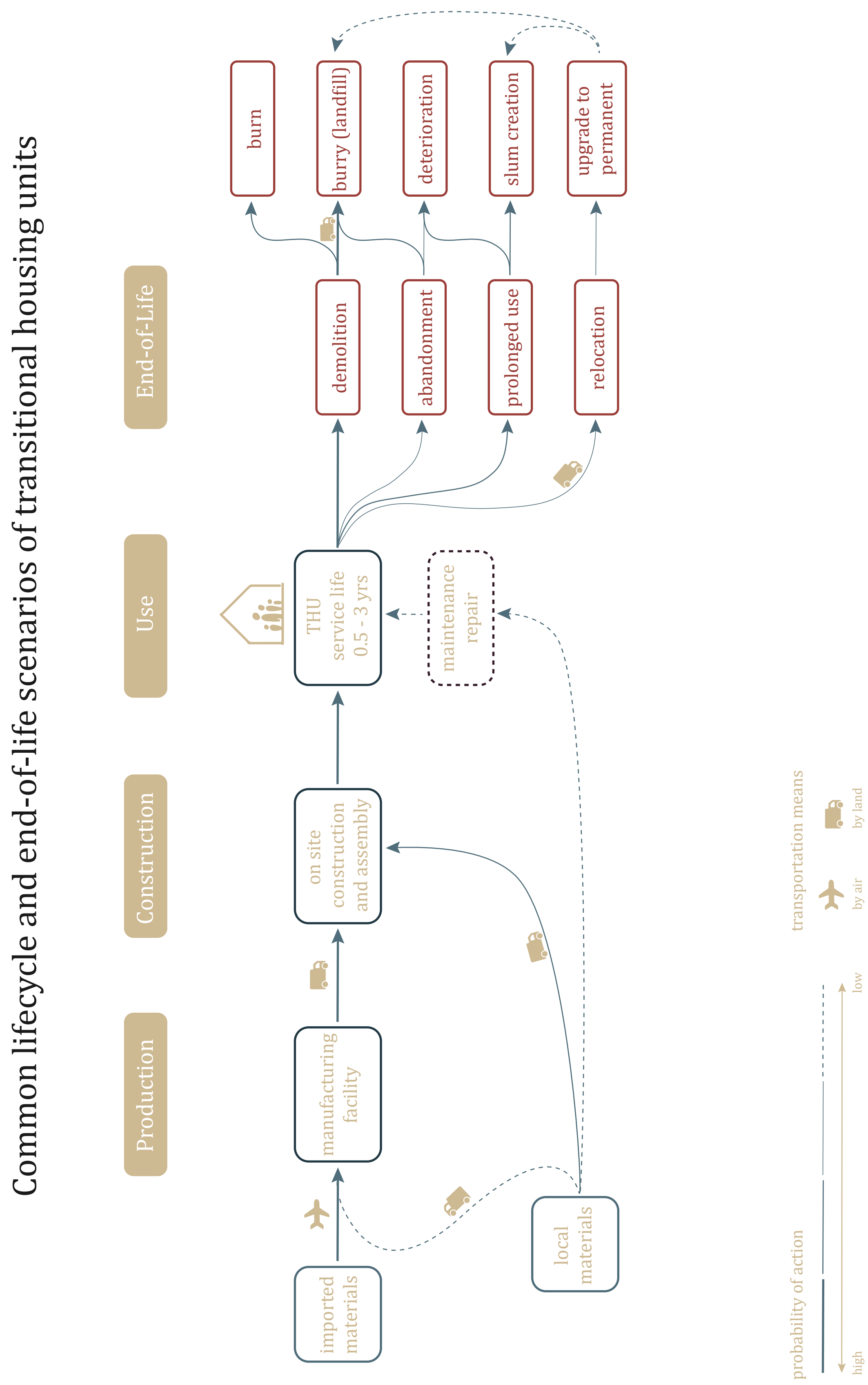
Demolition | A common scenario is the demolition of THUs at the end of their service life, after which the materials end up being burned or left at a landfill. This leads to a loss of raw materials and investment, while generating a high amount of waste. If not demolished properly, it can lead to degradation and pollution of the local environment, which in turn can heighten the risk of natural disasters.

Upgrade to permanent | Core shelters are used as a starting point for an incremental house reconstruction. Usually, they are placed directly on a plot owned by the beneficiaries. A THU, which has been used on a temporary location, could be relocated to a permanent site and be converted into or integrated in the permanent building (Lizarralde et al., 2010; Shelter Centre, 2012; Abulnour, 2014). This has a lot of advantages, as it allows the affected family to rebuild with their own speed and financial capacity.

If incremental evolution of the building is planned in from the beginning, allowing for disassembly, it can still retain the value of materials and components even if the land needs to be freed up. Transitional shelter designs guidelines also recommend prioritising better quality materials, so that at least parts of the units can be used by beneficiaries in the reconstruction. For example, roof beams made of timber or bamboo, which are otherwise expensive, can be utilised (IFCR, 2011).

Donation | In some cases, units provided by HO get donated to local organisations after their initial use. This way the HO gives up the responsibility of what happens with the materials. If the local organisation reuses the units directly and takes care of later recycling of the materials it is a more circular option, however, this is not always the case.

Figure 12.
Common lifecycle and end-of-life scenarios of transitional housing units



2.4. Common design principles

Introduction to existing humanitarian shelter guidelines | Humanitarian Organisations have developed shelter recommendations based on their experience in the field as a means to support the design process in a disaster aftermath. The *Sphere Handbook* and additional guidelines, provided by global organisations like UNHCR and IFRC, which are the main HO for conflict and natural disaster refugees respectively, are internationally accepted and followed. Those standards are by no means mandatory, furthermore, they provide general recommendations with little explaination on how to achieve them. But they stress the importance of *shelter appropriateness* (adaptation to needs, culture and capacity) (IFRC, 2011). Moreover, in each country, region and for each situation a different response is adequate, meaning that there isn't a universal unit or a single approach which is able to address the challenges for every area.

Once the need for transitional housing has been identified, a *design brief* is being prepared (IFRC, 2011). In this document different key criteria, based on the said guidelines, are being identified and weighted. Ideally multiple stakeholders (subchapter 2.5) participate in the development of the brief – affected population, government, and other coordination bodies.

Moreover, in each country, region and for each situation a different response is adequate, meaning that there isn't a universal unit or a single approach which is able to address the challenges for every area.

Design recommendations based on humanitarian guidelines | Based on the Sphere Handbook (2018) and the IFRC booklet "*Transitional Shelters - Eight designs*" (2011), the following general recommendations can be identified:

Life span | The THU' expected service life needs to be defined in the design brief, based on the context. This will influence the materials' quality in consideration of the units' duration and cost. The material specifications should also be described in the design brief and used for quality assurance. The expected service life of the units should be determined in consideration with the reconstruction planning.

Covered living space | The size requirements might differ in every situation, but according to Sphere (2018), a minimum 'covered living space' of 18 m^2 or 3.5 m^2 per person is prescribed. If cooking and sanitation facilities are included, the required space is 4.5 - 5.5 m^2 per person. External living spaces, such as verandas, are included in this number.

Head height | A minimum of two meters is required. It is recommended to keep ceilings in colder climates low and increase the height to over 2.60 m in hot climates.

Hazard resistant construction | THUs should prevent fatalities or injuries in a secondary disaster (IFRC, 2011). This requires a careful analysis of the potential hazards. If the area is prone to earthquakes, floods or storms, the structure should be able to resist or at least not endanger the occupants if it fails structurally. THUs should be planned in such a way to mitigate existing and expected hazards (flood, storms, earthquake etc.). Beside a safer settlement location, some design alterations can help prevent injuries or damage. For example, in flood areas, it is recommended to raise the floor level.

Ventilation and Thermal Comfort | THUs should be adapted to the weather and seasonal changes of the disaster location. Having an option for cross ventilation is recommended for warm climates, while care for minimising air infiltration is suggested in cold areas.

Accessibility | People with disabilities or specific needs of any kind, should be considered in the design process.

Simplicity | Overcomplication should be avoided. Design requirements, too difficult to implement or engineer, will result in a high cost or construction delays due to additional training or resource requirements.

Shelter as teaching tool | Some elements of the THU, like location of openings or connections, can be used to teach safe building practices to the locals. This capacity building strategy supports people's self-resilience.

Consideration of Building codes | Even though usually building codes are for permanent structures and are not always directly applicable to temporary ones, complying with them will ensure safety. If no local building codes are available, the International Building Code / Uniform Building code can be used as a reference.

Plot size | The plot size should be at least twice as big as the shelter footprint. Preferably, this are can be increased to four or five times.

Fire safety | Distance between shelters should be enough to prevent a fire spreading. A minimum of 2 meters, preferably double the building height.

Local resources | Taking the local context in consideration in the design process is extremely important. This includes the culture, traditions and customs, religion, politics, economy, as well as the natural environment and climate. Utilising *local resources*, such as materials, workforce, construction techniques and building forms, is a good way to ensure social acceptance, while reducing the transportation and maintenance costs (Felix et al., 2013; Antonini et al., 2020). It can be a push for the local economy and local materials are usually suitable for the climate.

Simple technologies (low-tech) can provide comfortable indoor and outdoor conditions with a limited energy input, making them a sustainable and affordable option for transitional housing (Antonini et al., 2020). This does not mean that new innovations are seen as redundant, but rather complimentary if introduced carefully (ibid.). Especially in THUs for DP, when units will remain at a certain location for a limited amount of time, innovation can enhance the use of local resources.

Common design concepts | Even though there is a great variety of THU designs, there are several approaches that are commonly followed, based on the materials used and production location: *Steel framed prefab units; Timber/Bamboo framed units; Combined materials.*

Steel framed prefab units - A universal design for transitional housing is a fully prefabricated unit like the Better Shelter Relief Housing Unit (RHU) or the Azraq T-shelter (Figure 13). This approach includes a steel frame and sandwich roof and wall panels. The whole unit can be easily manufactured, packaged, and shipped, usually from abroad. It is lightweight, which makes assembly onsite easier. However, those units are meant for a multitude of locations and situations, thus they are not adapted to a particular culture nor climate. Such units tend to overheat, especially in hot climates, so that modifications are needed to increase the indoor comfort (Turk, 2022). Those modifications are not always executed in a safe manner as they are not planned for in the initial design. Maintenance and repair can also be difficult as foreign materials are being used. Overall, those units tend to be quite expensive and carbon-intensive.

Figure 13.
Steel framed units
13.1. RHU Better Shelter, deployed worldwide incl. Pakistan;
Photo: Alaaddin Seyitisa
13.2. T-shelters with makeshift extensions for shading and privacy, Azraq Camp, Jordan;
Photo: Reuters
13.3. Post-earthquake shelter 2010 Spanish Red Cross, Haiti;
Photo: Beatriz Garlaschi


13.1.


13.2.


13.3.

Figure 14.
Timber/bamboo framed units
14.1. CRS transitional shelter 2012 Sindh, Pakistan; Photo: FE Altamash / CRS
14.2. Transitional timber frame shelter 2009 Sumatra, Indonesia; Source: IFRC (2011)
14.3. Transitional shelter being relocated 2011 Mindanao, Philippines; Photo: Charisse Mae Borja / CRS

Timber/Bamboo framed units - As an alternative to the steel frame profiles, timber and bamboo are often used for the main bearing structure (Figure 14). Especially in tropical and subtropical areas, where the climate is suitable for those materials and they can be procured locally. Using materials, which are familiar to the beneficiaries, ensures acceptance and ease of maintenance. The structure needs to be protected against termites and raising moisture from the ground. This is usually done by lifting the floor level with concrete bucket foundation or treating the components against pesticides. Often wall mats, roofing panels and flooring elements are fixed with nails to the loadbearing frame. These connections could damage the components during disassembly. A challange for those THUs can be the availability of materials as a high amount can be required on a short notice.

Figure 15.
Combined materials units
15.1. Transitional shelter 2010 Northern areas, Pakistan; Source: IFRC (2011)
15.2. Adobe houses in transitional settlement 2015 Idleb, Syria; Photo: QRC turkey / Media Unit
15.3. Transitional shelter 2017 Kalutara & Galle, Sri Lanka; Photo: Charmalee Jayasinghe

Combined materials - There are also THUs which have a combination of local and internationally procured materials (Figure 15). Usually, a locally sourced timber and bamboo structure is made. In some cases, bricks or mud are used for the wall construction. The higher thermal mass is beneficial in cold climates, however, it reduces the 'transportability' of the unit. Corrugated steel roofing and plastic sheets (tarpaulin) are often imported from abroad. The tarpaulin is one of the most widespread materials provided by HO in post-disaster situations. It is made of three layers of polyethylene and is created to be a strong, flexible, and waterproof (Antonini et al., 2020). Used as part of emergency or transitional shelters, the plastic sheet can be potentially reused by beneficiaries in the reconstruction of their homes as a vapour barrier. Even though multifunctional, the material has a high environmental impact and is difficult to recycle.

2.5. Stakeholders in transitional housing projects

Stakeholders | When it comes to post-disaster emergency handling, recovery and reconstruction, management and logistics become very important. Humanitarian crises are complex and can involve a lot of coordination between stakeholders on local, national, and international level. Depending on the country and context, the actors and their responsibility in the transitional housing design process may vary, but mainly those include: the government (local and national), members of the affected community, HOs and NGOs, donors, civil and voluntary associations, private sector (designers, builders, and suppliers), academic institutions and media (Abulnour, 2014).

Dealing with complex problems like construction, especially in extreme circumstances, is connected to a lot of uncertainty and restrictions. Decisions need to be taken about the quantity and quality of the units, the materials and building techniques, possibility of community involvement and likely EoL scenarios among other things. In this subchapter some of the main different stakeholders and their roles will be investigated, as well as their relations between each other.

Depending on the country and context, the actors and their responsibility in the transitional housing design process may vary, but mainly those include: the government, members of the affected community, HO and NGOs, donors, civil and voluntary associations, private sector, academic institutions and media.

The government | Often one of the main actors, and usually first to respond, is *the government*. Depending on the magnitude of the crisis it can be the national or local government, or both. Different governmental agencies and ministries are also included. The main role of a government in general is to support and help its people. In a post-disaster situation, it is usually the main coordinator, responsible for logistics, management, reconstruction plans, funding. This stakeholder is present through all emergency phases, from direct response, through recovery, to the long-term mitigation and preparedness. An active involvement in the latter two can significantly increase the resilience and reduce the vulnerability of the people and area to future crisis situations.

Affected population | *Crisis-affected people* can be displaced, non-displaced or be part of the host community. The DP is considered most vulnerable, as they are unwilling or unable to remain in their current location. This uncertainty can be coupled with different legal or social issues. Non-displaced people are able to stay where they are, for example if they are landowners. Indirectly affected by the crisis are also members of the host community, where DP have moved to. This can be due to pre-existing resource or housing scarcity. In any case, people, affected by a disaster or conflict, are a key stakeholder in the post-crisis recovery.

It is essential for AP to be involved from the beginning in the shelter design, coordination, and construction process, as they know best what their capacities, needs, priorities and vulnerabilities are (Shelter Centre, 2012; Global Shelter Cluster, 2021). It is also important to have representatives from all segments of the population to *ensure social equity*, especially marginalised groups, which may face bigger challenges or have special needs.

Moreover, by giving people a role in the planning of their own housing unit, communal collaboration and the sense of ownership, identity and empowerment are being strengthened. This has a direct influence on the acceptance and maintenance responsibility people feel towards their transitional housing. However, community participation in the form of interviews, workshops, or surveys, even though helpful, may not always bring reliable and useful information, as beneficiaries don't always understand the possible consequences of certain desires (such as higher maintenance cost of a detached unit) (Lizarralde et al., 2010). To prevent such issues, adequate professional advice needs to be present.

Humanitarian agencies | *Humanitarian agencies* are the turning wheels of the humanitarian sector. HO vary in size and capacity, but the main goal is to provide aid to people in need. The bigger agencies usually operate on an international level and have additional local teams in multiple countries. A common coordination methodology followed by international (and replicated by national) HOs is *The Cluster approach* (IFRC, 2013). Several HOs can group (cluster) and focus on a particular action sector, such as Shelter, Health, WASH, Education, etc., and together plan a coordinated response. The Cluster approach divides the responsibilities between the agencies and ensures better leadership and coordination. Furthermore, communication between the sectors is important, as they inevitably influence each other. Without the provision of water and sanitation (WASH) or protection, shelter units might get rejected. Inter-sectoral response coordination can ensure that aid is distributed more equitable, avoiding gaps and duplications (Global Shelter Cluster, 2014).

Donors | HO are highly dependant on donations for their operations. Without funds, they are unable to provide aid. *Donors*, therefore, play an important role as a stakeholder. In some cases, donotations are linked to specific requirements, such as amount of shelters provided, which can limit the agencies' capacity to adapt the design proposals to the current situation.

Private sector | The *private sector* can become a very important participant in a humanitarian responce, as it brings important expertise and capacity. It's involvement, however, needs to be in consideration with the non-profit essence of humanitarian aid (Shelter Centre, 2012). The involvement of small businesses can be benficial for the local economy.

The humanitarian stakeholder ecosystem can be complex and dynamic (Figure 16). As seen in this subchapter, there are many different actors, who coordinate on a national and international level.

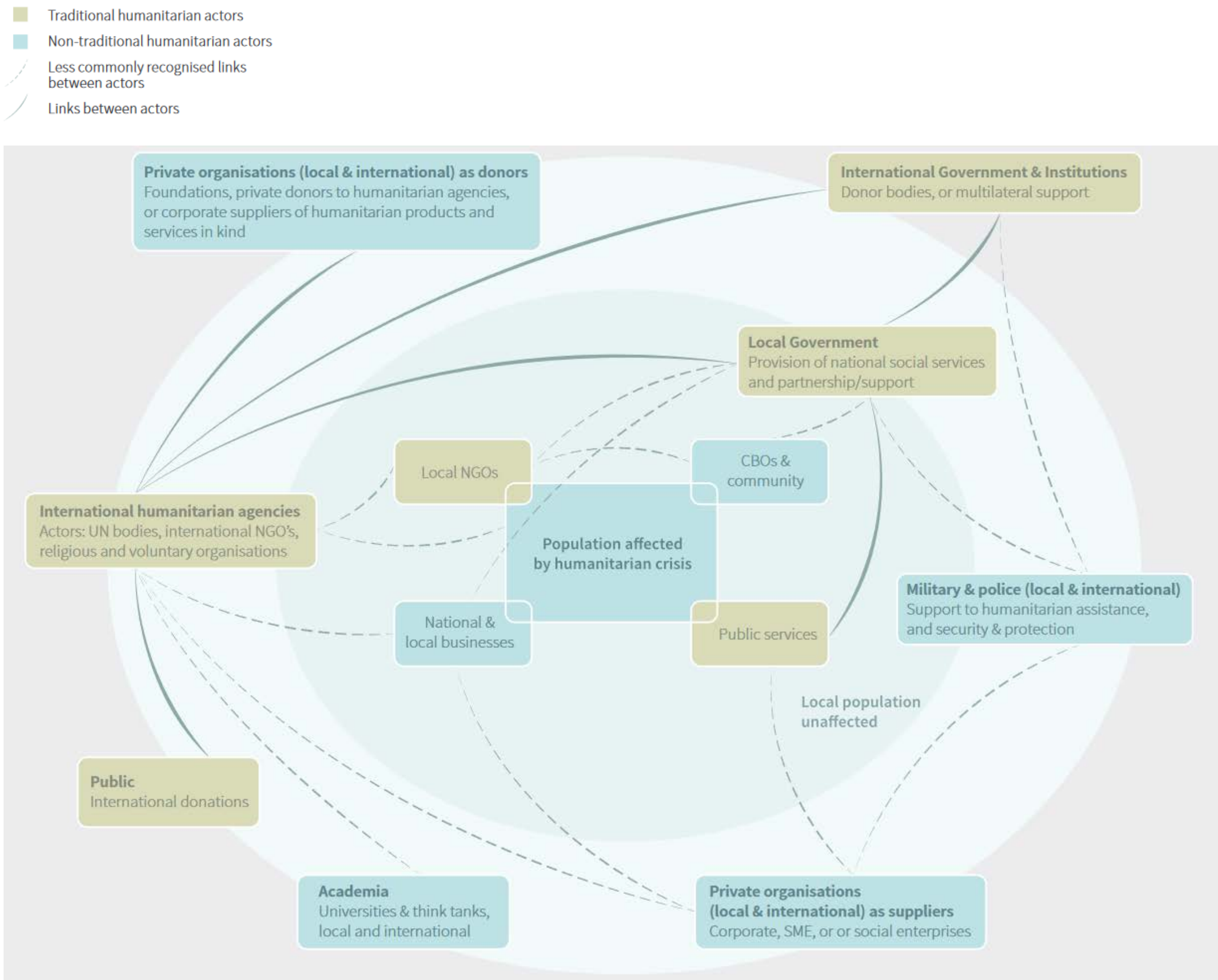


Figure 16.
The humanitarian ecosystem; Source: Betts et al., (2014)

2.6. Taxonomy of transitional housing procurement approaches

Top-down | *Top-down* and *bottom-up* seem to be the main approaches to humanitarian innovation (Antonini et al., 2020). The former one can be quite controversial. On one hand, it allows cross-sector collaboration and an adequate response by a lack of local resources; on the other hand, it can result in culturally and environmentally ignorant designs or high import and transportation cost (ibid.). Top-down units often make use of prefabrication benefits (fast manufacturing, quality control) and result in ready-to-use houses, such as the steel framed prefab units in subchapter 2.4.

Lizarralde (2010) describes it as 'a concentrated decision-making process' referring to a single entity or a small group of governmental or non-governmental organisations, which take on the planning, design, and management of housing units. Based on the gathered (not always available) information, usually one replicable housing model unit is identified and distributed (Lizarralde et al., 2010, Ch. 2; Rathnasinghe, 2021). This approach often leads to the formation of settlements on less desirable land, where infrastructure and employment opportunities are lacking. Lizarralde argues that it is hardly possible to come to a satisfactory result that can comply to diverse and dynamic requirements by following this decision-making process. Often the beneficiaries are not included in the top-down approach, which can alienate them from the THUs (Abulnour, 2014).

Bottom-up | The bottom-up approach is directly connected to community participation. It fosters community self-resilience, participation, and creativity, while commonly achieving more sustainable and economic results (Abulnour, 2014; Antonini et al., 2020). AP are often able and willing to get involved in the reconstruction works, which can assure a proper response to their acute needs and a sense of wellbeing (Felix et al., 2013). Furthermore, community-based approaches help bring the beneficiaries to the decision-making table of the long-term development opportunities (Abulnour, 2014).

Lizarralde (2010) argues that formal reconstruction projects can improve by learning from the low-cost and adaptable construction techniques of the informal sector. Though most of those techniques target a more permanent housing establishment or reconstruction, important lessons can be learned for the 'transitional' case as well, especially connected to space utilisation, personalisation, and adaptability.

Meeting in the middle | Generally, top-down approaches aim to deliver a great number of similar units in the shortest timeframe, while bottom-up ones usually produce less but more diverse units (Abulnour, 2014). A middle approach, as a combination between the top-down and bottom-up, can be beneficial in many cases. The advantages of the decentralised planning can be achieved by involving affected families as much as possible in the planning of their own unit (and neighbourhood) under proper organisation and professional advice. The advantages of prefabrication can still be utilised by creating standardised components, which can be assembled in a variety of configurations. A combination of community participation and standardised components can bring both economic and social benefits to the project (ibid.).

> *A combination of community participation and standardised components can bring both economic and social benefits to the project.*

Management | Many of the problems associated with transitional housing can be prevented or mellowed down through timely planning. In many cases, the THU design process starts after the onset of the crisis during the emergency response and early recovery. In those urgent circumstance, decisions need to be made quickly, in order to help as many people as possible. Including THU planning in the preparedness phase, before a crisis occurs, can save resources, time, and assure a locally adequate design. Disaster preparedness and mitigation is especially important in disaster prone areas. Furthermore, when a crisis does occur, it can become an opportunity to improve pre-existing conditions rather than return to the same standard (Abulnour, 2014).

> *Including THU planning in the preparedness phase, before a crisis occurs, can save resources, time, and assure a locally adequate design.*

3. Circularity for transitional housing

This chapter investigates circularity in the built environment and in the humanitarian sector. Circularity building principles applicable to transitional housing projects are identified and analysed for their potential risks and benefits. The various possible combinations of principles are shown on three case studies of circular projects. Based on the findings, alternative end-of-life scenarios for transitional housing are suggested.

3.1. Introduction to circularity

In a nutshell, *circularity* provides an alternative to the current linear throwaway economic approach by keeping the value of resources in the biological and technical material loops. Thus, the growth-based economy can be disassociated from the consumption of finite materials.

Circular Economy introduction | As the goods provided by the earth are limited, unrestrained consumption without regeneration of resources cannot be sustained indefinitely. This leads to social, environmental, and economic challenges. Instead disposing of materials and products after their useful life, in a circular system the value is being kept in the loop and waste is not generated in the first place. Thus, the resource consumption is decoupled from the economic growth (Zimmann et al., 2016). The guiding principles of Circular Economy (CE), as defined by the Ellen MacArthur Foundation (EMF), are to *eliminate waste and pollution, circulate products and materials* and *regenerate nature* (EMF, 2017) or with other words: *use less* (virgin materials), *use longer* (existing materials), *use again* (secondary materials) and *make clean* (renewable energy instead of fossil fuels)(Figure 17)(Circle Economy, 2023).

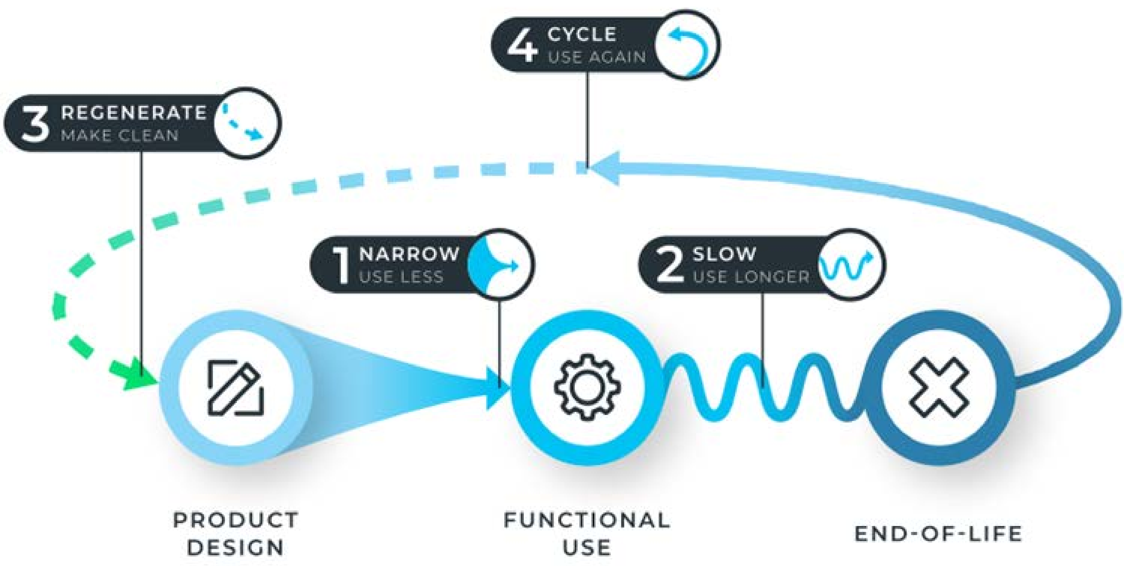


Figure 17.
Circular Economy principles;
Source: Circle Economy (2023)

Current status quo | According to the latest Circularity Gap Report (2023) the global economy is only 7.2% circular, with this percentage shrinking in comparison to previous years. This is due to an excessive extraction, overconsumption, and waste of materials (Circle Economy, 2023). There are enough available resources on the earth to ensure a good living standard for all of humankind, even with rising population numbers, without compromising healthy ecosystems or biodiversity (ibid.). Currently the distribution is not equitable, but a reimagining of the *take-make-waste* economic model and a collaboration between multiple actors can change that.

Scales of circularity | The CE is a holistic framework for covering the needs of the global population and future generations while remaining within the means of our planetary boundaries. For this to function effectively, all scales and their relations need to be considered, from the individual level (micro) to bigger communities and organisations (meso), as well as globally (macro)(EMF, 2017).

The interconnectedness and interdependence between the different scales can clearly be seen, for the context of the built environment (BE), in the *'Scales to Aspects'* model, developed by the Circular Built Environment (CBE) Hub of TU Delft (CBE Hub, 2022), seen in Figure 18. Beginning with Materials, zooming out to Buildings and ultimately looking at Regions, the model portrays the links between the scales. A products' circularity is therefore related to and dependant on several levels (Klein, 2023). The outer circle of the model depicts six aspects, or topics, which need to be taken into account as they have an influence on the transition towards circularity. The 'Scales to Aspects' model is an example for *systems thinking*, which is fundamental for a CE and will be explained further in subchapter 3.5.

Figure 18.
Scales to Aspects model Source: DelftX: CESBE1x Circular Economy for a Sustainable Built Environment

3.2. Humanitarian housing and circularity

Circularity in the humanitarian sector | There is a growing interest in sustainable and environmentally friendly approaches among humanitarian actors as the effects of climate change hit hardest the same peoples those organisations are trying to help. In line with the do-no-harm principle, many global HO work on reducing their emissions both internally and on the field, following global goals such as the SDGs (ICRC et al., 2023). Circularity is still a very new topic within the humanitarian sector. Nevertheless, it holds a lot of potential to utilise and improve the existing value chains across the different domains and actors.

Circular principles can transform THUs into material and component sources for new units or even other products (Perrucci et al., 2020). The retaining of the material value can as a result reduce the overall expenditure in the sector by providing a new income. The aim of this research is, therefore, to investigate how circular building principles can be integrated in the planning of humanitarian transitional housing and thus reduce the negative impacts THUs may have.

*"**Circularity is still a very new topic within the humanitarian sector.** Nevertheless, it holds a lot of potential to utilise and improve the existing value chains across the different domains and actors. Circular principles can transform THUs into material and component sources for new units or even other products.*

Humanitarian architecture and circularity as drivers of innovation|
The transition of the current throwaway economy towards a regenerative system is not going to happen overnight. Rather, it is a continuous process, in which business models, production techniques, and the general way things are being done, needs to be re-evaluated. This shift of thought requires innovation across a multitude of sectors. As a result, technological advancements, new market opportunities, and creative product development contribute to the generation and retention of value while minimising the environmental impacts.

Humanitarian assistance faces new challenges with the rising amount of affected people, limited funding, and prolonged severe crises. Innovation in the business models, logistics and technology can help the sector become more adaptable and resilient to change. There are, however, several hurdles to implementing new ideas in the sector, including a closed market system, ethical constraints, and aversion to risk (Betts et al., 2014). Nevertheless, the necessity and benefits of innovation are recognised and explored by humanitarian actors.

The extreme conditions, uncertainties, and constraints of humanitarian shelter construction in particular pose a playfield for process, product, and business model innovation, which can accommodate the varying environmental, social, cultural, and economic requirements of post-disaster architecture (Antonini et al., 2020, p. 6). Transitional housing units can further be seen as an example for small-scale architecture made in a scarce and harsh environment. A circular approach to such a complex design assignment can be a precedent for other global architectural challenges such as housing scarcity.

Especially in low-income countries, circularity appears to provide a pathway for sustainable development (Preston, 2017). Highly populated areas, which are often impacted by disasters, such as the south Asia region, may benefit from the creation of new sustainable business models and utilisation of available industrial secondary materials (Niazi et al., 2020). Overall, circular economy could be a 'powerful driver for innovation' in the humanitarian sector, while post-disaster architecture can as well 'provide a useful reference to manage the transition to the circular economy' (Antonini et al., 2020, p 47). Introducing circularity in transitional housing has the potential to foster crucial innovation in the humanitarian sector, which in turn could also be applied to tackling the challenges faced by the built environment.

Introducing circularity in transitional housing has the potential to foster crucial innovation in the humanitarian sector, which in turn could also be applied to tackling the challenges faced by the built environment.

3.3. Circular building principles

Circular Built Environment | Transitional housing is part of the humanitarian construction, which in turn is included in the broader sector of Architecture, Engineering and Construction. About a third of the world's material consumption and waste generation and roughly 40% of global GHG emissions can be attributed to the built environment (Circle Economy, 2023). This major impact on the planet, expected to grow even further if the business-as-usual approach is kept, can be reduced by implementing a closed-loop economic model.

The guiding principles of circularity: use less, use longer, and use again, help shape a CBE, which is defined as *"a system designed for closing resource loops at different spatial-temporal levels by transitioning cultural, environmental, economic & social values towards a sustainable way of living (thus enabling society to live within the planetary boundaries)"* (CBE Hub, 2022). Further benefits of a CBE include a higher resilience towards volatile commodities and prevention of delays and rising costs as a consequence of an increasing demand (Zimmann et al., 2016). Circular building principles are still being developed to adhere to the complexity of architectural planning. The rest of the subchapter fucuses on different circular building principles and how they can be implemented in transitional housing projects.

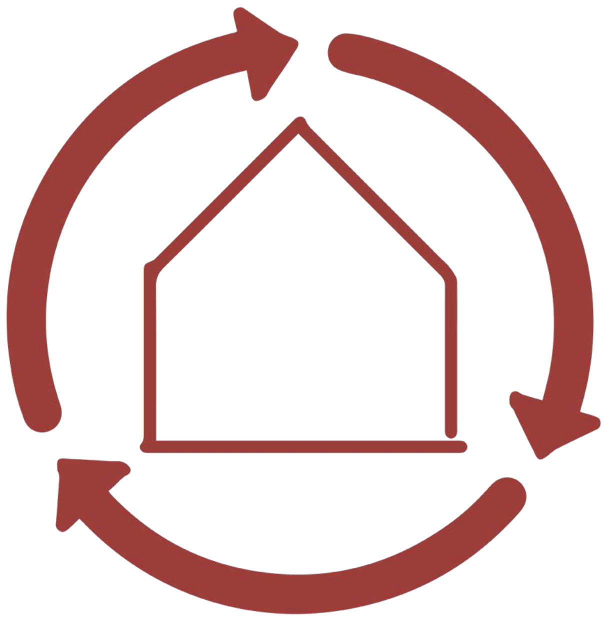


Figure 19.
Circular Built Environment

Product life-stages | A product, or a building as a whole, goes through several stages in its life cycle: *production, construction, use* and *end of service life*. Each of those stages has different duration and impact on the environment (Klein et al., 2019). The linear business-as-usual process leaves a lot of resources unutilised or wasted, while in a CBE the life cycle aims to restart after the end of service stage. In Figure 20 we can see in more detail the steps associated with each life cycle stage, like transportation and maintenance. This is important, when examining which stakeholders are involved and where interventions can be made to make a design more circular.

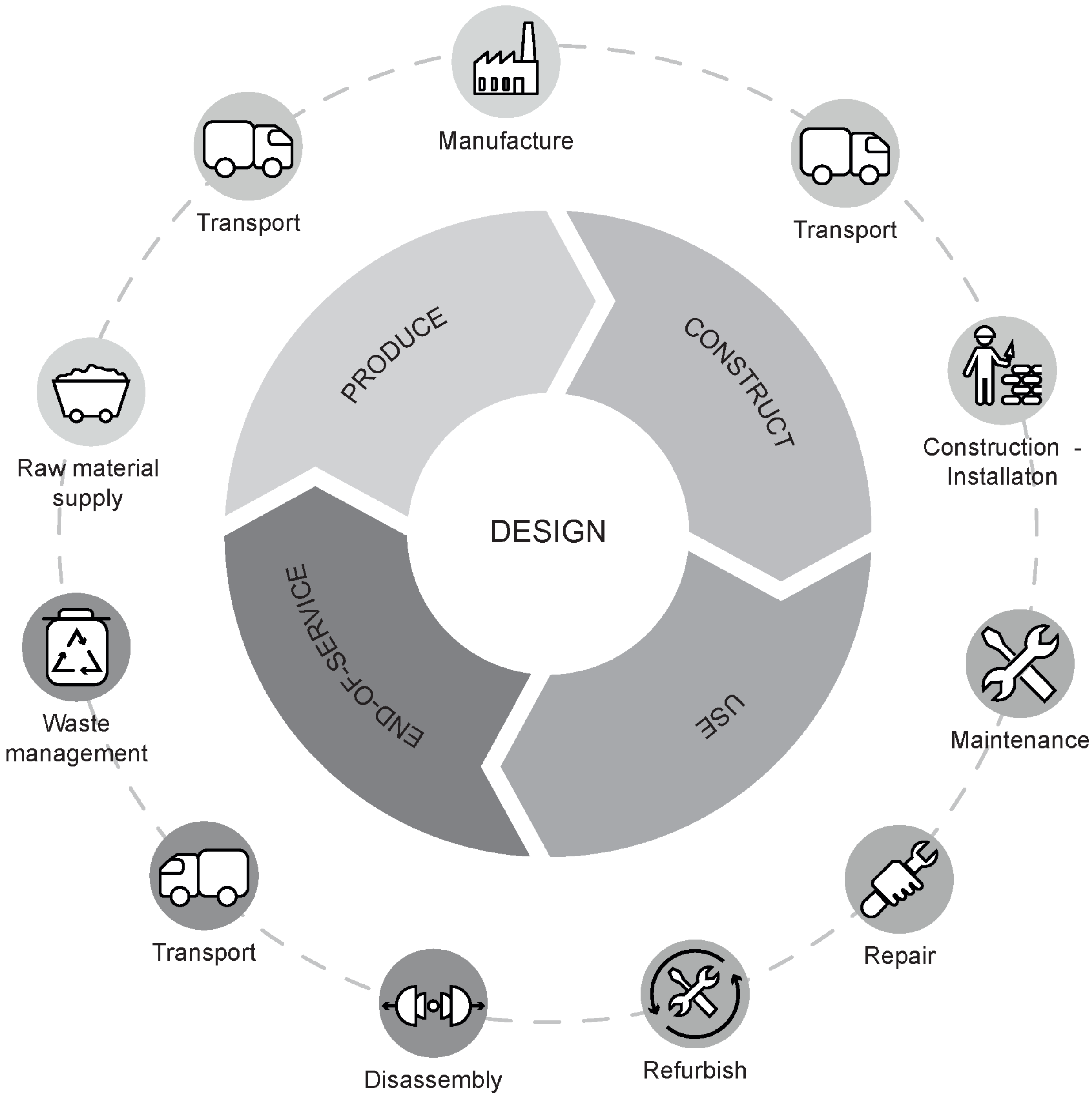


Figure 20.
Circular product lifecycle; Source: DelftX: CESBE1x Circular Economy for a Sustainable Built Environment

R strategies | The *10 R-strategies*, seen in Figure 21, are the main guidelines to design out waste. The most effective one is refuse, which questions whether a product is necessary to be created in the first place. The following R's become less circular. The first three strategies - refuse, rethink and reduce - are most powerful and target the initial product design stage. The following five – reuse, repair, refurbish, remanufacture, repurpose – aim to extend the product's lifespan and are utilised during the construction and use phases. When the EoL stage is reached recycle and recover can be used to retain some value. Recycling is a common EoL scenario, in which discarded materials are processed into new products with high quality (upcycling) or very often results in a lower material quality (downcycling). All of those strategies can be translated to THUs (subchapter 3.4). However, their implementation requiers innovations in technology, as well as collaboration of stakeholders and a shift of mentality (Ioannou, 2023d).

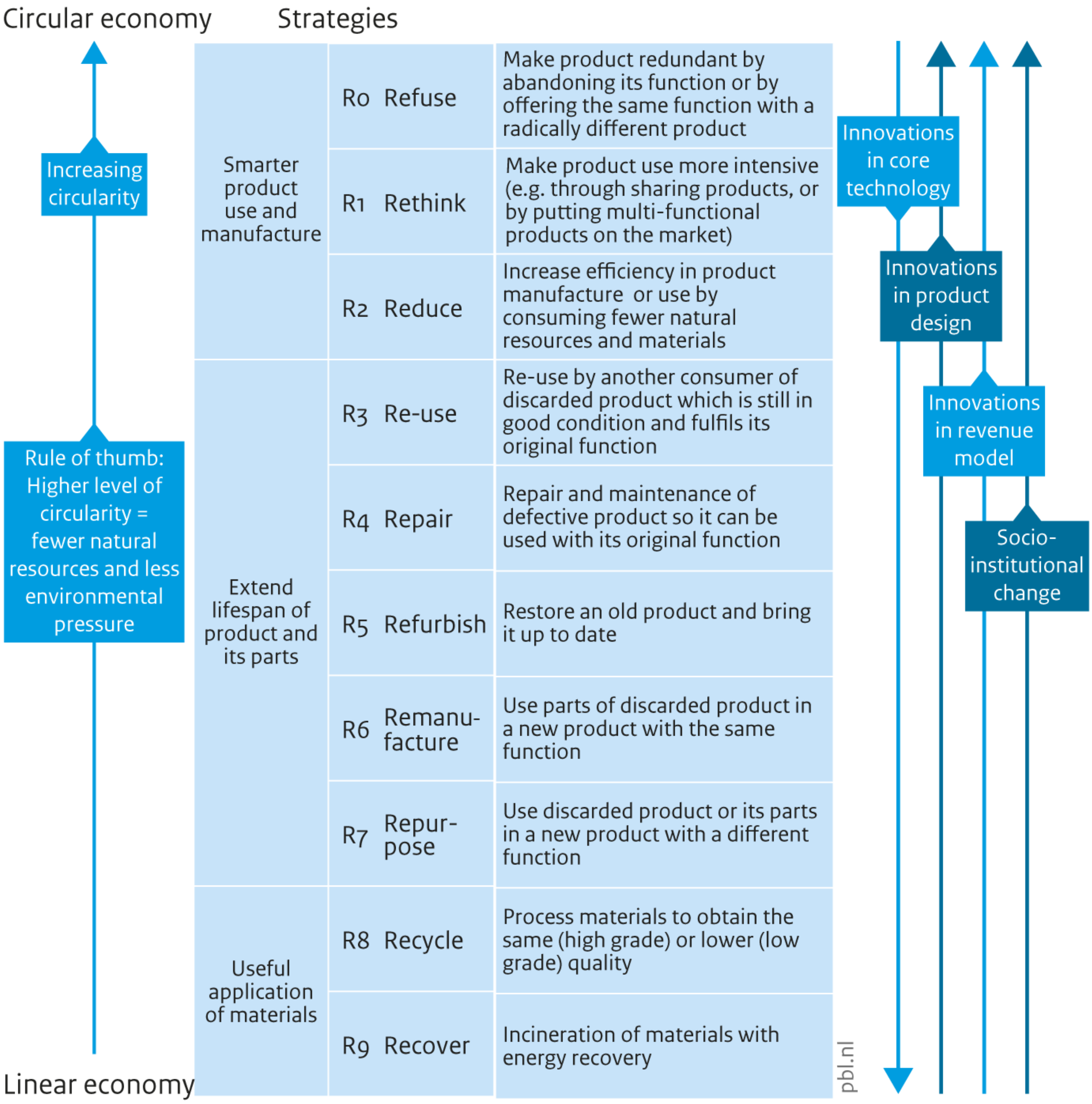
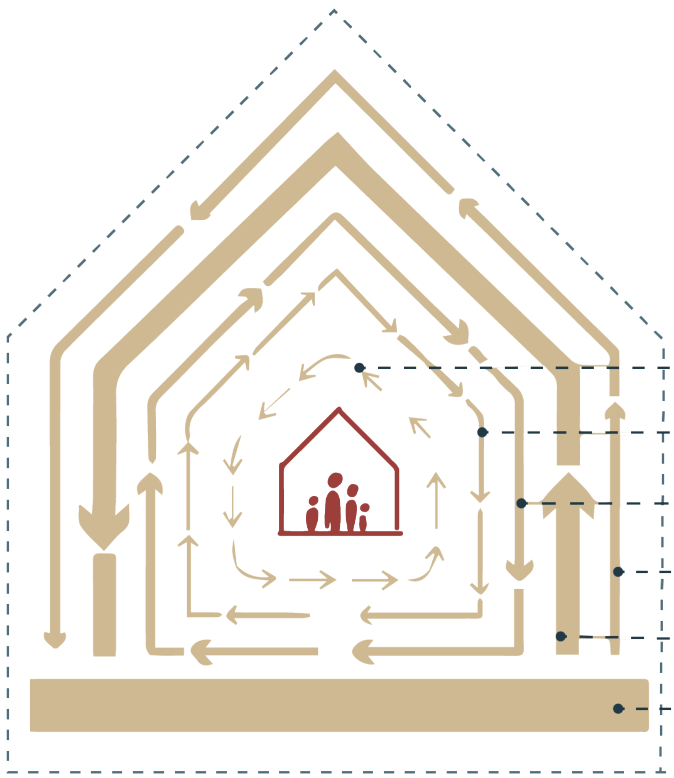


Figure 21.
10 R-strategies; Source: RLI 2015; edited by PBL

Shearing layers | A building has many different elements like structure, façade, and services. The *Shearing Layers of Change* concept, first introduced by Frank Duffy in the 70s and later developed by Stewart Brand in the 90s, explains that different layers of the building, like the skin or space plan, change at a different speed, meaning their lifespan differs (Brand, 1994). To implement circular design principles, those varying speeds of the six layers - *site, structure, skin, services, space, stuff* - and their features need to be considered. Thus, the circularity potential of a building can be increased from the beginning of the design process (Klein et al., 2019). By considering the layer of each component, it can be designed in such a way, that elements with a shorter lifespan can be removed, repaired, replaced or moved without affecting the longer-lasting ones.

Analysing the shearing layers of Transitional Housing can identify certain potentials and challenges. As seen in Figure 22, the duration of the separate layers of a THU is extremely shortened compared to those of conventional buildings. The biggest challenge is the uncertainty of the use (occupancy) phase, for which the context plays an important role. This context is considered as the seventh shearing layer called 'system', added by Arup (Zimmann et al., 2016). It includes all services and infrastructure for example in a district or a shelter settlement. The determination of the shearing layers duration of a THU is essential in developing strategies for the end of service life phase.



	Conventional Building	Transitional Housing
STUFF	0 - 5 years	daily
SPACE PLAN	3 - 30 years	0 - 1 years
SERVICES	7 - 15 years	0 - 3 years
SKIN	20 - 50 years	0.5 - 10 years
STRUCTURE	30 - 300 years	1 - 15 years
SITE	eternal	temporary
SYSTEM		

Figure 22.
Shearing Layers of Change; adapted from Brand (1994) and Arup (2016)

Domains of circularity | This research aims to compile a set of principles for circularity in the built environment which can be integrated in the planning of humanitarian transitional housing units. A comprehensive literature review, involving a systematic search and analysis of scholarly articles, reports, and other relevant literature from various sources, including academic databases and industry publications was conducted. The reviewed literature provided a diverse range of perspectives and approaches towards circularity which can be grouped into the four topics of *Materials, Design, Manufacturing,* and *Management* (Klein et al., 2022).

By examining these topics and principles, it becomes apparent that for a product or building's circularity potential to be high, a holistic approach that addresses all domains is required. In Table 1 the sources that contributed to each topic area are demonstrated, providing a clear and transparent outline of the literature review process. By drawing upon the collective knowledge and insights from these sources, this study aims to provide a comprehensive overview of circularity principles which can be applied in the context of humanitarian shelters. The rest of the subchapter focuses on each of the domains individually and maps out the relevant principles, as well as benefits and risks associated to applying them.

Table 1.
Literature review - overview of sources based on the topics: Material, Design, Manufacturing and Management

No	Source	Material	Design	Manufacturing	Management
1.	Abulnour (2014)	X	X	X	
2.	Antonini et. al. (2020)	X	X	X	X
3.	Arslan (2005)	X	X		
4.	Arup & EMF (2022)	X	X	X	X
5.	Bakker et al. (2014)		X		
6.	Circle Economy (2023)	X	X		
7.	Circularity for Educators (2023)*	X	X	X	X
8.	Felix et al. (2013)	X	X	X	
9.	IFRC (2011)	X			X
10.	Klein et al. (2022)	X	X	X	X
11.	Kuittinen et al. (2015)	X			
12.	Kuittinen (2016)	X			
13.	Lizarralde et al. (2010)	X		X	
14.	Marques (2014)		X		
15.	Nunez (2017)	X	X	X	
16.	Perez-Valcarcel et al. (2021)		X	X	X
17.	Perrucci et al. (2020)	X	X	X	
18.	Rathnasinghe et al. (2021)				X
19.	Shelter Centre (2012)	X	X	X	
20.	Widyarko et al. (2021)	X	X		X
21.	Zimmann et al. (2016)	X	X	X	X

*Circularity for Educators (2023) is a joined reference for the following sources: Azcarate Aguerre (2023), Brancart (2023a, 2023b), Ioannou (2023a, 2023b) and Smit (2023)

Materials | The choice of materials and how they are handled is crucial for circularity (Azcarate Aguerre, 2023). The material extraction rate has been growing over the last decades, reaching 100 billion tones per year, and leading to environmental damages (Circle Economy, 2023). It is therefore important to consider where and how are materials being extracted and what happens at the end of their service life in order to keep their value circulating.

Timber, for example, is a common THU frame material. It is renewable, captures carbon from the atmosphere and can biodegrade. If taken from a sustainably managed forest, no harm is done. But in some cases, like the construction of settlements after a disaster, a rapid and excessive use of wood for shelters is necessary. Taken unmonitored from a nearby location, it can lead to an irreversible deforestation of the local environment (Brangeon et al., 2020, p.20). Materials acquired unsustainably have up to over 50% more kg CO_2 emissions per m^2 compared to materials coming from sustainably managed forests (Kuittinen, 2016). This shows that even generally sustainable materials can become unsustainable if not procured responsibly.

In a CE waste is seen as resource, which can lead to many unusual but effective creative ideas, which fit the local context. That way available material streams from other industries can be reclaimed as a resource for the building project, becoming an alternative to the traditional local material. Waste materials such as car tires or rubble can be reused as foundation. Other unconventional materials have also been used for emergency shelter construction as well, such as old skis, carboard tubes, or even beer crates (Figure 23).

Figure 23.
Shelters made from unconventional materials
23.1. *Ski shelter in Cacine, Guinea Bissau; Source: Salvalai et. al, 2016*
23.2. *Papertube shelter, Shigeru Ban; Photo: Shigeru Ban Architects*
23.3. *Beer crates shelter - ECS-p1; Photo: Richard Douzjian*

Butterfly diagram | Biobased materials, such as timber, are part of the biological cycle (left) of the *Butterfly diagram* (Figure 24), which portrays the material flow system in a CE (EMF, 2019). After the use and potential reuse of the biobased materials, they can be returned to the ecosystem through composting or anaerobic digestion. The smaller the circle on the diagram, the higher the circularity potential. The technical cycle, the right side, portrays the destiny of man-made materials such as plastic or metals. They are often present in limited quantities and require a lot of processing before becoming useful in construction (Azcarate Aguerre, 2023). Technical materials can further be a cause for pollution, during extraction, manufacturing or degradation.

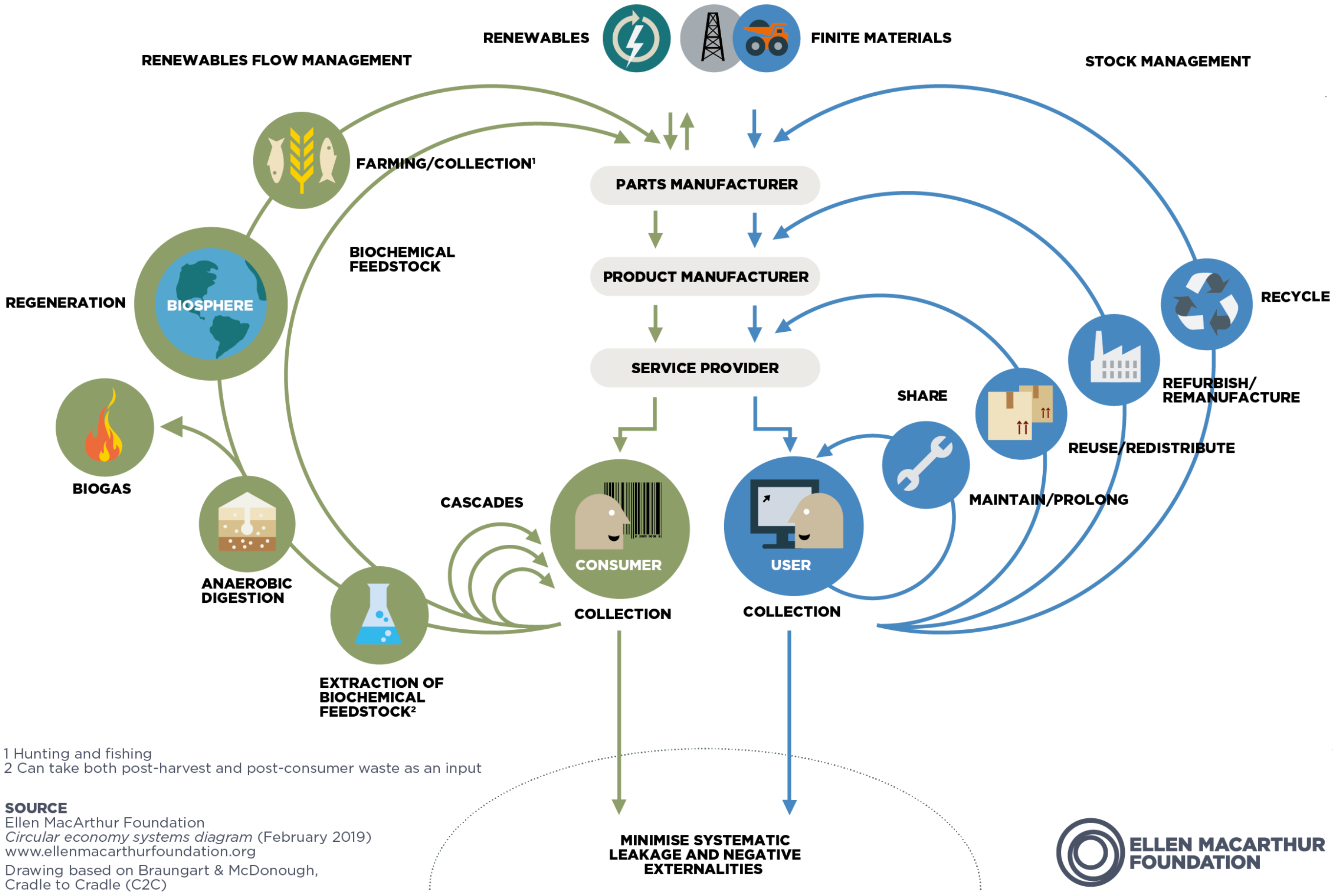


Figure 24.
Butterfly Diagram; Source: EMF (2019)

Table 2.
Material Circularity Strategies relevant for transitional housing projects

In Table 2 the main circularity principles connected to *Materials* in the context of THUs are described. Further, some of the benefits and risks associated with applying those strategies are explained. The relevant sources, listed in Table 1, are indicated with their corresponding number.

Strategy	Description	Benefit	Risk
Local material [1][3][4][6][7][8][9][13][15][17][19]	Biological or technical materials, which can be (sustainably) sourced and processed from the area, region or country	∘ Reduction of delivery and transportation time & cost ∘ Locals are familiar with the materials and how to use and maintain them ∘ Support of the local economy ∘ Reduce tension between DP and host community	∘ Excessive/unregulated use can lead to resource exhausion or environmental deterioration ∘ Availability might be limited (due to market, infrastructure damage, seasonal change, etc.) ∘ Price increase due to high demand
Biobased material [4][6][7][10][11][12][20][21]	Materials, which can be returned to the ecosystem through composting or anaerobic digestion.	∘ Regenerative materials ∘ Material can be returned to the ecosystem thus not leaving waste ∘ Some biobased materials absorb carbon dioxide from the atmosphere	∘ Biobased materials often require coatings to protect them from fire, insects or rot. Such coatings may be toxic or prevent/disturb the composting process. ∘ Availability might be limited (due to the harvest season)
Waste material [2][4][6][10][21]	Materials, which are considered waste or are a byproduct from another process or industry	∘ Utilising existing materials/components extends their lifecycle, thus preventing extraction of raw materials ∘ Less emissions and embodied energy	∘ Quality of the material can be compromised; requires checking ∘ Availability might be limited (due to market, infrastructure damage, seasonal change, etc.)
Recyclable material [3][4][6][10][20][21]	Materials, which can be recycled into new components with the same properties	∘ More flexibility in design ∘ Usually materials are kept 'pure'	∘ The right recycling facilities need to be available in the host country ∘ Materials need to be collected at their end of life (transportation and logistics) ∘ Material quality might degrade after one or several cycles
Secondary streams [4][6][20]	Materials and components that have been reclaimed and reused.	∘ Utilising existing materials/components extends their lifecycle, thus preventing extraction of raw materials ∘ Less emissions and embodied energy	∘ Quality of the material can be compromised; requires checking ∘ Availability might be limited (due to market, infrastructure damage, seasonal change, etc.)

Design | In terms of design there are also several strategies that can be followed to incorporate circularity principles from the beginning, such as Design for Disassembly (DfD), Design for Repair (DfR), modularity and convertibility among others. Most of those strategies are not stand alone, but rather influence and complement each other.

Modularity, as a design method, can be very efficient for transitional housing as it can combine the benefits of prefabrication with specific occupant needs. Potentially, prefab modules can be more cost effective, rapidly assembled and disassembled and easily transported. Furthermore, a modular construction allows for design flexibility, upgrades and an incremental approach (Antonini et al., 2020). However, in some cases modular units may not be culturally appropriate, thus not universally suitable (Perrucci & Baroud, 2020).

Closely related to modularity is also the design for standardisation strategy, where components following a certain standard can fit and exchange with other products. This approach is cost effective as it allows the user to use parts from other manufactures, ensuring easy replacement, reuse, repair, and recycling (Bakker et al., 2014).

DfD ensures uncomplicated deconstruction and potential reassembly of the parts. This is a paramount principle for a circular design as it pays a lot of attention to the EoL handling of materials and components from the very beginning of the design stage. In a DfD the reversible (dry) connections are of upmost importance, with bolts and ropes preferred over inseparable adhesives or nails, which may damage the component.

Most of those strategies are not stand alone, but rather influence and complement each other.

An overview of the *Design* principles can be seen in Table 3. The benefits and risks associated with applying those strategies are explained. The relevant sources, as seen in Table 1, are indicated with their corresponding number.

Table 3.
Design Circularity Strategies relevant for transitional housing projects

Strategy	Description	Benefit	Risk
Design for disassembly [2][3][4][5][6][7][8][10][14][15][19][20][21]	Enabling the dismounting of components at the buildings end-of-service-life without damaging them in order to recover value. Possible reassembly. Some elements can be reused in another system.	∘ Recovery of material value at EoL phase ∘ Enabling R strategies ∘ Reduction of embodied carbon emission in long term ∘ Reduced raw material extraction in long term	∘ Connections may be more complicated (compared to using nails or glue) ∘ Potentially higher material use in first use cycle
Modular design [4][6][7][10][14][16][17][20][21]	A system containing several standardised parts (modules), which can be independently created, combined and exchanged.	∘ Allows for customisation, flexibility, and variation within the limits of the modules. ∘ Modules can be individually replaced ∘ Enabling reuse strategies	∘ Flexibility is limited to the amount and design of the composing modules.
Design for longevity [1][2][4][5][7][14][21]	Life of components is extended (through durable materials or flexible spacial layout), so that they can survive the expected service life (wear and tear) and even beyond that, in order to utilise reuse strategies.	∘ Enabling reuse strategies ∘ Less repairs needed ∘ Easy maintenance ∘ Reduced raw material extraction in long term	∘ Higher quality materials have a higher initial cost ∘ Possible overdimensioning of structure or spaces
Design for standardisation [2][5][7][10][19][20][21]	Components are designed following (inter)national norms and rules (standards), making them compatible and interchangeable with elements from other systems	∘ Easy repair/maintenance ∘ Quality assurance through definitive parameters ∘ Usually cheaper components ∘ Reduced manufacturing and assembly time ∘ Enabling reuse strategies	∘ Customisation is limited

Strategy	Description	Benefit	Risk
Design for adaptability [2][4][5][7][8] [20]	Adapting to changing function requirements during the use phase (or in a second life) through spacial layout reconfigurations, extensions or partial dismantling	∘ Adapting to new functions can prolong the service life ∘ Enabling reuse strategies ∘ Reduction of embodied carbon emission in long term ∘ Reduced raw material extraction in long term	∘ Custumisation might be limited ∘ Potential future functions might require higher material quality, load cases or openings
Material optimisation [4][6][20][21]	Optimisation of components and thus reduction of the necessary material; reduction of material waste and packaging	∘ Less material use / extraction ∘ Less carbon emissions and embodied energy	∘ Reuse potenial can be compromised ∘ Compatibility with other elements might be limited
Design for recycling [4][14][17] [20][21]	Keeping materials separated (pure) in order to make recycling possible	∘ Enabling R strategies ∘ Enabling proper disposal of materials at their EoL, thus reducing waste	∘ More complicated connections might be necessary

Manufacturing | Manufacturing is a crucial element in achieving a circular built environment. It is related to the fabrication of building components. Circularity strategies can contribute to optimising the manufacturing process by reducing production and packaging waste through more efficient tools and practices, while incentivising the reuse, remanufacturing, and recycling of materials. Closed-loop production systems further aim to create a circular flow of resources, including materials, energy, and water, where waste from one process becomes a valuable input for another.

Prefabrication, additive manufacturing, CNC milling, and robotics are examples of manufacturing techniques that can be employed to enhance circularity (Figure 25). The prefabrication of building components in factories can bring several benefits such as quality assurance, increased efficiency, and improved safety on site. Prefab elements are an integral part of modular construction methods. By using preassembled components, the construction on site is often faster and the need for energy-intensive heavy machinery is minimised.

Additive manufacturing, also known as 3D printing, allows for the creation of complex shapes by using only the necessary amount of material. Often residual waste can be used again as filament. CNC milling involves the use of computer-controlled machines to carve out building elements from raw materials, resulting in precise and accurate components. Robotics, on the other hand, involves the use of machines to perform repetitive tasks such as bricklaying, which increases the efficiency of construction. It can also be very well combined with prefabrication of components.

Building techniques, used by the local population, are especially relevant for humanitarian projects. They often use available materials and are adapted to the climate and culture. In some countries using vernacular techniques might be associated with a lower economic status as industrialisation has brought materials like concrete to the forefront. Nevertheless, incorporating local construction methods in post-disaster housing can provide sustainable, affordable and easily maintained options. Furthermore, vernacular building techniques can be coupled with the innovative ideas, creating more resilient construction.


25.1.


25.2.


25.3.

Figure 25.
Manufacturing methods
25.1. *TECLA, fillament of local soil from Massa Lombarda, Italy; Source: WASP, 2021*
25.2. *Flex office, TNM, Winterswijk, Netherlands; Source: TNM, 2020*
25.3. *Robotic fabrication of the BUGA Wood Pavilion 2019; Source: ICD/ITKE University of Stuttgart*

Table 4.
Manufacturing Circularity Strategies relevant for transitional housing projects

These manufacturing techniques contribute to circularity in the built environment by reducing waste and physical labour, while improving resource efficiency and construction safety. Table 4 gives an overview of those strategies.

Strategy	Description	Benefit	Risk
Pre-fabrication [1][4][7][10] [13][15][16] [17][19][21]	Components or units are prepared and assembled usually in controlled conditions, before reaching the building site	∘ Quality assurance ∘ Controlled production environment (temerature, humidity, etc.) ∘ Increased efficiency and reduced assembly time ∘ Improved safety on construction site ∘ Reduced material waste and operational energy	∘ Transportation to building site needs to be considered (size, weight of components) ∘ Potentially need for large factory space, storage and specialised equipment
Additive manufacturing [10][21]	The process of building up components by continiously adding material (layering)	∘ Relative big design freedom / mass customisation ∘ Use of one material ∘ Less waste and tools needed	∘ Special printers required, heavy machinery on site (unless used for prefabrication of components) ∘ High initial investment
CNC milling [10][16]	Computer-controlled machines carve out material to form components, substractive manufacturing	∘ Precision and production speed, less manual labour ∘ Safer and faster assembly ∘ Reduced waste ∘ Customisation	∘ High initial investment ∘ Special machinery required
Robotics [7][10]	Robot executes specific tasks with great precision. Following a computer profram the machine can run continiously in repetitive cycles	∘ Safer work environment ∘ Precision and production speed, less manual labour ∘ Control ∘ Great for repetitive tasks	∘ High initial investment ∘ Special machinery required
Vernacular building techniques [1][2][7][8] [13][19]	Utilising local knowledge on construction. Vernacular architecture is often accommodated to the local climate and culture	∘ Local availability of materials and experts ∘ Adaptation to the local context (climate, culture) and available technical knowledge ∘ Easier maintenance by the local population ∘ Cost reduction and push to local economy	∘ Possible lack of reliable information or available experts / skills ∘ Vernacular techniques might be stigmatised

Management | The management of a project has an enormous impact on the preservation of the material value. Even when circularity and sustainability principles have been implemented in the design process, if there is not enough information or proper regulation, the embedded potential can remain unutilised. A common circular business model is having a product as a service, rather than selling it. That way the customer is not owning the component but rather paying a monthly fee for use. This has the benefit that the provider remains responsible for the product, incentivising the use of quality materials and proper maintenance.

Usually, THUs are planned and provided to beneficiaries by NGOs or governmental organisations. The preferred afterlife scenario is for components to be used in reconstruction (IFRC, 2011), but often it is unknown what happens with the materials. Instead, THUs can be seen as a material bank, which consists of a set of materials and components, temporarily assembled in an unit, that can later be returned in economical circulation. Agreements between the HOs, the beneficiaries and local manufacturers and suppliers can incentivise take-back business models. Table 5 illustrates the circular *Management* strategies.

Table 5. *Management Circularity Strategies relevant for transitional housing projects*

Strategy	Description	Benefit	Risk
Create guidelines [9][20]	The lack of information is one of the biggest challenges when it comes to circularity. By providing manuals, the owners will be able to recover value and reuse materials safely.	◦ With the right information, material value can be kept in the loop. ◦ Empowering of beneficiaries through self-sufficiance	◦ Guidelines are incorrect / confusing
Take-back agreements [10][21]	Suppliers / producers provide a take-back service; they collect their products at their EoL stage (or free or an agreed fee) or if they are being damaged	◦ Enabling reuse, refurbish, repair strategies ◦ Waste prevention ◦ Potential income for suppliers in terms of material value ◦ Potential financial income for beneficiaries	◦ Additional logistics needed ◦ Additional storage needed
Scenario planning [7][18]	Planning for possible future (EoL) scenarios for the units as part of the design process thus testing the efficiancy of the design concept	◦ Necessary agreements can be made upfront ◦ Material and component value can be utilised ◦ Enabling R strategies	◦ Design / procurement process might be delayed ◦ Potential added cost

Strategy	Description	Benefit	Risk
Product as a service [4][10][21]	Suppliers lease out products rather than selling them, or offer an additional service with the product, thus remaining responsible for the quality and maintenance.	◦ Local providers can lease components for the THUs to the government ◦ Materials will be returned to the local economy after displacement ◦ Maintenace of the products by the supplier	◦ Local availability might be unsufficient
Building information model (BIM) [10][16][21]	Digital representative 3D model (twin) of the physical building. Includes data of all elements, cost and systems.	◦ Improved coordination and communication ◦ Enables easier and faster construction ◦ Enables R strategies	◦ High initial investment in software ◦ Quality data input is essential for avoiding errors
Material passport [2][10][21]	A document, containing information on the origin, composition, and characteristics of construction materials	◦ Enables R strategies ◦ Improves transperancy and accountability in the supply chain	◦ Obtaining enough accurate data might be challenging
Buildings as material banks (BAMB) [2][7][10][17]	Materials and components are temporarily assembled (stored) in a building configuration. They retain their value and are easy to be used again in another project through BIM and material passports	◦ Preservation of raw materials ◦ Enables R strategies ◦ Promotes innovation in BE ◦ Waste reduction	◦ Obtaining and updating data might be challenging

Implementation | It is challenging to measure the circularity of a building as it entails the whole product lifecycle and is further dependant on context and various factors involving material, design, manufacturing, and management decisions. In Tables 2-5 a conglomeration of circularity principles in these domains is portrayed (Table 6). It is evident that there isn't one strategy to make a building circular. Depending on the context and the local environment, some principles will have a bigger impact than others. A multitude of combinations of those principles can lead to an overall good project with a high circularity potential. By integrating a blend of those circularity principles across the four domains, transitional housing can be designed and constructed sustainably, efficiently, and economically, while promoting a circular economy and minimising the impact on the environment.

Table 6. *Overview of circularity principles according to Tables 2-5*

Material	Design	Manufacturing	Management
Local material	Design for disassembly	Prefabrication	Create guidelines
Biobased material	Modular design	Additive manufacturing	Take-back agreements
Waste material	Design for longevity	CNC milling	Scenario planning
Recyclable material	Design for standardisation	Robotics	Product as a service
Secondary streams	Design for adaptability	Vernacular building techniques	BIM
	Material optimisation		Material passport
	Design for recycling		BAMB

"By integrating a blend of those circularity principles across the four domains, transitional housing can be designed and constructed sustainably, efficiently, and economically, while promoting a circular economy and minimising the impact on the environment.

3.4. Alternative lifecycle and end-of-life scenarios of transitional housing units

The most common end-of-life scenarios of transitional housing units are discussed in subchapter 2.3. There are, however, other possibilities, which can be derived from the information gained in subchapter 3.3. Designing THUs with a longer lifecycle in mind, opens opportunities for a secondary material use, thus reducing the negative impact on the environment (Widyarko et al., 2021). Following the R strategies, the subsequent alternative end-of-life scenarios are possible.

Reuse (same function)

Reuse is one of the best EoL practices in terms of retaining material value. THUs can thus be reused without a functional change. Especially in regions, which are prone to natural disasters, already existing units can save a lot of time and cost when the need for a shelter arises. The THUs and settlement site can be held ready for a future use, remaining inactive until a crisis strikes. Hence, the necessary infrastructure is present, but will require maintenance (Arslan et al., 2008).

Alternatively, the units can be disassembled and temporarily stored. The structure needs to be dismantled without damaging the connections (Perrucci et al., 2020). In this case design for disassembly is essential. Additionally, the foundation type is important, as it also needs to be removed without leaving a lasting damage to the environment. Another concern can be maintenance and storage itself. Storing the disassembled parts, as well as the transportation to the storage and to a new location can lead to high expenses (Lizarralde et al., 2010; Felix et al., 2013). Refurbishment of the units and inspection is needed to ensure safety. The uncertainty of when and where a disaster may strike, and thus when the units will be needed again, can make this option undesirable for investors. It does, however, reduce the response time if a crisis does happen.

Reuse (other function)

In some cases the units can be directly reused for another function. For example, after being a post-disaster transitional housing, the structure can be repurposed into a store, student housing or community place. This option is preferrable as it saves resources, eliminates the concerns of component storage, and brings value back to the community. The units can also fill the market gap for affordable rental housing, which commonly widens after a crisis (Lizarralde et al., 2010, p82). THUs can thus become core shelters, turning into permanent houses over time (Arslan et al., 2008). In this scenario the management and ownership of the units and land need to be considered. The THUs can be relocated if needed. Another aspect to consider in making transitional housing fit for a secondary function is keeping the interior space flexible.

Selling | The unit as a whole (or its components) can be sold after the initial use as post-crisis dwelling (Felix et al., 2013). For this option it is also important to be able to disassemble the parts without damaging them in order to retain a high value (Askar et al., 2019). Finding buyers can, however, be challenging or unsuccessful. Selling or donating smaller components like doors or windows on low price can be beneficial for permanent reconstruction projects. Important for this alternative would be having standardised components, which can be used with other products. Nevertheless, incentives can be made in order to make this option more desirable. For example, the government can make agreements with local suppliers, which promote a take-back business model.

Recycling | If the units are damaged or cannot be reused or refurbished, some of the material value can be returned by recycling of the components. This can be supported by avoiding inseparable connections like adhesives. Finite materials can be remanufactured or recycled into new components and renewable materials can be returned to the ecosystem figure (butterfly diagram).

Potentials of alternative end-of-life scenarios of THUs | A careful consideration of the EoL scenarios of THUs can have positive effects on the economy, the environment, and the people, especially in a region weakened by crisis. It will also justify a higher initial investment by portraying the return of value. Seeing THUs as a *material bank*, an assemble of quality materials for a limited time, which can and will return to the economy, can potentially change the way displaced communities are perceived by the host population as well.

“*Seeing THUs as a material bank, an assemble of quality materials for a limited time, which can and will return to the economy, can potentially change the way displaced communities are perceived by the host population as well.*

Alternative lifecycle and end-of-life scenarios of transitional housing units

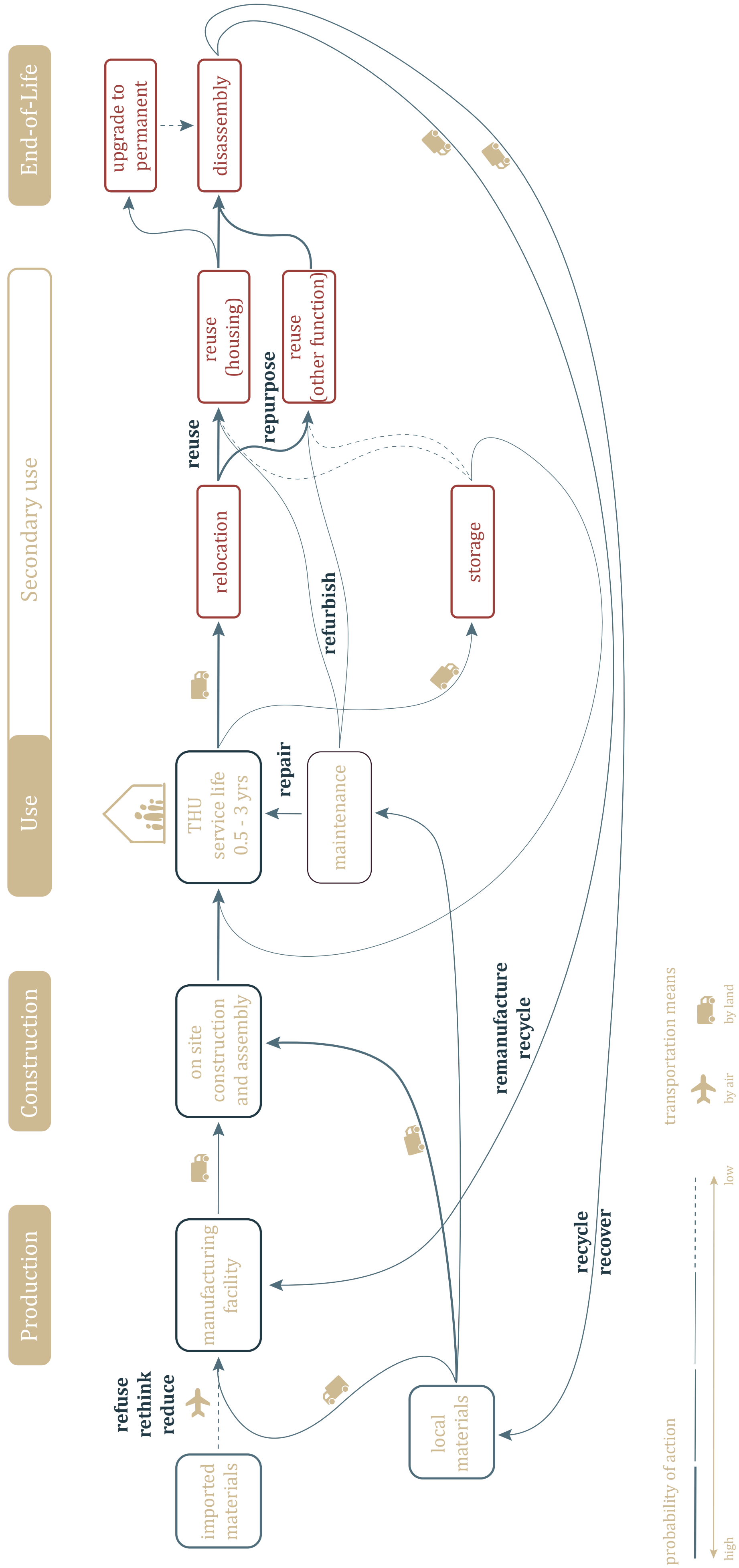


Figure 26.
Alternative lifecycle and end-of-life scenarios of transitional housing units

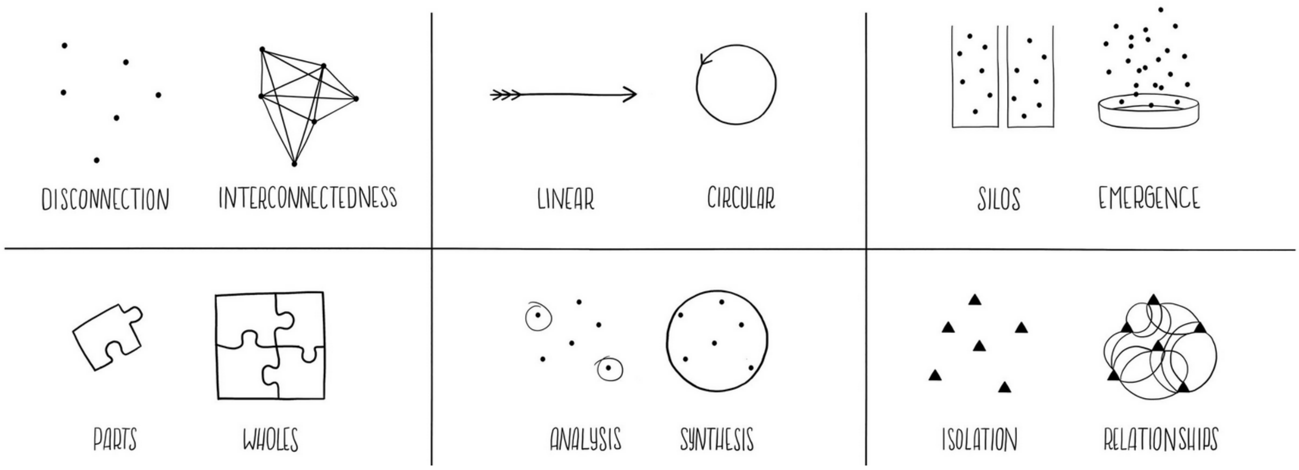
3.5. Systems thinking

Complex global challenges require a lot of coordination, cooperation, and creativity. In order to find suitable answers, it is important to understand the big picture and the interdependencies between different networks. That is why systems thinking can be crucial for understanding the humanitarian sector, the built environment and circularity and how they can be connected.

Systems thinking and humanitarian aid | The humanitarian sector is a complicated system of systems, which includes many actors – government, NGOs, AP etc. (subchapter 2.5), but also depends on emergencies, donations, and media among other things. Zooming in at HOs we can recognize the cluster system – one cluster focuses on nutrition, another on sanitation and a third on shelters. But they all work together to provide necessities to AP. The shelter cluster is further a network of multiple organisations, who collaborate and develop response plans. Each of them has its own parts – coordinator, constructors, architects, volunteers - who work together with additional externals like suppliers, donors, local governments. Looking deeper into the planning of a shelter in a specific context, it can be investigated how the system of the unit (the construction) integrates in the local natural and social ecosystems, how it influences the political, health and educational systems or what impact it has on the economy.

System definition | The term *system* is used to describe a set of organised elements, which interact with each other to function as one (Kauffman, 1980). A separate part cannot be fully understood without a consideration of the whole (EMF, 2017). Systems are all around, for example a city, a university, a society or even the human body. They can also exist as parts of each other, called subsystems, and rely on each other to function properly. Like a tree cannot thrive without soil, insects, and rain. So, thinking in systems means the ability to recognise the *relationships* and *interconnectedness* between the different parts and comprehending their influence on the *whole*. This allows a better understanding of causalities between not always obviously related elements, identifying problems, and finding new opportunities (EMF, 2017).

Figure 27.
'Tools of a system thinker' showing the change in mindset when thinking in systems (from left to right); Source: Leyla Acaroglu 'Tools for Systems Thinkers: The 6 Fundamental Concepts of Systems Thinking' (2017)



Systems thinking and circularity | The usual way to deal with complex challenges for a very long time has been scientific reductionism. This approach is linear: the problem is broken down into small parts, which are then analysed separately, since the whole is seen simply as a sum of its parts (Ioannou, 2023c; EMF, 2017). This ignorance towards the organisation of the individual elements has failed to see the patterns and similarities between the different fields of study (Kauffman, 1980).

The linear economy is unsustainable because there is a lack of direct information transfer from the output (pollution of natural ecosystems) to the input (extraction of raw materials) and thus missing the necessary adjustments. Systems thinking, on the other hand, focuses on finding and explaining the relations between the individual parts. The system is thus seen as more than just a conglomeration of its components, rather it functions as a whole with its own properties (Ioannou, 2023c). Systems by essence are circular, as a part influences the whole and the whole affects this part back, which is called a feedback loop (Kauffman, 1980).

By identifying stakeholder roles, cross industry relations, natural reserves and co-operation potentials, material loops can be closed and resources utilised. Thinking in system can thus explain circularity values, pinpoint root problems, and draw alternatives. In a similar way, recognising the underlying systems in the built environment and the humanitarian sector highlights underlying issues and possible interventions.

Thinking in systems can thus explain circularity values, pinpoint root problems, and draw alternatives. In a similar way, recognising the underlying systems in the built environment and the humanitarian sector highlights underlying issues and possible interventions.

Systems thinking and transitional housing | Transitional housing is also a system. Looking through the lens of the 'Scales to Aspects' model (subchapter 3.1), THUs are at the scale of Buildings. They are composed of Components – structural frame, walls, roofs, which in turn are made of Materials – locally available or imported. Zooming out, THU are located in settlements – the Neighbourhoods and Cities scales. This includes all the necessary infrastructure to make the shelters habitable – sanitation, electricity, and waste flows, as well as educational, religious and health services. The Regions scale encompasses the host population and the wider connections to the area, including material stocks. Furthermore, the four domains explored in subchapter 3.3 – Materials, Design, Manufacturing and Management, are elements with relevance to the overall circularity potential of the whole THU.

This being said, it becomes evident, that for transitional housing to become *truly* circular, a change in design will not be sufficient, but rather a systemic shift towards circularity within different areas and aspects is necessary. It requires collaboration between stakeholders, innovation in technology, new management models and economic incentives.

"(...) for transitional housing to become truly circular, a change in design will not be sufficient, but rather a systemic shift towards circularity within different areas and aspects is necessary.

3.6. Case studies

Implementing circularity in the built environment comes with many challenges. Nevertheless, there are projects which aim at closing as many material loops during their lifetime as possible by incorporating a variety of the strategies described in subchapter 3.3. This Subchapter will look into three circular projects in order to showcase how different combinations of circularity principles can be implemented and what can be beneficial for transitional housing units.

*Circular Tiny House CTH*1* - Tiny houses can be a very good example for transitional housing projects as they often use smart strategies to make the most of a limited living space. Students from the Coburg University of Applied Sciences and Arts in Germany developed a prototype of a tiny house following circularity principles. The CTH*1 aims to investigate the potentials of a reduced living space for issues like resource scarcity, energy consumption and densification in inner cities (Pintos, 2022). It was built in 2022 and will be occupied by two inhabitants for five years. During this period the performance of the building will be monitored.

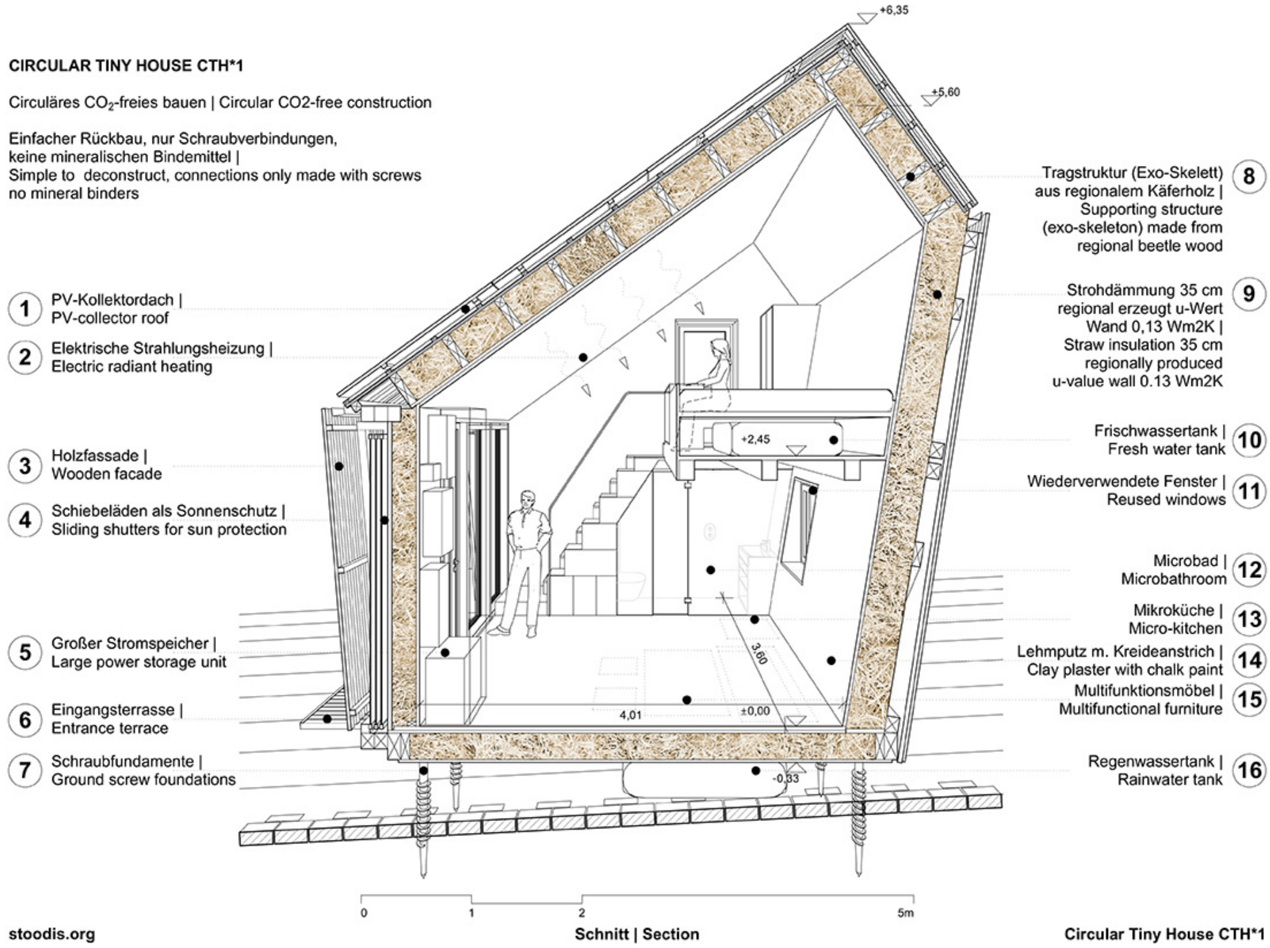
The tiny house is compact enough to be located on a parking lot. A kitchen, micro-bathroom, sleeping area and a working station are fitted within the 19 m^2. The design incorporated locally available renewable materials and reused building components such as retrieved windows. The bearing structure is made of timber and the walls are finished up with straw and clay. For the foundation ground screws are used, which makes relocation possible. The CTH*1 is designed to be off the grid. Electricity is generated through solar panels, while rainwater is being stored and purified.

At the EoL the building can be fully disassembled without damaging the elements as dry connections have been applied. Furthermore, the materials will be available for reuse is other projects. The straw and the clay will be returned to the supplier, where they can be ploughed back in the earth.

Figure 28.
*CTH*1 pictures;*
Photos: Sebastian Kolm
Source: Archdaily

Figure 29.

*CTH*1 section and construction pictures;*
Photo: Sebastian Kolm
Source: Archdaily



The following Table 7 shows which circularity principles, as desribed in Tables 2-5, are implemented in the CTH*1 project.

Material	Design	Manufacturing	Management
Local material	**Design for disassembly**	Prefabrication	Create guidelines
Biobased material	Modular design	Additive manufacturing	**Take-back agreements**
Waste material	Design for longevity	CNC milling	Scenario planning
Recyclable material	Design for standardisation	Robotics	Product as a service
Secondary streams	Design for adaptability	Vernacular building techniques	BIM
	Material optimisation		Material passport
	Design for recycling		BAMB

Table 7.
*CTH*1 implementation of circularity principles according to Tables 2-5*

Build Reversible In Conception (B.R.I.C.) - The B.R.I.C. project is a pilot by the Brussels-based interdisciplinary training centre EFP. The building is seen as a material bank, where materials' lifespan is extended and their capacity to be re-used several times is analysed. The project has been constructed for the first time in 2017 as an office space. The following years the building is reassembled several times with changing function: shop in 2019 and an acoustic laboratory in 2020.

The reversible connections and adaptability approach allow for several transformations. Like the previous project, ground screws are used for the foundation. The bearing structure is timber. Bidirectional structural columns and interchangeable insulation boxes allow the building to be scalable and adaptable to different functions. The structural system is calculated with an additional floor in mind. Moreover, the beams can be adjusted for a pitched as well as a flat roof. The services are also assembled in a circular manner. The ducts of the heat pump are interlocked and clipped, which makes separating them easy.

A Material Passport system was used to link the physical materials to the digital model and to provide the necessary logistics and inventory for an easier reassembly process. The generated waste during the first disassembly is ca. 3.5 m^3 and consists of twisted screws, torn membranes, and tailored pieces. The researchers identified standardisation and an extended preparation period as important for the success of the concept. Overall, the B.R.I.C. project demonstrates how the material quality can be retained even when the function of the building is only temporary.

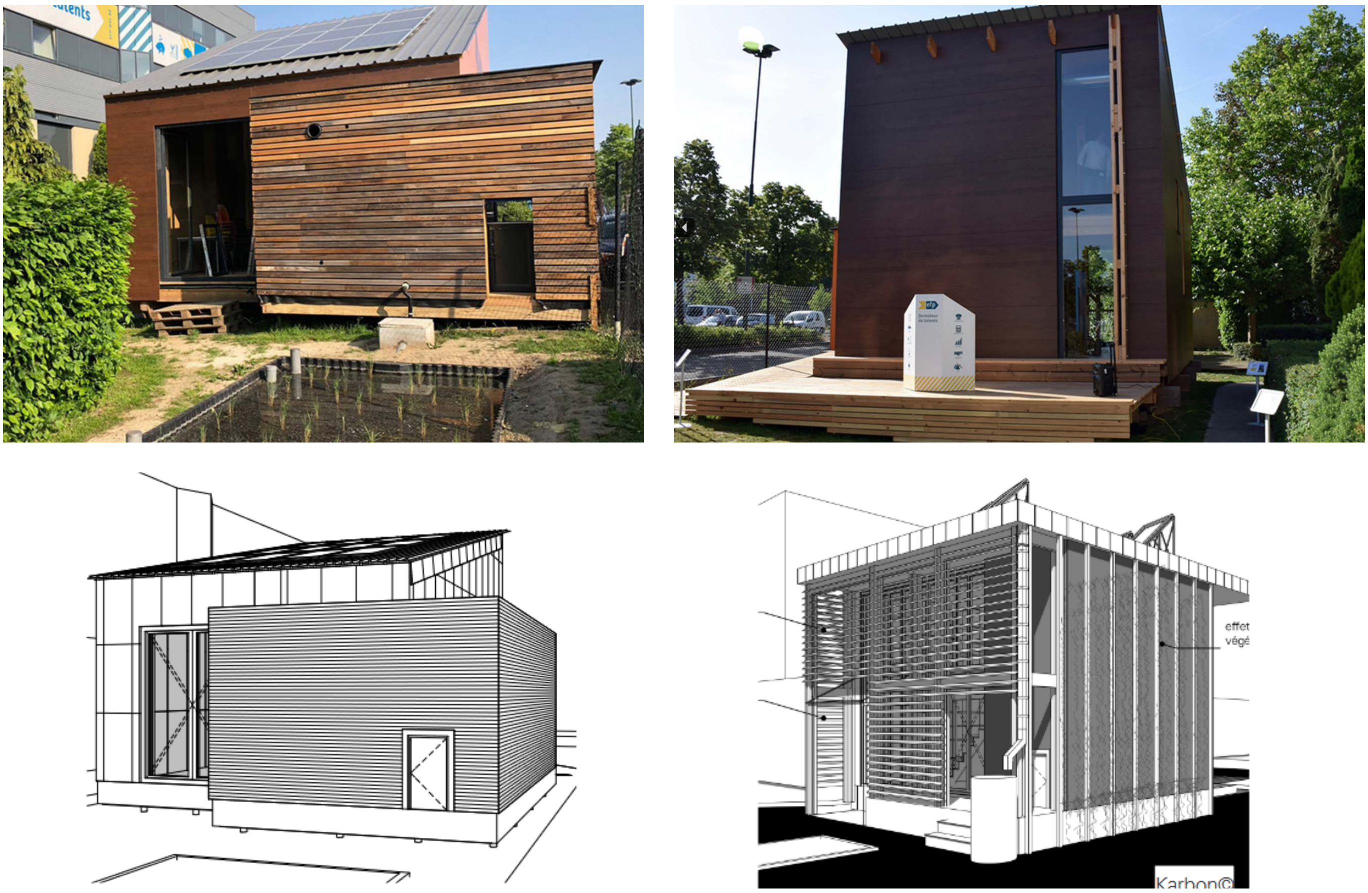
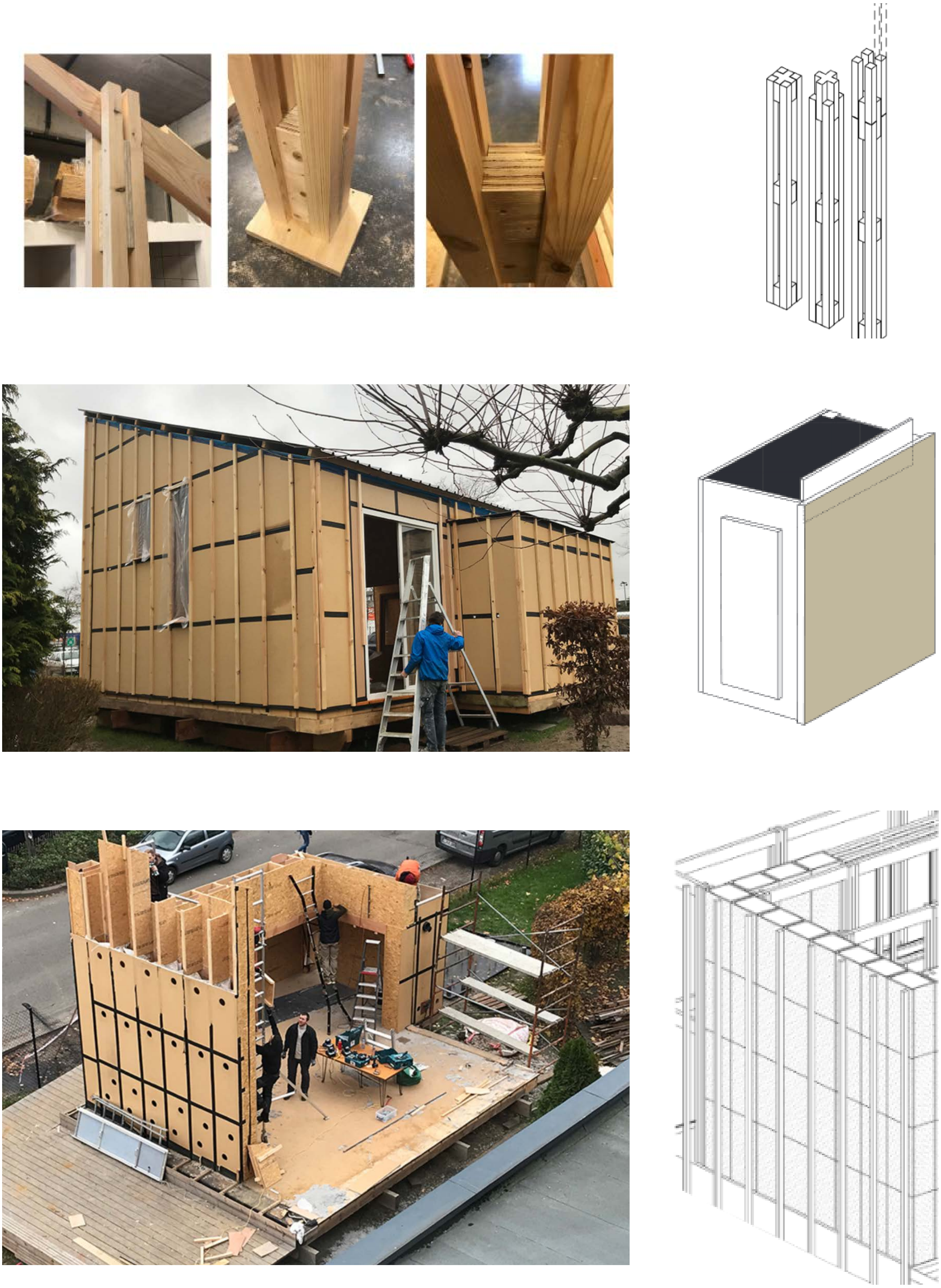


Figure 30.
B.R.I.C. project;
Source: BAMB 2020

Figure 31.
B.R.I.C. project details;
Source: BAMB 2020



The following Table 8 shows which circularity principles, as desribed in Tables 2-5, are implemented in the B.R.I.C. project.

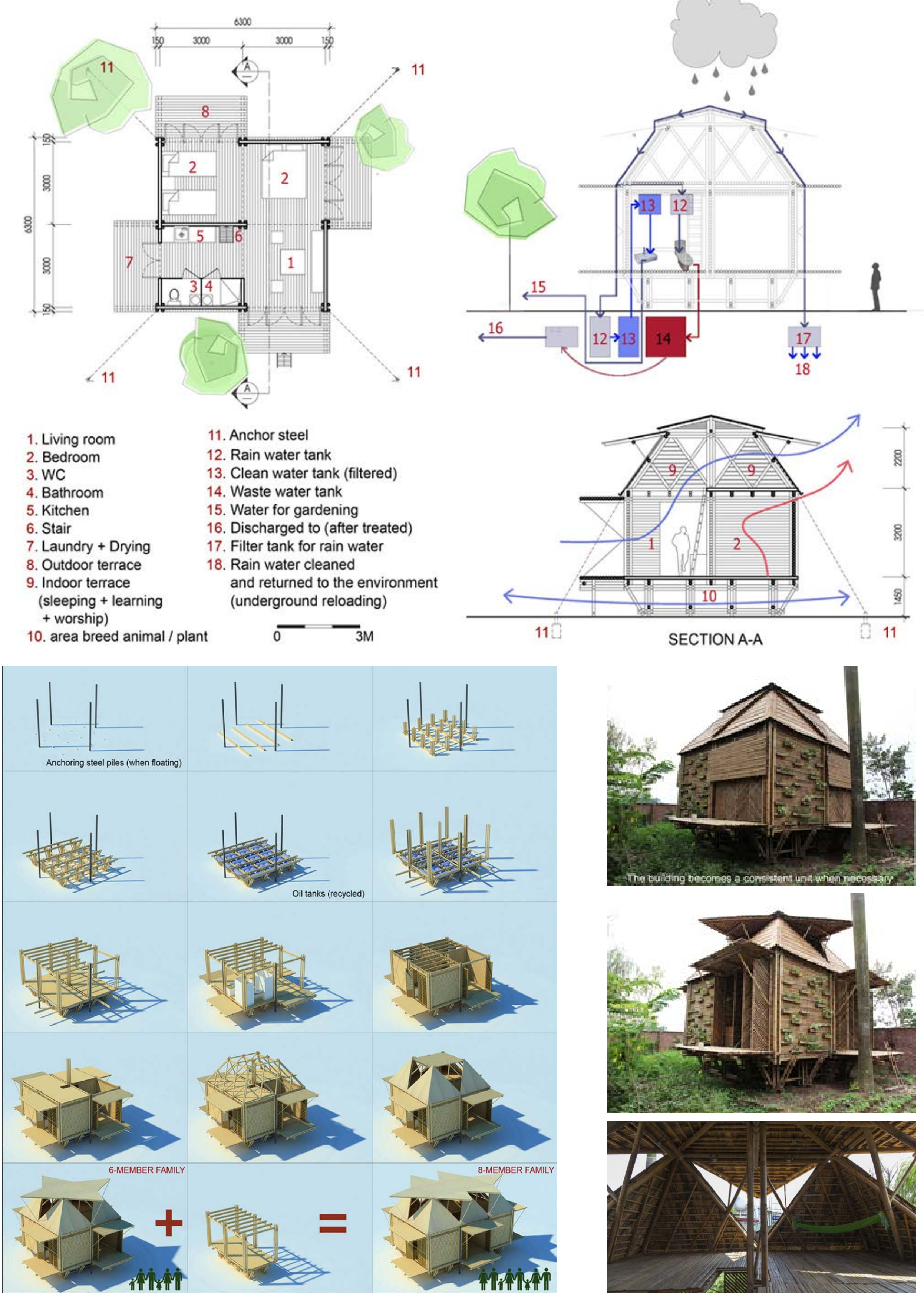
Material	Design	Manufacturing	Management
Local material	Design for disassembly	Prefabrication	Create guidelines
Biobased material	Modular design	Additive manufacturing	Take-back agreements
Waste material	Design for longevity	CNC milling	Scenario planning
Recyclable material	Design for standardisation	Robotics	Product as a service
Secondary streams	Design for adaptability	Vernacular building techniques	BIM
	Material optimisation		Material passport
	Design for recycling		BAMB

Table 8.
B.R.I.C. implementation of circularity principles according to Tables 2-5

Blooming Bamboo Home - The Blooming Bamboo Home (BB Home) is developed by H&P Architects as a response to the annual natural disasters in Vietnam. The multifunctional space has 44 m² and is elevated to withstand 1.5 m floods. The skin, which can be diverse, depending on the local availability, is fixed to the bamboo structure. Some walls and parts of the roof can be opened for cross ventilation. The columns are bidirectional. The home is designed as a module, which could potentially be extended. The bamboo components are 3.3 and 6.6 m long with varying diameters (8-10 cm and 4-5 cm) and are assembled through binding, bolting, hanging and placing.

Figure 32. *Blooming Bamboo Home pictures; Credit: Doan Thanh Ha; Source: Archdaily*

Figure 33.
Blooming Bamboo Home pictures;
Photo: Doan Thanh Ha; Source: Archdaily



The following Table 9 shows which circularity principles, as desribed in Tables 2-5, are implemented in the BB Home project.

Material	Design	Manufacturing	Management
Local material	Design for disassembly	Prefabrication	Create guidelines
Biobased material	**Modular design**	Additive manufacturing	Take-back agreements
Waste material	**Design for longevity**	CNC milling	**Scenario planning**
Recyclable material	Design for standardisation	Robotics	Product as a service
Secondary streams	**Design for adaptability**	**Vernacular building techniques**	BIM
	Material optimisation		Material passport
	Design for recycling		BAMB

Table 9.
BB Home implementation of circularity principles according to Tables 2-5

Overall evaluation of case studies | The described case studies show practical examples of the utilisation of circular building principles. In all the projects locally available biobased materials are chosen. Dry connections are used to make the disassembly process easier and to minimise waste. However, besides B.R.I.C., the other projects have not been disassembled yet and the reversibility of the structure has not been proven. Nevertheless, the case studies showcase how circularity can be beneficial for transitional buildings due to the retention of material value.

The feasibility of the projects on a bigger scale is also underexplored. In terms of cost, the case studies are quite expensive compared to a typical THU budget, with 30 000 EUR for CTH*1, 78 500 EUR for B.R.I.C. and 2 300 EUR for the BB home. This price tag is due to the location of the projects, the size, as well as the material quality and experimental nature. Moreover, CTH*1 and B.R.I.C. are using high-tech products, which brings their price further up. The BB Home incorporates community participation in the construction process and low-tech building techniques, which keeps the house affordable.

4. The extreme climatic conditions in Pakistan, displacement and the need of sheltering

The context of the thesis research is set in the Sindh province of Pakistan, which is used as a case study for extreme conditions. The local climate, the population needs and culture are investigated. Vernachular architecture and the available construction materials are analysed. The floods of 2022 are discussed, portraying the need of transitional housing options.

4.1. Country profile

Pakistan means the "Land of the Pure" in Urdu and Persian. The country is an Islamic republic located in South Asia. It is divided in the territory of the Islamabad Capital and four provinces: Punjab, Sindh, Khyber Pakhtunkhwa, and Baluchistan (Figure 34). Additionally, there are two administrative territories of Azad Jammu and Kashmir and Gilgit–Baltistan in the north. Located on the Arabic sea, Pakistan borders on the west with Afghanistan and Iran, India is on the east and Xinjiang province of China is to the north.

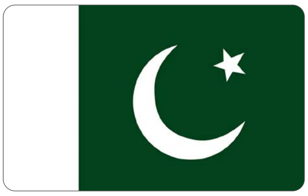


Figure 34.
Pakistan map and flag

People | The population of Pakistan is steadily growing with over 230 million people est. in 2023, making it the fifth most populous country. The majority is predominantly young with about two thirds being under the age of 30. The country is ethnically and culturally diverse. Urdu is the official tongue, but there is a great variety of languages used. The predominant religion in Pakistan is Islam, with the majority being Sunni Muslims. Though there is a fast urbanisation, over 60% of people remain in rural areas. Even with a growing economy, a great part of the population is poor, with over 90% living on less than 10$ per day.

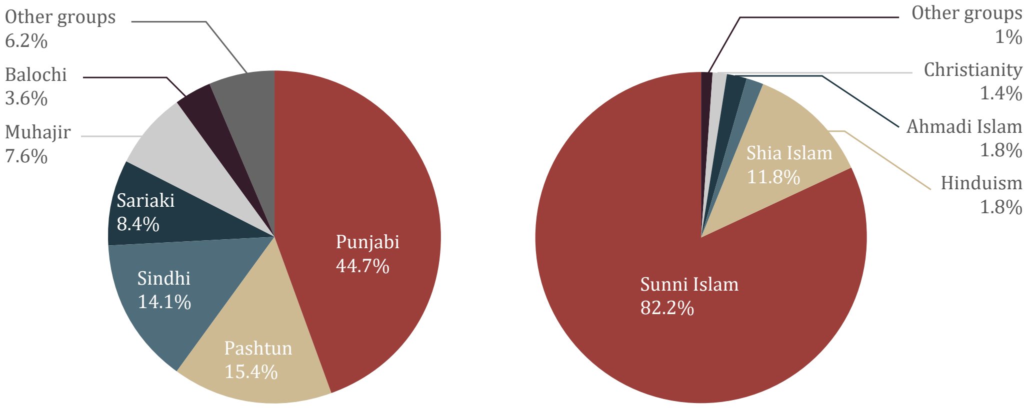


Figure 35.
Pakistan ethnic (left) and religious (right) groups; adapted from John Misachi (2019) World Atlas

Pakistani families are relative big with an average of 6-7 people per household. Though nuclear families are becomming more common in urban areas, often extended families stick together forming multigenerational households. Social connections, especially with close friends and family members, are very important for daily life. This is illustrated in the concept of *wasta* - relationship forming. This network creates a strong support system and sense of community. Households are traditionally men-led with patriarchal gender roles.

Figure 36.
Insights of rural living in Pakistan. Low income family $100-300 per month; ***charpai*** *- traditional woven bed; Source: Gapminder, Dollar Street*

Topography | The country has a variety of topography, from the high peaks of the Karakoram and Himalaya Mountain ranges to the lowlands of the Indus valley and Punjab Plain. Generally, there are five regions: the Northern Mountainous region, The Indus Plain, The desert region, the coastal region, and the western mountainous region. The north area houses glaciers, which form the largest snowmass outside the polar region. The longest and most important river is the Indus. Its basin is home to the majority of the population. The plains around the river are fertile, which makes them important for agriculture. Located on the border with India is the Thar desert, one of the largest in Asia.

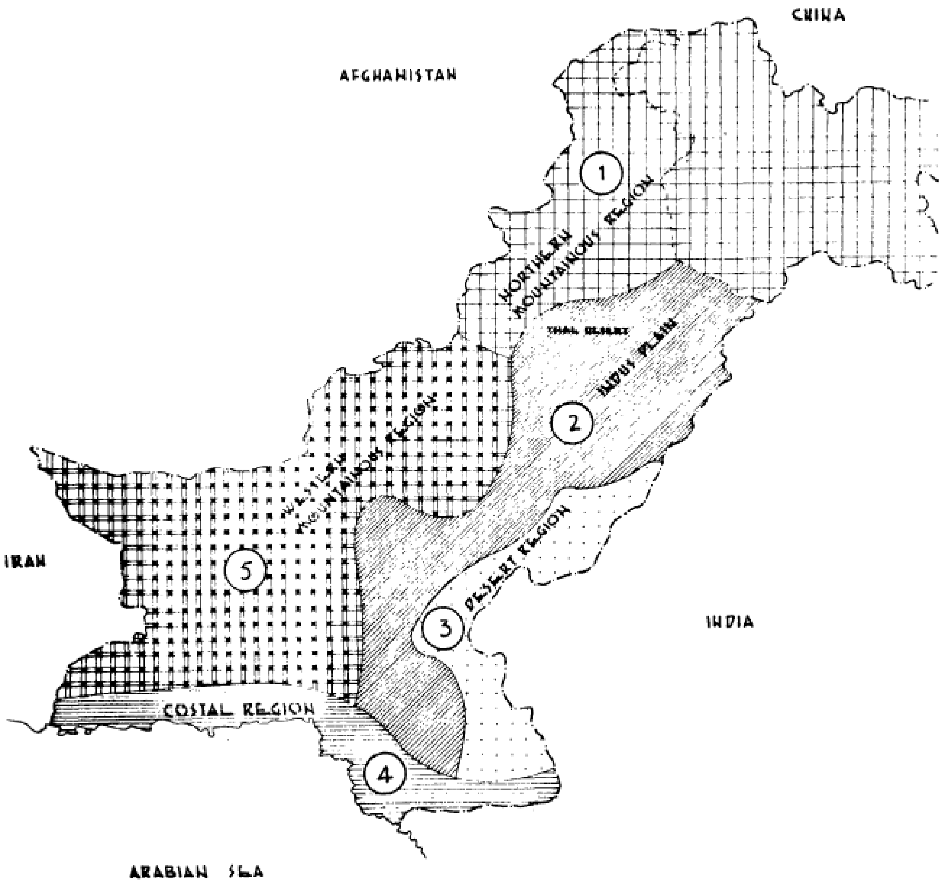


Figure 37.
Pakistan geographic regions; Source: Mumtaz (1978)

Climate | Pakistan has a very diverse climate due to its topography. It is mostly part of the subtropics, being arid and semi-arid in the south and becoming more temperate and alpine to the northwest. The climate is predominantly hot in most of the country, while the northern mountains remain cold. Pakistan is also characterised by extreme temperature variations. In summer the mean temperature in Sindh is about 36°C, with high temperatures rising to 48°C. The highest temperature record measured in Jacobabad, Sindh, is 53°C.

The heath is accompanied by hot winds, dust storms or occasionally thunderstorms. The evening temperatures drop significantly allowing for night-cooling. In winter it is cold, with temperatures under 10°C. In several regions snowfall is common. Though rainfall is excessive during the summer monsoon period (July - September), areas like the Baluchistan plateau remain very dry.

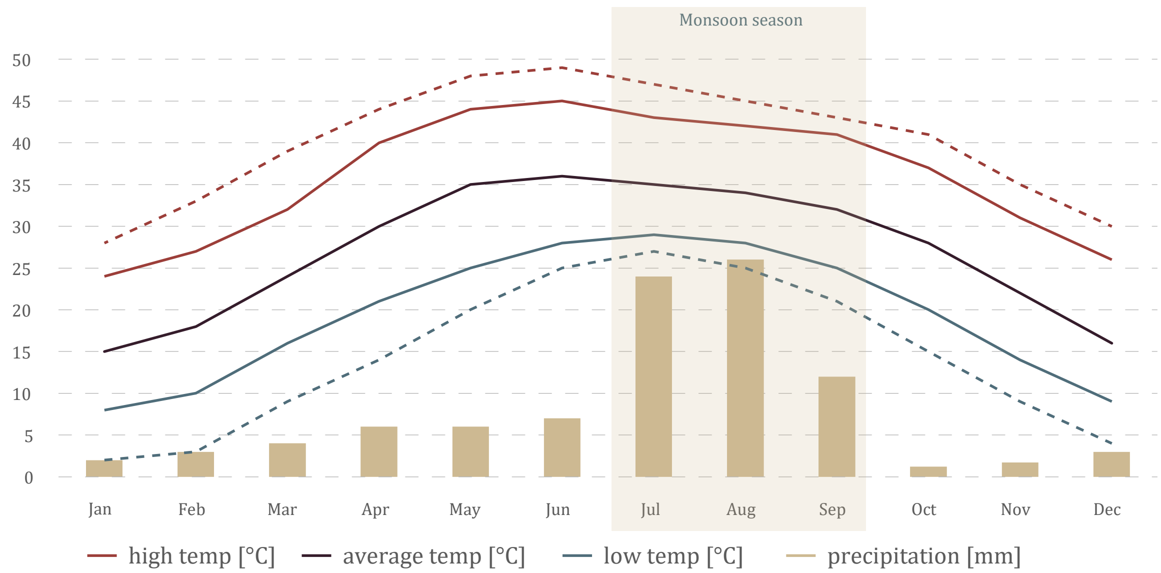


Figure 38.
Temperatures and precipitation in Sukkur, Sindh province;
Source: meteoblue, weatherspark

4.2. Vernacular architecture

Current housing stock | By the 2017-census population count the division between rural and urban population is about 60 to 40 percent (Pakistan Bureau of Statistics, 2017a). Urbanization and population growth are, however, pressuring the housing stock in Pakistan, with more than 40 million people expected to move towards bigger cities by 2025 (Khalid, 2020). This trend puts a lot of pressure on urban areas to accommodate the influx of people. City expansions are usually unplanned and are rarely done in a safe manner. This poses risks for future disasters. Moreover, unfit, low quality material choices or building techniques can contribute to overheating and environmental degradation (ibid.).

The most common construction materials used nowadays in Pakistan for walls are backed bricks, concrete blocks and stones (over 90% in urban and over 64% in rural areas) (Pakistan Bureau of Statistics, 2017b). For roofing, most common are concrete slabs and iron sheets. Such houses are referred to as *pucca* (done, permanent). A quarter of the rural houses rely on unbaked bricks or mud for walls and around a third of the rural housing stock uses wood or bamboo for the roof structure. Those houses are categorized as *katcha* (undone, non-permanent). Rural houses usually have only limited and basic facilities. Natural materials, though available locally, are less favoured in urban areas. The modern architecture has thus largely been influenced by globalisation. Nevertheless, vernacular architecture in Pakistan has a rich and diverse tradition that reflects the country's unique cultural and environmental context. The variety of those construction and passive design techniques can largely inform and inspire modern development as well as transitional housing in a humanitarian response.

Vernacular elements | The vernacular architecture in each of the geographic regions has developed to accommodate the available materials and local climate as well as the country's history and culture. One of the most distinctive features is the use of intricate geometric patterns, which are often seen in the form of elaborate woodwork or tile mosaics. Many vernacular buildings also incorporate elements of Islamic design, such as domes, arches, and calligraphy. Another notable aspect is the use of verandas and courtyards found across the country. They serve as open-air living spaces, incentivise social gathering and provide natural ventilation and shade. Sometimes they are also shared with livestock. In warmer regions it is also common to sleep outside in summer, either on the roof or in the courtyard.

39.1.

39.2.

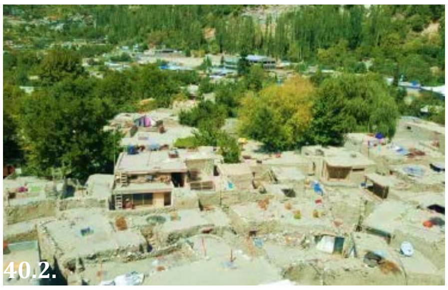
39.3.

Figure 39. Vernacular architecture
39.1. Decoration on the royal graveyard Makli in Thatta Pakistan, 15 cen AD; Photo: Syed Kumail Hasan 2019
39.2. Shaded veranda; Source: Khalid, 2020
39.3. Outdoor sleeping in courtyard; Source: Khalid, 2020

Northen regions | In the colder north areas, the use of pine wood, stones and mud bricks is common. Great artistry and craftmanship is shown in wood and stone carvings. As the region is prone to disasters like earthquakes, special techniques such as mixing lime mortar with egg yolk are used to increase the strength (Khalid, 2020). Roofs are low and people often walk on them. As a means to let more light and air in the house, a roshandan is used, it is a combination between a skylight and ventilation opening.

Figure 40.
40.1. Highland roof; Source: Khalid, 2020
40.2. Hunza village; Source: Khalid, 2020
40.3. Roshandan over windows Serhi house, Peshawar; Source: Pintrest


40.1.

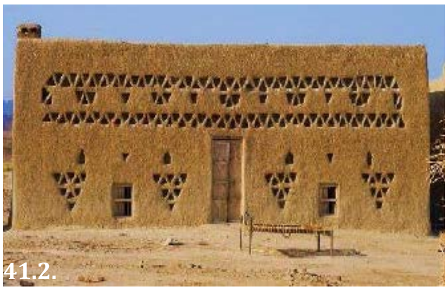

40.2.

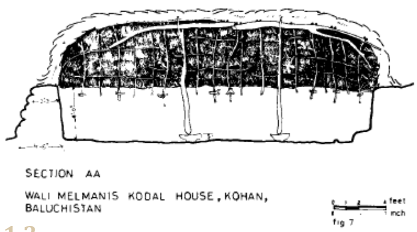

40.3.

Baluchistan | The Baluchistan vernacular architecture is highly connected to tribal traditions. In mountainous areas, massive stone walls are used as protection against the harsh weather and unwanted visitor. Openings are small and minimal. Roofs are often flat but do get a slope in the regions where heavy rain and snow occur. Rooms are usually clustered around a walled courtyard, which is the hearth of the house. A traditional rural house archetype is the gidan (Baluch) or kodal (pathan). It consists of an one-room elliptical floorplan with a low masonry wall and a wagon-vaulted dome (Mumtaz, 1978). In the southern part palm trees form pitched roofs. All parts of the palm is used – the trucks, the fronds and the leaves.

Figure 41.
41.1. Stone rubble masonry; Source: Khalid, 2020
41.2. Village house with small openings; Source: Khalid, 2020
41.3. Gidan house; Source: Mumtaz, 1978


41.1.


41.2.



41.3.

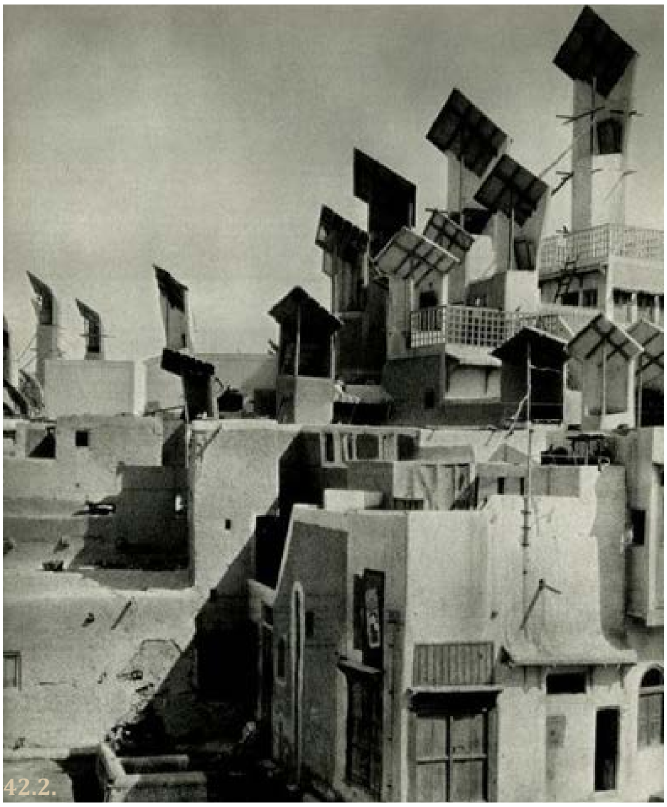
Indus plain | The lowlands around the Indus plain commonly use earthy materials like mud, clay and pisé for the wall construction. Locals often use the materials plasticity to make distinctive patterns as decoration on the exterior and interior. A common house in Sindh is the 'kothi house'. It is originally made of mud, which later has ben exchanged to sun dried or baked bricks. Sheesham, acacia or neem timber is then used to form the roof structure. Floors are often made from earth and rice straw. The roofs and walls of some houses are painted white to reflect the sun rays.

In Sindh there are some simple houses called 'chapper house' (Safiruddin, 2005). There are several versions, one of which uses bamboo. Bamboo is used for the structure as well as foundation. The walls consist of leaves and grasses, plastered with mud. Another traditional house is the 'waung house' (arches), which due to the complexity of the construction is usually implemented by the wealthier families. Great attention is given to details and decorations.

Coastal region | South, in the coastal regions, vernacular houses have higher ceilings, adapted to the warmth and humidity. Roofs are double sloped, with a central ridge and often thatched with juniper stems. In the lower delta region juniper stems are also get bundled together with reeds to form light permeable walls. Acacia and sheesham timber is used for structural frames, while walls are plastered with a combination of earth and straw. Overhangs and cross ventilation ensure a more comfortable indoor climate. Indigenous windcatchers, called mungh, are used as a passive cooling system for taller several-story buildings (Mumtaz, 1978).

Figure 42.
42.1. Mud house with decorations in Punjab; Source: YouTube, ApnaPunjabAe
42.2. Mungh windcatchers in Hyderabad; Source: insideflows.org

42.1.

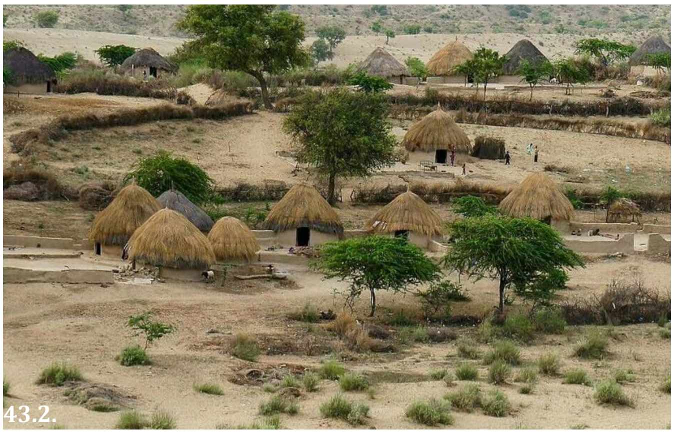


42.2.

Figure 43.
Chaunras;
43.1. Source: Khalid, 2020
43.2. Photo: Emmanuel Guddu

Desert region | The desert Thar region in Sindh has its own particularities as well. Small circular huts with a conical thatched roof, chaunras, mud and grass walls with small openings are gathered in clusters. Acacia wood is used for the roof structure. The huts consist of one room with about three to four meters in diameter (Safiruddin, 2005). Ropes are made by watering and twisting local grasses called Khip and Sinr. A mixure of mud, grass, water and donkey dung is used for plastering.


43.1.


43.2.

Techniques applicable to transitional housing | Overall, traditionally thermal mass is used as a means to create a stable comfortable indoor environment. This can be seen in the hot arid parts with mud walls, northern cold with stone masonry or the Baluchistan's kodal house. The essence of transitional housing, being temporary and easy to move, doesn't immediately fit with this concept. However, the design can be adapted in such a way, that it can benefit from thermal mass. If the load bearing capacity is taken care of with a timber frame, the thermal mass can be achieved with a non-structural material. Passive cooling is achieved through overhangs for shadings, cross ventilation, use of outdoor space like courtyards and verandas and in some cases windcatchers or ventilators.

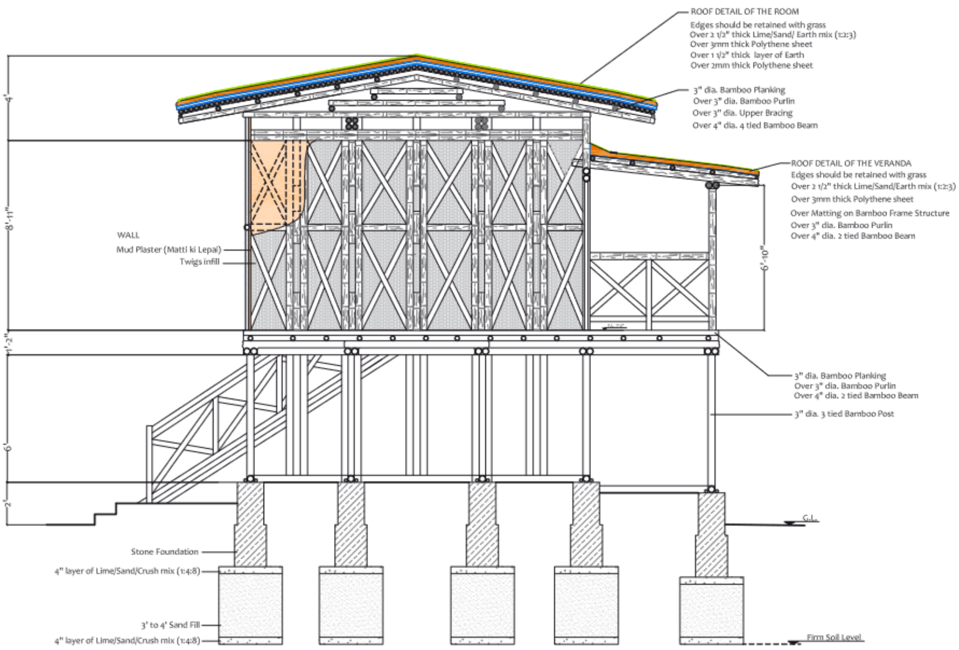
The new vernacular | With time some of those vernacular materials and techniques have become forgotten. Often the use of natural materials like mud or bamboo is associated with lower quality or economic status. This is not necessary the case and in the dawn of a warming climate, such natural materials provide a sustainable and affordable alternative to carbon-intensive resources. There is a raising interest in using renewable materials by contemporary architects.

Yasmeen Lari | One of the best examples in Pakistan is the work of architect Yasmeen Lari. Since the beginning of the century, Lari has been post-retirement focusing on reconstruction project using mud, lime, and bamboo. Together with a team of volunteers and skilled artisans from the Heritage Foundation of Pakistan, they have analysed the vernacular building techniques and work on improving the strength and stability of those structures by developing new building archetypes and details.

Lari and her team have developed and constructed shelters, community centres, traditional outside chulah (stove) and more. The buildings, constructed with mud, lime, and bamboo have proven to be resilient to earthquakes and floods, surviving consecutive disasters. After the 2010 floods, their work is also focused on the Sindh province. Lari's work, described by her as 'Barefoot social architecture' has been internationally recognised for strengthening community participation, empowering women, and promoting sustainable building techniques.

One of the Heritage Foundations' projects are the Green Women's Centres in Sindh (Figure 44). It is raised on stilts to provide protection in case of a flood. The upper level is dedicated as a safe meeting place for women, whereas the ground floor is used as a school for children. The shaded lower area remains cool in the hot summer days. The structure is circular with ca five meters diameter. Similar structures have also been used as a health centre and primary school.

Figure 44.
Women's center on stilts built by Heritage Foundation in village Darya Khan Shaikh, in katcha area, Khairpur.
Source: Heritage Foundation of Pakistan



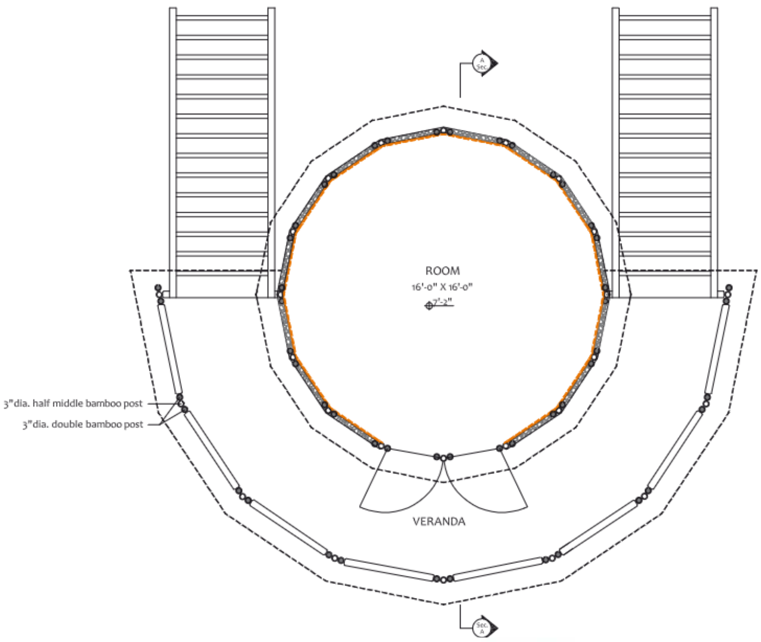


Figure 45.
Women's center on stilts built by Heritage Foundation
Source: Heritage Foundation of Pakistan. (2020)

Tipu Sultan Merkez | Another example for the new vernacular architecture in Pakistan is the Tipu Sultan Merkez (TSM) earthen school in Jar Maulwi by the German architecture office ZRS Architekten. The building is constructed from bamboo and cob and is resistant to floods and earthquakes. Eight classrooms are accommodated in the two-storey structure as an extension to the existing school. The upper floor is a light bamboo construction situated on top of two earthen cubes. The cob walls are 60 cm thick and provide thermal comfort.

Figure 46.
Tipu Sultan Merkez
Source: Ziegert | Roswag | Seiler Architekten Ingenieure

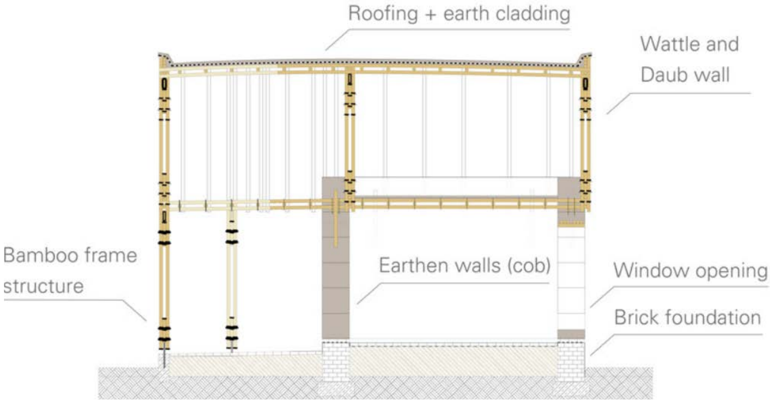


Figure 47.
Tipu Sultan Merkez construction
Source: Ziegert | Roswag | Seiler Architekten Ingenieure

4.3. Crisis and displacement

Pakistan is responsible for less than 1% of global GHG emissions, yet it suffers tremendously from climate change impacts (Figure 48). According to the Global Climate Risk Index for 2021 Pakistan ranks 8 among the 10 countries most affected by extreme weather events between the years 2000 and 2019 (Echstein et al., 2021). Since the beginning of the millennia alone there have been multiple earthquakes, most severe in 2005, 2008 and 2013, devastating floods in 2010 and 2022, draught in 2019 and high and low temperature extremes (Figure 50 - next page). Natural disaster like these lead to reduction of agricultural productivity and water availability. This in combination with pollution heightens the population's vulnerability to infectious diseases like COVID-19 (IFRC, 2022). Thousends to millions of people lose their home due to the crises. Conflict within and outside Pakistan's borders is yet another driver of displacement. There are about 3 million Afghan refugees across the country. Some of them have come generations ago but remain in temporary settlements due to legal reasons.

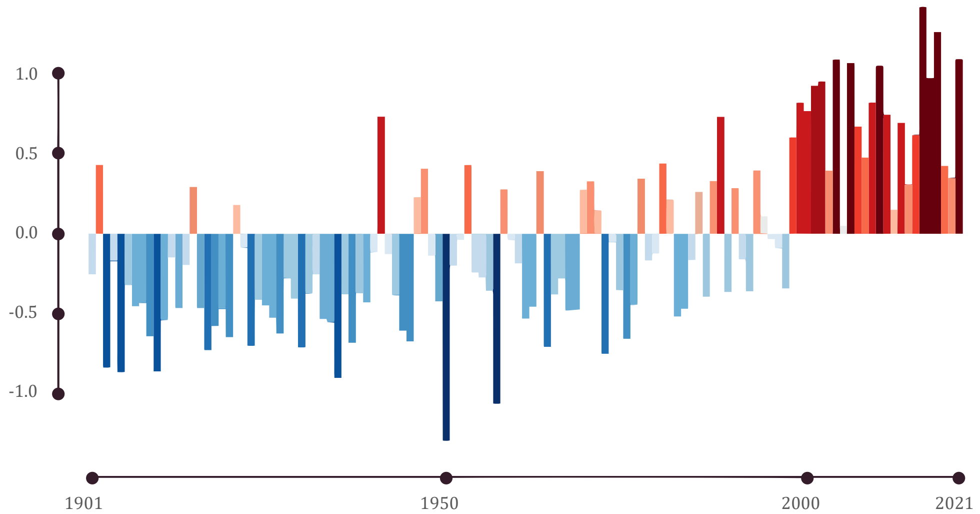


Figure 48. *Temperature change in Pakistan, relative to average of 1971 - 2000 [°C]; adapted from Ed Hawkins, https://showyourstripes.info/l/asia/pakistan/*

Figure 49. *Matiari, Sindh province, Pakistan, August 2022; Photo: AFP/Shakeel Ahmad*

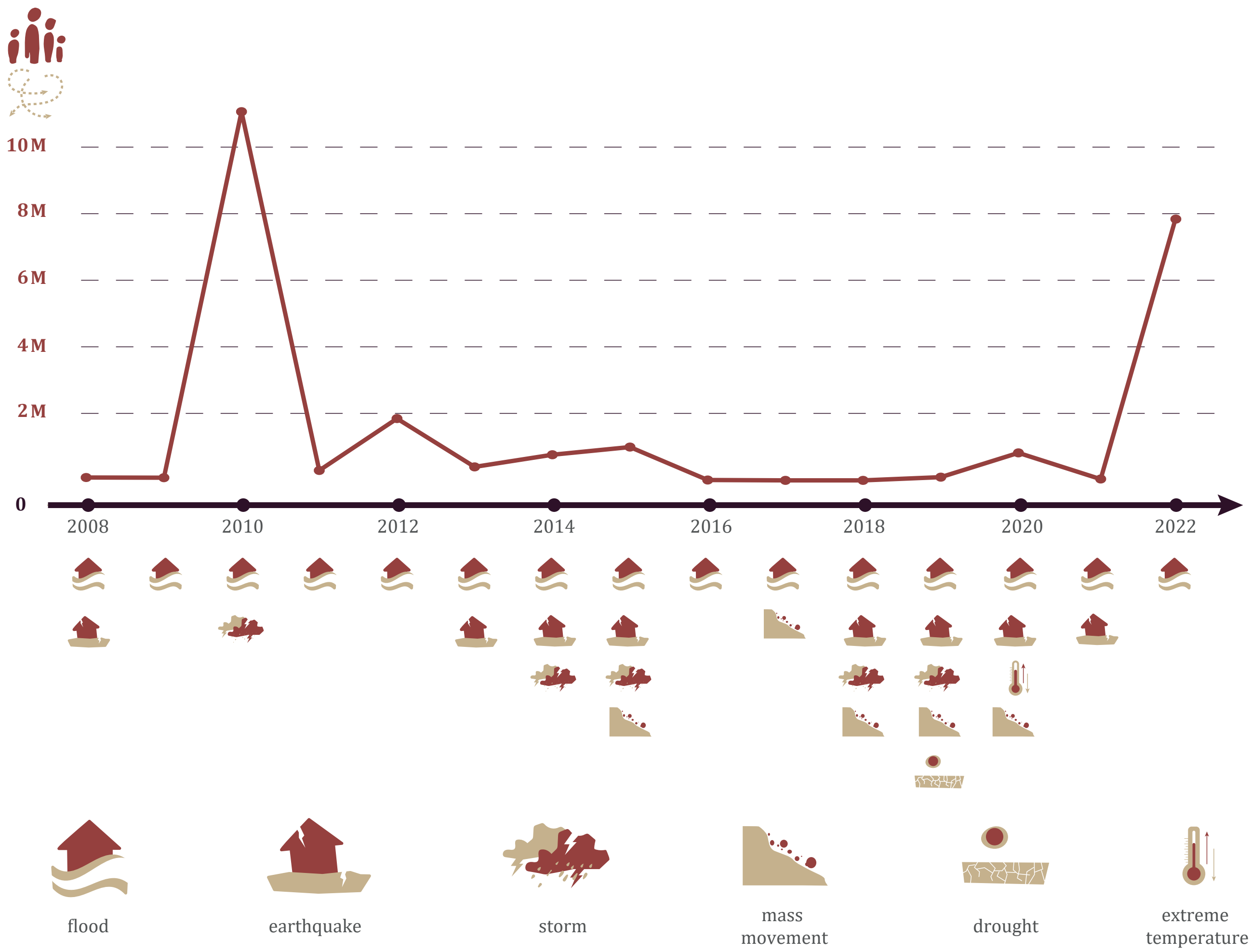


Figure 50.
Natural disasters and amount of IDPs in Pakistan for the period 2008 - 2022

Figure 51.
Sindh province, Pakistan
Photo: UNICEF/ UN0730486/Bashir

Floods 2022 | In summer 2022 Pakistan experienced a very heavy monsoon season, leading to devastating flooding and landslide, across the whole country. About 33 million people got affected and over 1700 lost their life. More than 2.1 million houses got partially or fully destroyed, leaving about 8 million people displaced (CDP, 2023). Months after the crisis has occurred, floodwaters remain stagnant, endangering the 1.8 people living in proximity to it with contamination. Malnutrition, inflation, waterborne diseases, and job losses are follow-up challenges for the people in affected areas.

Figure 52.
Evolution of floodwater extent;
Source: OCHA, 2023

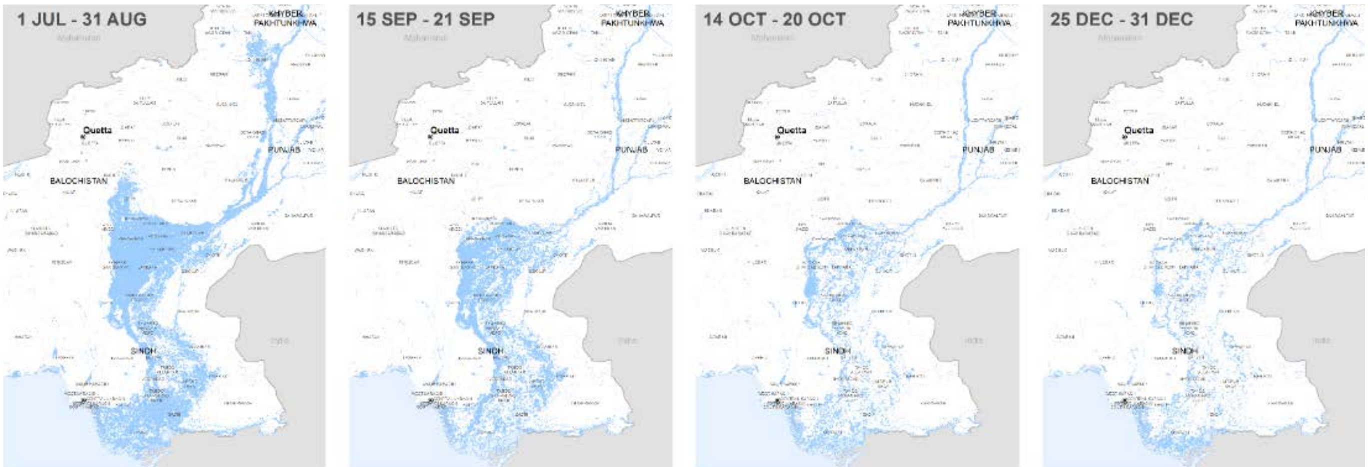


Figure 53.
Flood damage;
Photo: Thomas Koch / Shutterstock.com

The province of Sindh was severely affected, receiving 8.3 times its average rainfall (OCHA, 2022). Almost ninety percent of all housing and infrastructure damage is there: over 1.1 million houses damaged, over 683 000 fully destroyed, 64% of the roads and 40% of the bridges destroyed nationwide (ibid.). Livestock loss is also very high, around 430 000 in Sindh alone. Agriculture and livestock are a main livelihood for many households, thus leaving them under economic pressure.

The need of shelter | The provision of shelter remains an acute need. In the immediate response to the disaster, and in the following months, thousands of emergency tents have been provided to the people in need. Due to the large amount of DP and the limited resources, some household received only one tarpaulin. This results in a large amount of people living in makeshift shelters, which lack privacy, security and pose health threats. Moreover, women and girls are especially vulnerable to gender based violence. Many of the IDPs remained living in emergency shelters throughout the winter, when the temperatures fall below 10°C or even below zero in some areas. As of March 2023, over 30 000 people remain internally displaced in the province of Sindh alone (OCHA, 2023 – Situation Report 15).

Figure 54.
Destroyed and damaged houses per district October 2022; source: OCHA, 2022

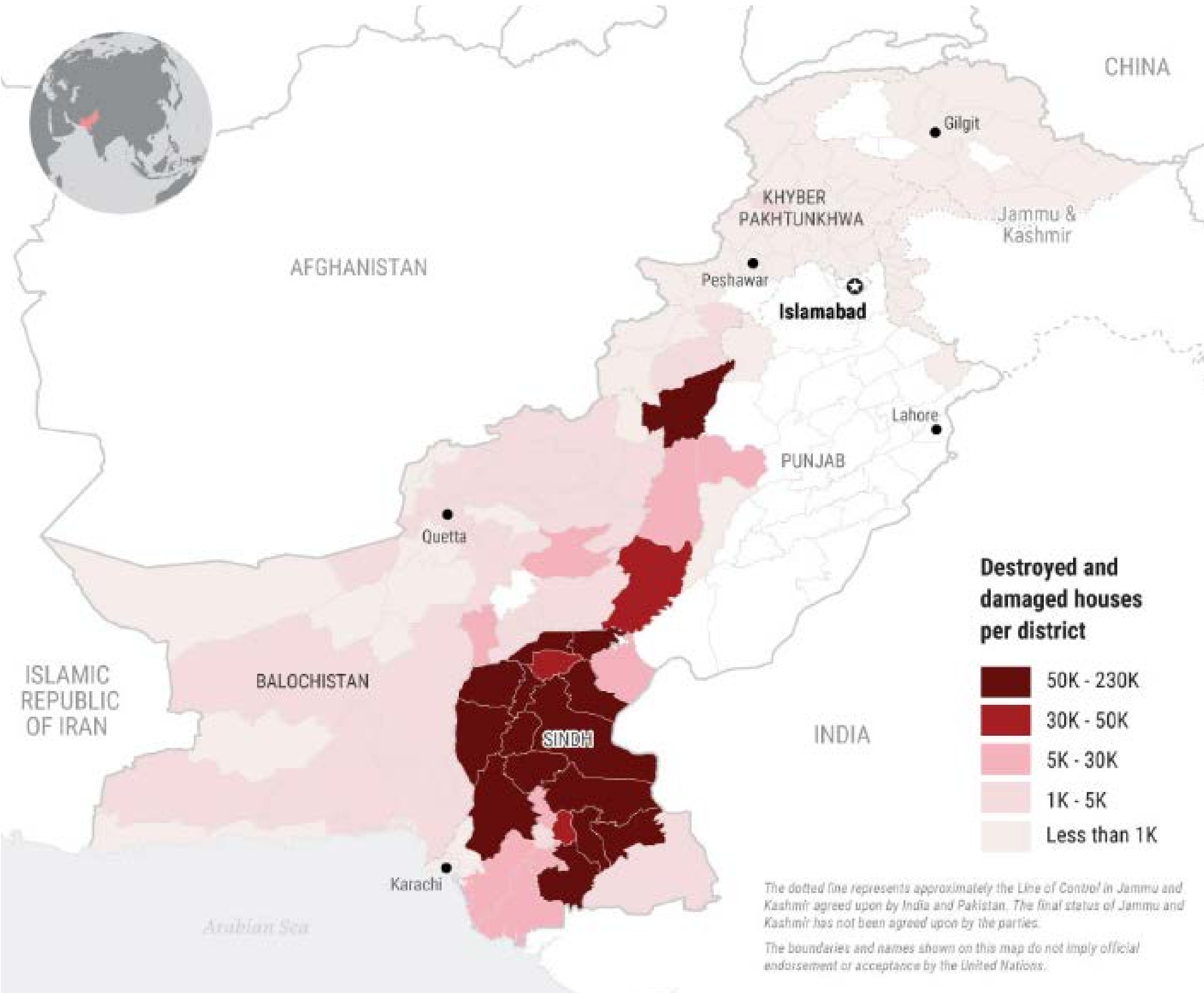


Figure 55.
Displaced population
55.1. *Settlement by the road, where the ground is elevated;*
Source: UNICEF Pakistan 2022 Asad Zaidi
55.2. *Girls in a makeshift shelter in Jogiyani Chandiyo village;*
Source: UNOCHA Gideon Mendel

5. Recommendation set and visual evaluation tool for circularity informed design decisions

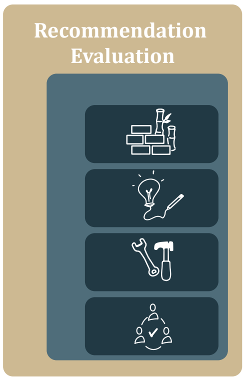
This chapter introduces a dual suggestive tool as a means to support THU planners with taking circularity informed design decisions. The purpose and structure are explained and the limitations are discussed. The implementation of the visual evaluation is showcased on the previously introduced circularity case studies.

5.1. Purpose

This research aims to investigate how circular building principles can be integrated in the planning of humanitarian THUs and thus reduce the negative impacts they may have. Based on the literature review in Chapter 2, it is evident that there is a great variety in the stakeholders, procurement methods and general design approaches for each transitional housing project. Most commonly, THUs are provided by governmental agencies or humanitarian NGOs, which work with project teams. Those teams are small and might consist of architects, coordinators, or engineers. Due to the high pressure of uncertainty and urgency, decisions need to be taken quickly.

Circularity is not yet a topic of consideration during the design process, as there is a lack of awareness and understanding why it could be beneficial and how it can be implemented. So how can humanitarian project team members be assisted in making circularity informed design decisions?

In Chapter 3 several circularity principles are explored (Tables 2-5). Those circularity principles can be translated to transitional housing projects in two ways:



1. | *Design support* - Circularity principles can inform design decisions. For that purpose, a set of recommendations for each of the circularity principles is proposed. The recommendations provide information about the possible options and limitations. This list can be used proactively during the THU design process.

2. | *Design evaluation* – Existing design proposals can be visually evaluated to provide an understanding of the strengths and weaknesses of the said proposal in regard to its circularity potential.

Intended use | The proposed recommendations are intended as a suggestive tool for humanitarian THU design team members to make circularity informed decisions. It can be most beneficial when used in the preparedness phase, before a crisis occurs (subchapter 2.6), or at the very beginning of the design process, as then the necessary research and agreements can be carried out. When used for already existing THU projects the possible alterations might remain limited.

Shelter projects need to take many elements into account and based on the given situation the design priorities may differ. Knowing how the circularity potential of THUs can be increased can help minimise the common critiques and benefit the local economy, the environment, and the affected population. The recommendation set and the evaluation section do not intend to be exhaustive, but rather they can be updated and expanded with further research and practical experience.

5.2. Structure

The suggestive tool has a dual functionality: a recommendation set (passive) to be used during the design process and a visual evaluation (interactive), which can be performed for existing design proposals. The tool is created in Microsoft Excel and can be seen in Appendix C.

Structure: recommendation set | The recommendation set is based on the circularity principles from Chapter 3. It has three columns: Category, Principle, Recommendation. Category refers to the type of strategy as defined in Tables 2-5: Material, Design, Manufacturing and Management. In the Principle column all relevant strategies are listed with an identification number and a short description of what they are. For each principle one or more Recommendations are added. Those recommendations are intended as an assistance to determine whether and how the relevant principle can be implemented in the design. It gives further information and indicates possible risks.

During the process of designing THUs, project team members can proactively refer to this recommendation set and draw inspirations, ultimately making more circularity informed design decisions. The context of the particular crisis needs to be taken into account, as some circularity strategies will be more relevant than others, depending on the circumstances.

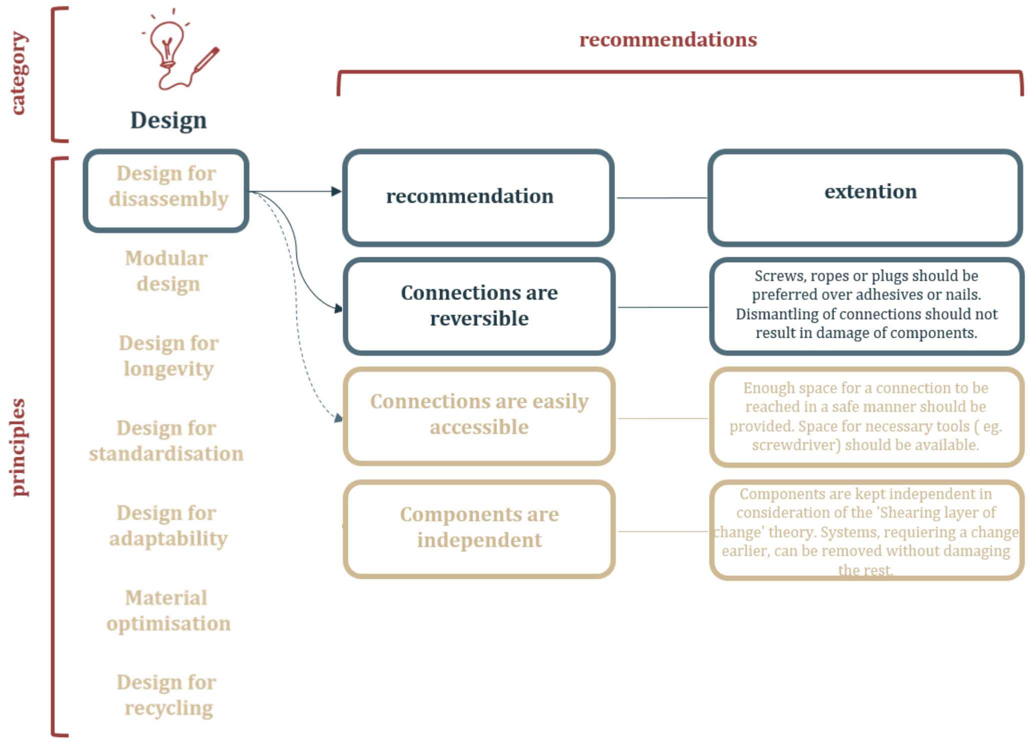


Figure 56.
Recommendation set scheme

Structure: evaluation | The second part of the tool is the Evaluation. It consists of two subparts: Performance and Score. It is difficult to quantify circularity as it depends on a variety of criteria, circumstances, and context. In some cases, some strategies are more useful than others, in others not even feasible (see 'risk' column in Table 2-5 in subchapter 3.3.). Reasons for that can be economical, political, environmental, cultural, and more. Furthermore, different combinations of principles can be applied. Based on that a more qualitative approach is followed for the suggestive tool. A traffic light system in the column Score gives an orientation for the circularity potential of the design.

In the Performance column the indicators are to be found. The indicator consists of a drop-down menu with five possible options, from best to worst (performing in terms of circularity) and non-applicable. Each of those options is directly linked to the corresponding colour in the column Score, which changes automatically. The Performance indicators can be adapted in the sheet 'Data'.

A THU design proposal can be evaluated by selecting the most relevant statement for each of the performance indicators from the drop-down menu. The colour-score can then showcase in which area of the design (Material, Design, Manufacturing or Management) the circularity potential is high – more green and yellow points; or low – majority of red or orange. This can indicate to the project team where design changes might be necessary in order to achieve a more circular transitional housing unit.

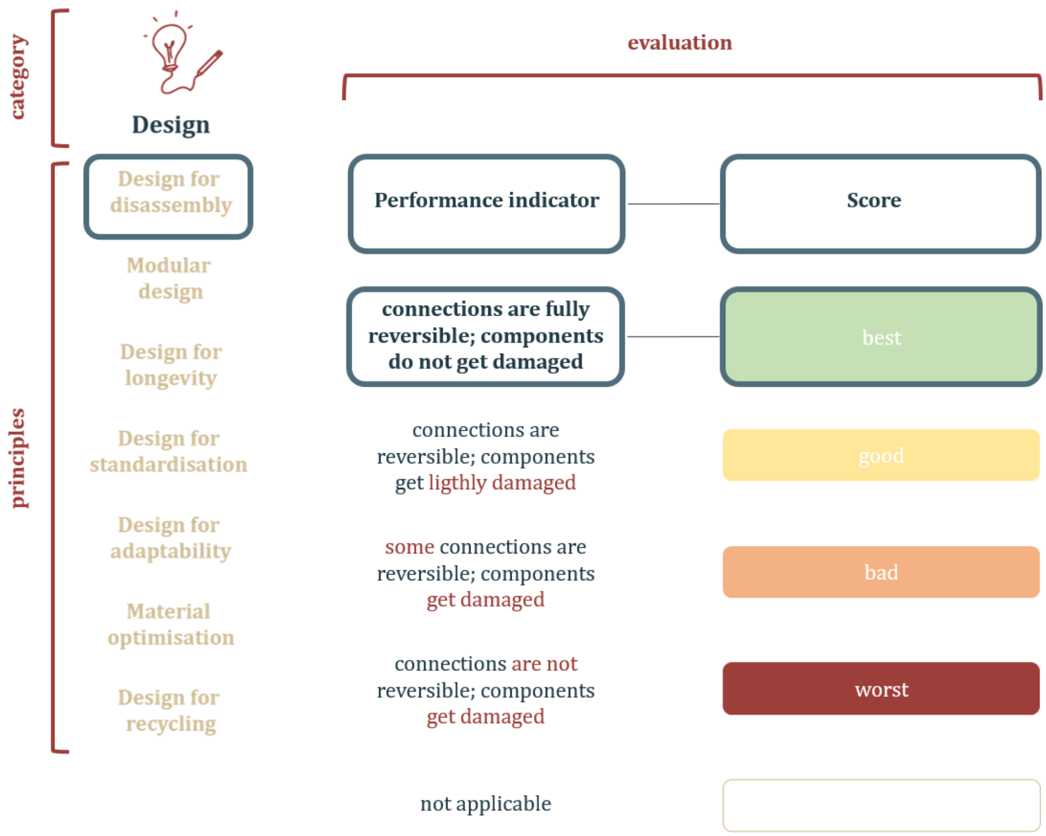


Figure 57.
Recommendation set + evaluation scheme

5.3. Limitations

The implementation circularity in the built environment does not always follow a straightforward approach. As seen in the three case studies discussed in subchapter 3.6, there are many possible combinations of circularity principles (Tables 7-9), which can lead to a circular project. All principles, across the four explored domains, have an influence on one another. Some complement each other well, while others are not compatible at all. For instance, the choice of materials influences the manufacturing method: If wooden panels (biobased material) are used, CNC milling can be a viable production option, while additive manufacturing is rather unlikely.

There will also be many possible variations of combining circularity principles for the planning of THUs. The capacities of the host country and specific context will play a major role in determining the best circularity strategy. The evaluation part of the tool, therefore, aims to give an indication of the circularity potential.

5.4. Evaluation of circularity case studies

The visual evaluation tool is implemented on the three case studies from subchapter 3.6. Even though those projects are not transitional housing units, they can showcase how the tool can be used. Based on the available project information, the relevant performance indicators can be chosen from the drop-down menu. If a principle is not followed in the project, the option 'not applicable' is selected. The same option is selected if there is insufficient information available. For instance, it might not be stated if the materials are sourced sustainably.

Table 10 shows the '*Evaluation overview*' for all three projects. The full evaluation sheet with the selected performance indicators can be seen in Appendix D. As expected, the score is predominantly green, indicating an overall high circularity potential.

CTH*1

B.R.I.C.

BB house

No	Category	Principle	Evaluation overview	Evaluation overview	Evaluation overview
I.	Material				
		1.1 Local materials			
		1.2 Biobased materials			
		1.3 Waste materials			
		1.4 Recyclable materials			
		1.5 Secondary streams			
II.	Design				
		2.1 Design for disassembly			
		2.2 Modular design			
		2.3 Design for longevity			
		2.4 Design for standardisation			
		2.5 Design for adaptability			
		2.6 Material optimisation			
		2.7 Design for recycling			
III.	Manufacture				
		3.1 Prefabrication			
		3.2 Additive manufacturing			
		3.3 CNC milling			
		3.4 Robotics			
		3.5 Vernacular building techniques			
IV.	Management				
		4.1 Create guidelines			
		4.2 Take-back agreements			
		4.3 Scenario planning			
		4.4 Product as a service			
		4.5 Building information model (BIM)			
		4.6 Material passport			
		4.7 Building as material banks (BAMB)			

Table 10. *Evaluation overview for the circularity potential of projects: CTH*1, B.R.I.C. and BB home*

6. Circular transitional housing design proposal

This chapter shows how a design proposal for a transitional housing unit for the extreme conditions of upper Sindh province in Pakistan is made, based on the recommendation set, introduced in the previous chapter. After the programme of requirements and the main architectural concept are presented, the four previously determined domains of circular construction: materials, design, manufacture and management, are followed to explain the design process, concluding with an evaluation.

6.1. Programme of requirements

The design proposal is focused on the upper rural part of the Sindh province (Figure 58) as this area has been hit particularly hard by the recent floods. A high percentage of the damaged houses are located there, and consequently, a great amount of displaced people.

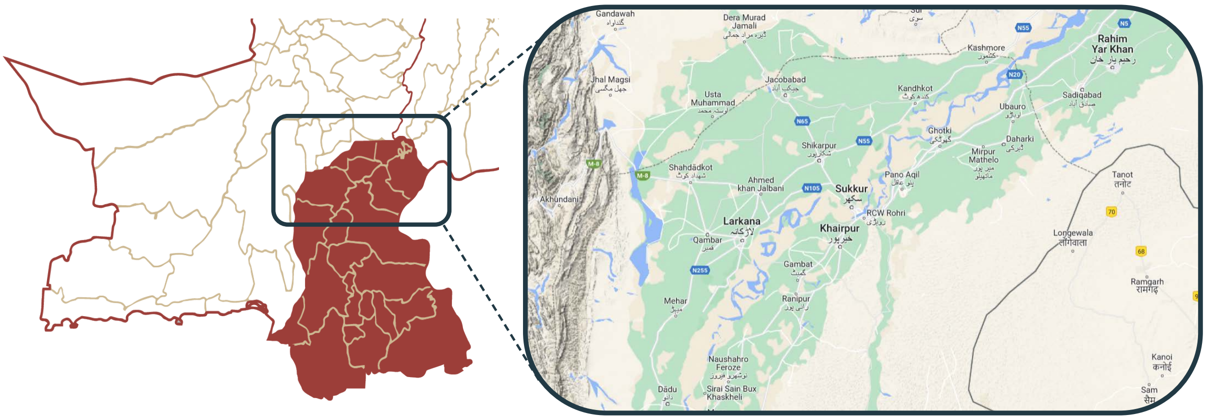
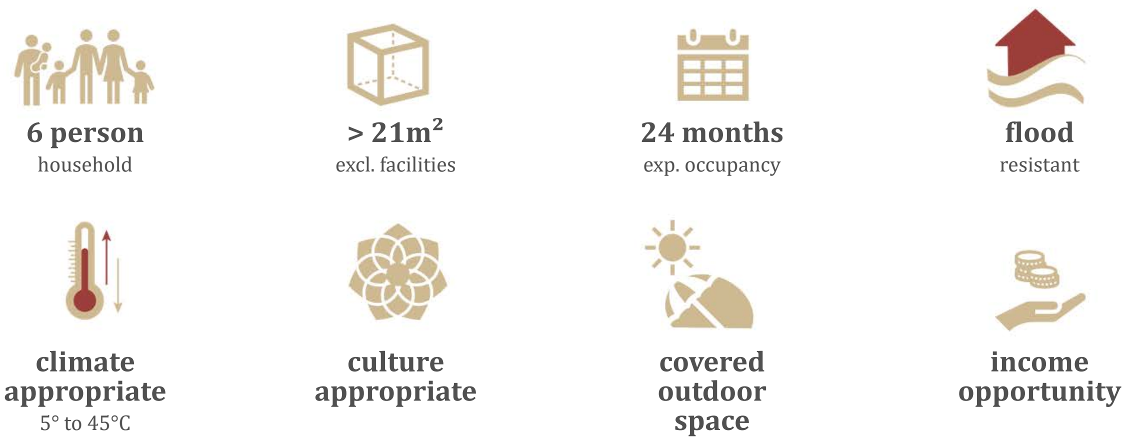


Figure 58.
Region for design proposal, upper Sindh province, Pakistan

In rural areas especially, housing is more than a living area. I it is connected to income generation and animal accommodation (Ministry of Planning Development & Special Initiatives, 2022). A transitional housing unit in this area should enable those activities. Moreover, the unit will provide a home to the DP until a permanent dwelling is available, which can take up to two or three years. Based on that the expected occupancy is set to 24 months. In this period subsequent floods could strike. As a flood-safe settlement area is not necessary a given, the shelters should be resistant to floods.

Size and layout | Based on the average household in Pakistan, the THU should accommodate six persons. According to the guidelines of the Sphere handbook (2018), a minimum of 21 m^2 excluding facilities is required. This aligns with the ca. 23 m^2 per household listed in the governmental reconstruction subsidy as described in the Post-Disaster Neeeds Assesment (PDNA) by the Ministry of Planning Development & Special Initiatives (2022).

Figure 59.
Design requirements



6.2. Architectural concept

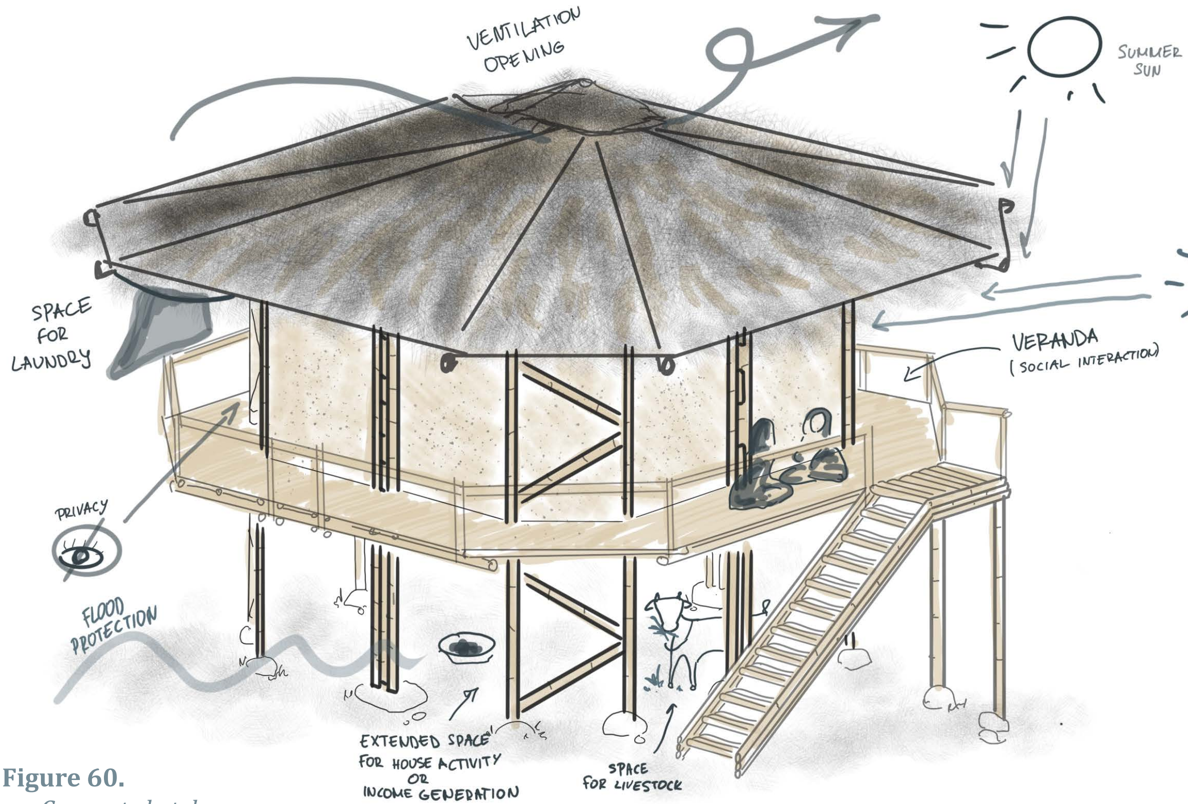


Figure 60.
Concept sketch

Elevated living space

The unit is a stand-alone structure made of local materials. The main living area is lifted on stilts to provide protection from flash floods. Though a shorter elevation would have sufficed, the floor is raised 2.5 m from the ground, allowing for a proper utilisation of the space underneath. This has been done before, for example in the Women's center on stilts built by Yasmeen Lari and the Heritage Foundation (subchapter 4.2). The created space is open and multifunctional. As many DP have animals, they can be accommodated there, protected from the direct sun. As the area is shaded it will remain cool during the hot days, allowing for socialising and gathering of bigger groups.

Income generation

Beneficiaries often use their home for income generation, especially women. Having the extra space as part of the THU, they can set up a small workshop or a store. The space can be fully or partially closed off with light materials if additional privacy is required. In case the THU is relocated to become a permanent dwelling, more stable cob walls can be added, thus expanding the total living area.

Veranda

The elevated living space is further encircled by a veranda, a common Pakistani house element. This shaded area creates a semi-private buffer zone, increasing the privacy of the home. Besides circulation, it can be used for social interactions or hanging of laundry.

Privacy & security

Lifting the living area has also several additional benefits. Privacy is ensured, as people walking by are unable to look inside. This further provides more security for people and belongings. A common problem in displacement settlements is the fear of rats and snakes. The elevated area minimises the chances of rodents entering the living space.

Passive strategies

The roof of the THU is extended providing both sun shading and protection of the structure against rain. The summer sun, which is located very high, at 82°, is prevented from entering the living area. On the other hand, the lower winter sun, at 38°, brings passive solar gains in the colder months. The roof has an opening on the top, which allows the stagnant hot air to escape. Cross ventilation can occur by opening the windows. As there are high diurnal temperature differences nighttime ventilation can occur. It is therefore advisable to keep the windows open at night. Mosquito nets are added to protect the beneficiaries from insects.

Settlement

The unit should also be considered in relation to a settlement. As the units have to sole function of living, space for cooking and latrines will be provided on site. The cooking in the rural areas is often done outside. In other displacement settings a design developed by Yasmeen Lari for an elevated version of the traditional outside *chulah* is used (Figure 61).

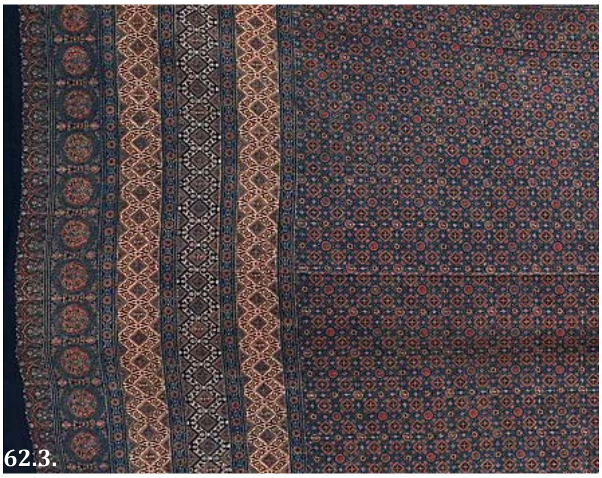
In the extreme scenario that a flood hits the settlement, and the water remains stagnant, elevated units with the function of enclosed kitchen space and latrines can be envisioned. For each five transitional housing households, one kitchen unit and two latrine units (male and female) should be provided. Bridges between the structures can ensure safe crossing even when the ground is inaccessible.

Figure 61.
' chulah' - traditional outside stove;
Source: Archiv Yasmeen Lari

Form finding | Ajrak is one of the most prominent symbols of Sindhi culture. It is a blockprinting technique used mainly for shawls (scarfs). The meaning of 'ajrak' is 'little brick' from Persian and 'blue' from Arabic, referencing the main colour used. Traditionally ajrak is made with natural indigo, crimson, black and white dye, a colour palette complementing the universe, depicting different geometries (Biswas et. al, 2015). Carved woodblocks are used to transfer the patterns onto fabric.


62.1.


62.2.


62.3.


62.4.

Figure 62.
Ajrak
62.1. Traditional pattern; Source: Biswas et. al (2015)
62.2. Woodblocks; Source: Biswas et. al (2015)
62.3. Ajrak shawl; Source: Visdaviva, CC BY-SA 3.0 via Wikimedia Commons
62.4. Children in Sindh wearing Ajrak;
Source: dawn.com (2014)

Ajrak is a pictorial element that creates a sense of belonging for the Sindhi population. The traces of ajrak go back to the period of the Indus valley civilisation. The shawls are worn by men and women and is often given as a gift of hospitality.

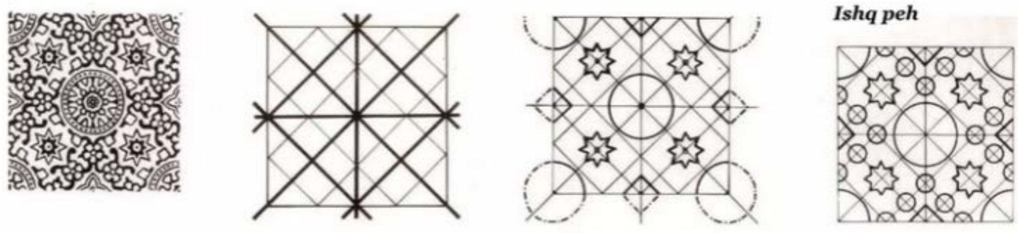


Figure 63. Ajrak pattern creation; Source: Biswas et. al (2015)

The depicted patterns follow geometries based on a square. By connecting diagonals and lines, adding more detail, the motif is created. The form of the THU is an octagon, based on this structure. Besides the cultural significance, the octagonal shape has further benefits for the transitional housing unit:

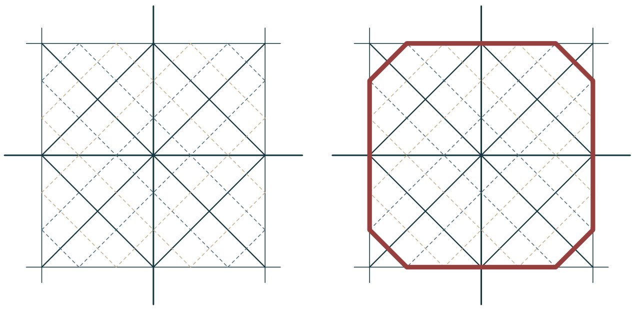
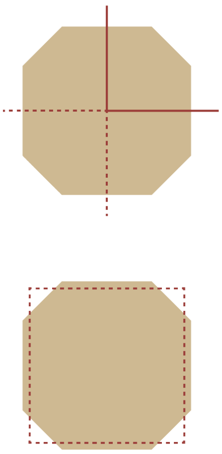


Figure 64. THU form finding



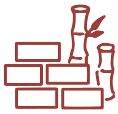
Symmetry - Due to the unpredictable circumstances of a disaster, the location of a displacement settlement will differ. Thus, the orientation of the units needs to remain flexible. The octagon is symmetrical, which allows an easier arrangement of units in relation to the site.

Area to perimeter ratio - The octagonal shape has a better area to perimeter ration compared to a square. This means, that the same square meters can be provided with less wall area, reducing the material needed per THU.

Figure 65. THU benefits based on octagonal shape

Design decisions | The next four subchapters (6.3 to 6.6) will explain the decisions made in regard to the four domains determined in Chapter 3: Material, Design, Manufacturing and Management. The recommendation set introduced in Chapter 5 is used to make more circularity informed decisions. The relevant recommendations will be mentioned with *italic and the colour blue*. The full list of recommendations and the detailed explainations can be seen in Appendix C.

6.3. Material



Material

Local material

Biobased material

Waste material

Recyclable material

Secondary streams

For the context of Sindh, Pakistan, the use of locally available biobased materials seems to be the right approach since this is common in the rural vernacular architecture. For that reason, *1.1 Local material* and *1.2 Biobased material* are the main circularity principles followed in this section.

The first step is to identify which local materials are available as per recommendation *1.1.1 Identify possible local building materials (area, region, country)* of the Recommendation set (Appendix C). An overview of the possible natural materials and their location in Pakistan can be seen in Appendix A. For the THU design proposal bamboo is used for the bearing structure and hempcrete (hemp + lime) for the walls. Both materials have a low environmental impact as they have a low, sometimes even negative, carbon footprint (recommendation *1.1.3 Environmental impact of materials' sourcing and processing*).

Figure 66. Circularity principles in the domain 'Material' implemented in the circular THU design proposal

bamboo **hemp** **lime**

Figure 67. Main materials used in the THU design proposal

Bamboo | Bamboo is renewable and extremely fast-growing, up to 1.2 m in only 24 hours (Dunkelberg et al., 1985). It requires little water and no fertilisers. This, in combination with the great tensile strength and light weight, makes bamboo a wonderful building material. The material is strong, durable but also flexible, making it an excellent alternative to traditional construction materials such as timber, concrete, and steel. Furthermore, bamboo burns slower compared to softwood (ibid.).

The biggest threats to the material are fungi, insects, and moisture. If left untreated, the bamboo elements will need replacement in 2-3 years, whereas, with proper preservation, the bamboo can last decades. Bamboo treating can be done through salt water immersion, smoking, fermentation or a chemical (recommendation *1.2.2 Avoid toxic chemicals*). A common technique to treat bamboo is with a borax based solution (Lalwani, 2020). With more and more contemporary projects utilising bamboo, the local population gains knowledge on how to properly take care of the material (recommendation *1.1.4 Consider ease of maintenance*).

As bamboo is locally grown, its use for construction can reduce transportation emissions and boost the local economy. Moreover, it can also provide employment opportunities for local communities, particularly in low-income countries where traditional construction materials may be expensive or difficult to obtain. The most common bamboo species in Pakistan and in the Sindh region is Bambusa.

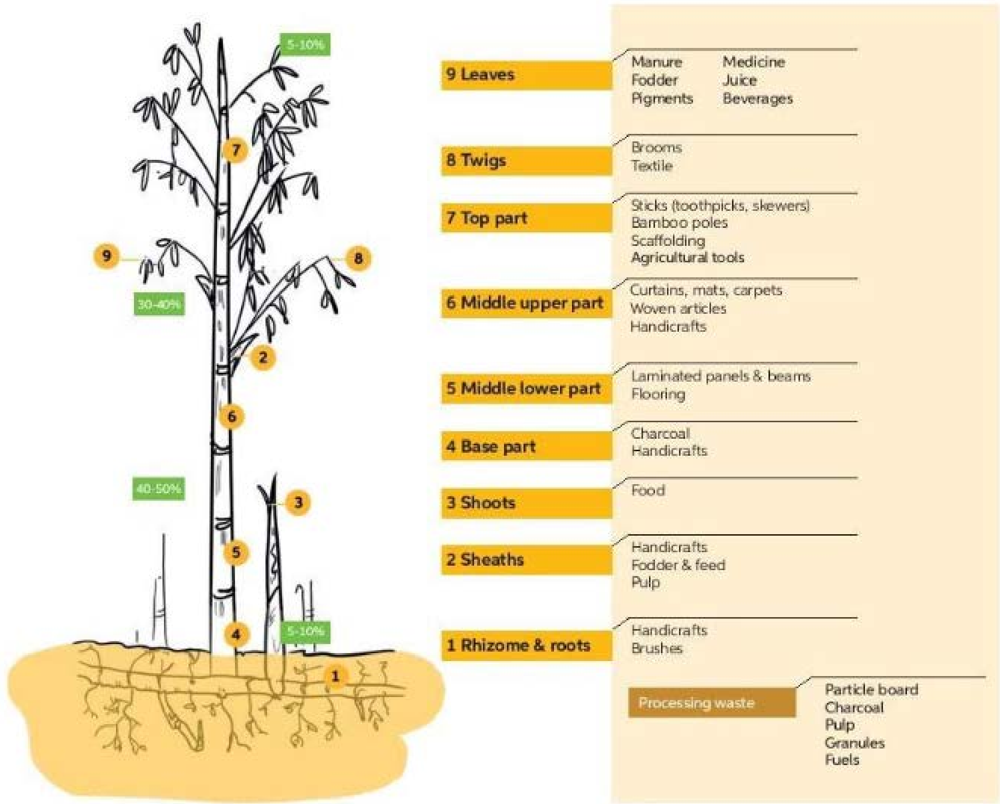


Figure 68.
Bamboo full utilisation
Source: van der Lugt (2017)

Hempcrete | In recent years a new material has entered Pakistan's economy: industrial hemp. The government legalised its use in 2019 as a means to push the local economy (Shahzad, 2020). The plant is native to central Asia and it's been growing naturally in the wilderness of Pakistan. Hemp is a very versatile product that can be used for fibre, textile, medicine, and as a building component among other things. Production of hemp is fast as it has a short growth cycle and can be harvested twice a year (recommendation *1.2.4 Consider the harvest season*). It uses less water than cotton and is naturally water and fire resistant. In construction it is mostly used as the biocomposite material hempcrete.

Hempcrete is gaining popularity in the construction industry due to its many environmental benefits. It is made of the hemp shives (the woody core of the hemp plant), a byproduct of hemp fibre production (principle *1.3 Waste materials*; recommendation *1.3.1 Identify waste materials (area, region, country)*), and lime-based binder. Hempcrete has very good thermal insulation qualities and is carbon-negative, as it stores more carbon than it produces. Besides the CO_2 amounts absorbed during the plants' growth, when the hempcrete is mixed, a carbonation process starts. The high silica content in the shives bonds well with the lime, causing calcium hydroxide in the lime binder to absorb more CO_2 and thus create calcium carbonate (limestone) (Schires, 2021). Further benefits of using hempcrete as a building material include improved indoor air quality, stable humidity and temperature, reduced energy consumption, fire-, mold- and pest-resistance, and excellent acoustic insulation properties (Yadav et al., 2022).

Hempcrete is not load-bearing and must therefore be integrated with traditional building construction systems. There are multiple construction ways, such as casting or spraying on site and prefabricated blocks or panels. Depending on the mixture proportion, the density can vary between 275 and 600 kg/m^3 (ibid.). Even though hemp-lime mixtures have been used for centuries, like in the Ellora Caves in India from the sixth century AD, it is relatively new to the modern construction industry. There may be a learning curve necessary for builders and architects who are not familiar with the properties and characteristics of hempcrete.


69.1.


69.2.


69.3.

Figure 69.
Hempcrete construction techniques
69.1. Casting; Source: Alex Sparrow (the last straw, 2014)
69.2. Blocks; Source: ISOHemp
69.3. Panels; Photo: Jorn van Eck (Archdaily, 2022)

Example of material combination | This particular combination of materials, bamboo and hempcrete, is quite new but it has been implemented before in a pioneer project in Mexico. The 100 m^2 building has been assembled as part of a hands-on training course on sustainable construction (Malazartes, 2016). Due to legal reasons the hemp couldn't be grown in the country, so it has been shipped from the Netherlands. Overall, the combination of bamboo and hempcrete is seen as complementary and the use of hemp in the project is considered very economic and efficient.


70.1.


70.2.


70.3.

Figure 70.
Hempcrete and bamboo construction in Oxtopulco, Tepoztlán, Mexico
70.1. Source: Heavengrown [Instagram] 2017
70.2. Source: (Malazartes, 2016)
70.3. Source: Heavengrown [web] 2023

Material's lifecycle | Bamboo is a very versatile material. Often the connections used are reversible – through binding or screwing, which means that components can easily be repurposed and reused. As an organic material bamboo biodegrades at the end of its service life. Alternatively, it can also be turned into charcoal, used for heating (recommendation *1.2.1 Identify suitable disposal options and their availability*).

Hempcrete is a very durable material. It can last up to 100 years. At the end of its service life, it can be directly reused, repurposed or turned into aggregate for a new hempcrete mixture, thus reducing construction waste (recommendation *1.2.1 Identify suitable disposal options and their availability*). Overall, hemp is a highly renewable crop, which can support the local economy. With the recent legalisation of industrial hemp, the industry is yet to be developed and expanded in Pakistan. The multiple positive properties of hempcrete make the material highly attractive and suitable for the diverse climate in the country.

Material lifecycle and end-of-life scenarios

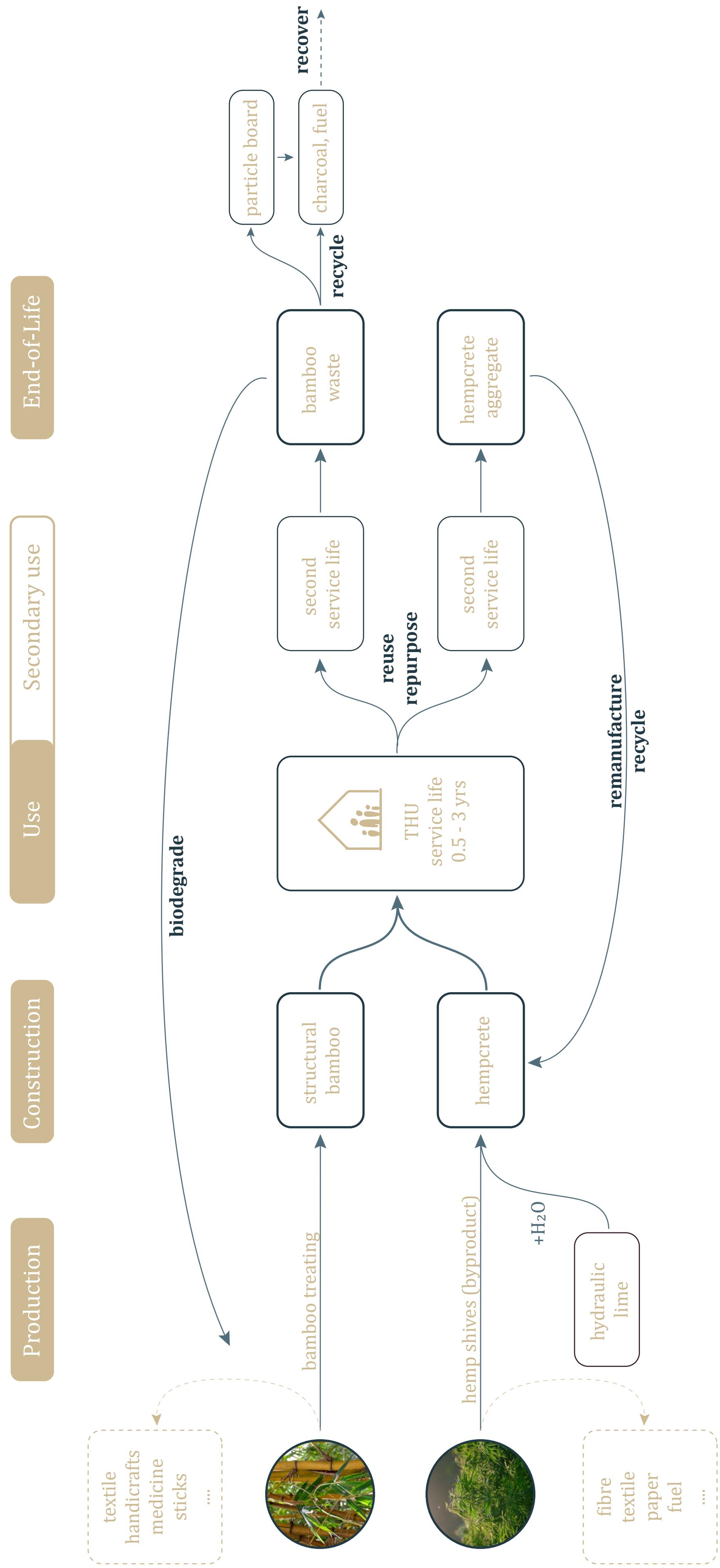


Figure 71.
Material (bamboo and hempcrete) lifecycle and end-of-life scenarios

6.4. Design

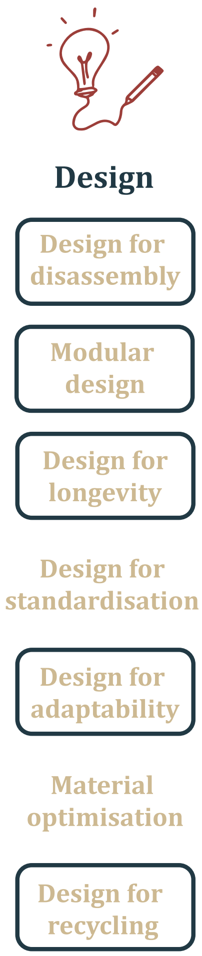


Figure 72. Circularity principles in the domain 'Design' implemented in the circular THU design proposal

The context of repeated flooding in Sindh calls for a flexible design, which can be relocated or be dismantled when the displacement period is over. For that reason, the *2.1 Design for disassembly* principle is followed. Furthermore, *2.3 Design for longevity* and *2.5 Design for adaptability* are considered as the THUs and their components are seen for their potential to be reintroduced in the local economy (subchapter 6.6). Finally, the materials can be separated for recycling according to the *2.7 Design for recycling* principle.

Bearing structure | The bearing structure is made of bamboo. There are the following main elements to the construction: the columns, the floor slab, and the roof. Figure73 shows the three types of columns used. The 'panel' prevents the torsion of the building. The bamboo stems have a diameter of 10 cm and are connected with threaded stainless-steel rod and nut and are enforced with ropes. Such connections can be easily dismantled (recommendation *2.1.1 Connections are reversible*), though the components can be directly reused as well. Extra care needs to be given during the drilling of holes to avoid cracking. Holes should be made close to the bamboo nodes, as this is the strongest part of the material.

The unit has a reciprocal roof with eight beams (four with 6 m length and four 5.6 m long). Each beam carries the weight of the previous and lies on the next one. This ensures a stable self-bearing system. There are two main beams (with three bamboo stems each) which cross each other, forming the base of the floor slab. They are carried by the columns on the ground floor. Additional beams between the columns and the panels are forming the frame, which carries the floor joists.

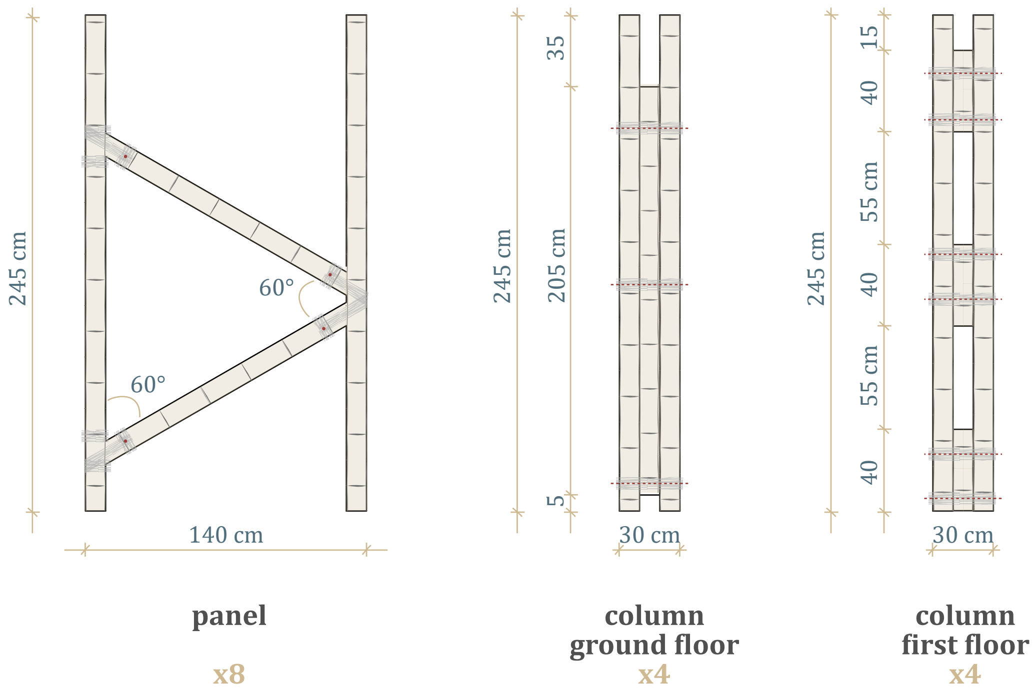


Figure 73. Bamboo column types and amount of elements per unit

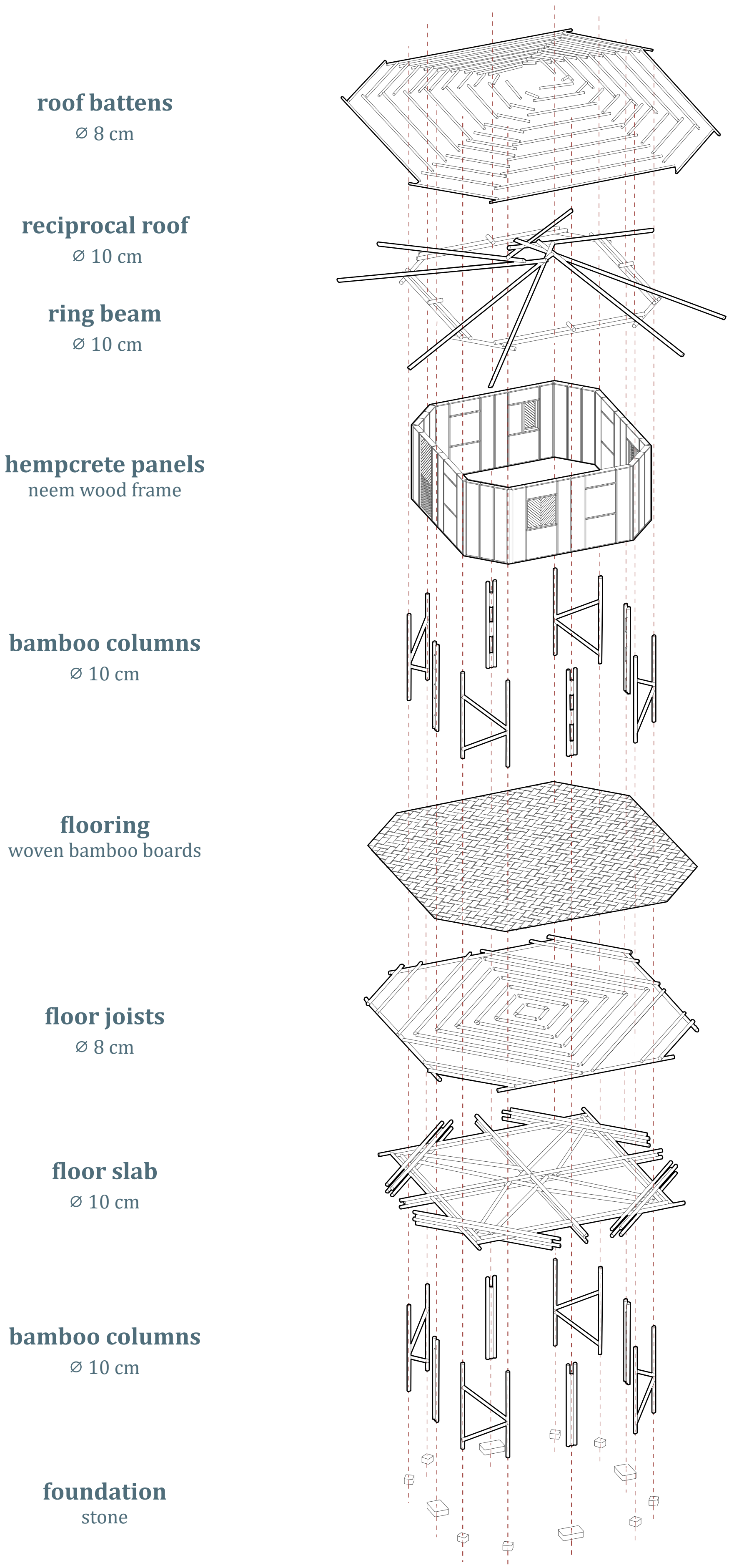


Figure 74.
Axonometric view

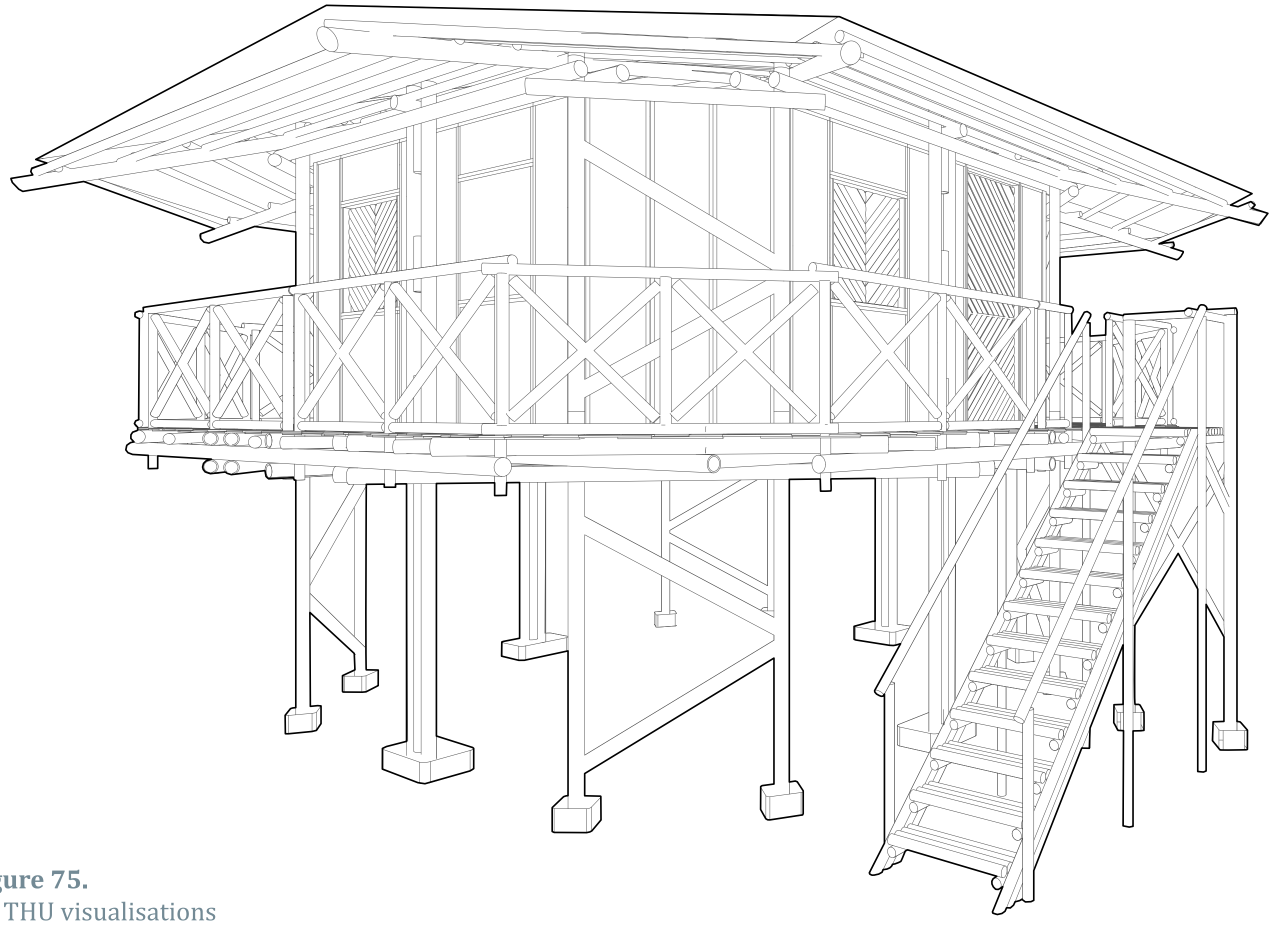
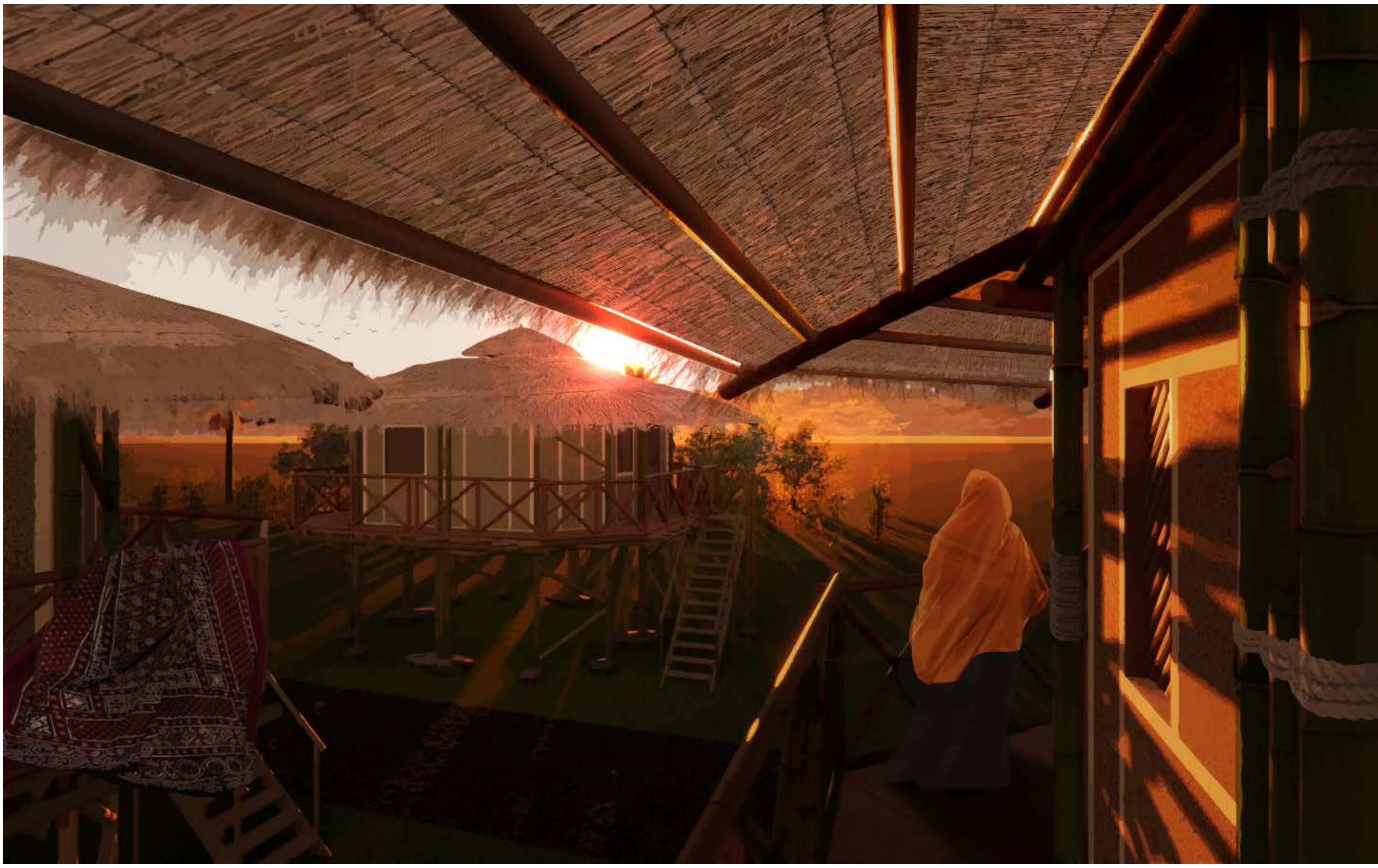


Figure 75.
THU visualisations



The connection between the columns is made with wood dowels from the branches of the Neem tree, which is a locally available hardwood (Appendix A). The dowels are cut to size and inserted halfway in the ground floor column (or panel) with the help of a hammer. To make the connection tight the dowels can be covered in lime cream as demonstrated by the Heritage Foundation of Pakistan (Lari, 2021). Then the first-floor column is added. Finally, a hole needs to be drilled, which will allow the threaded steel rod to pass through the bamboo and the dowel, keeping everything together.

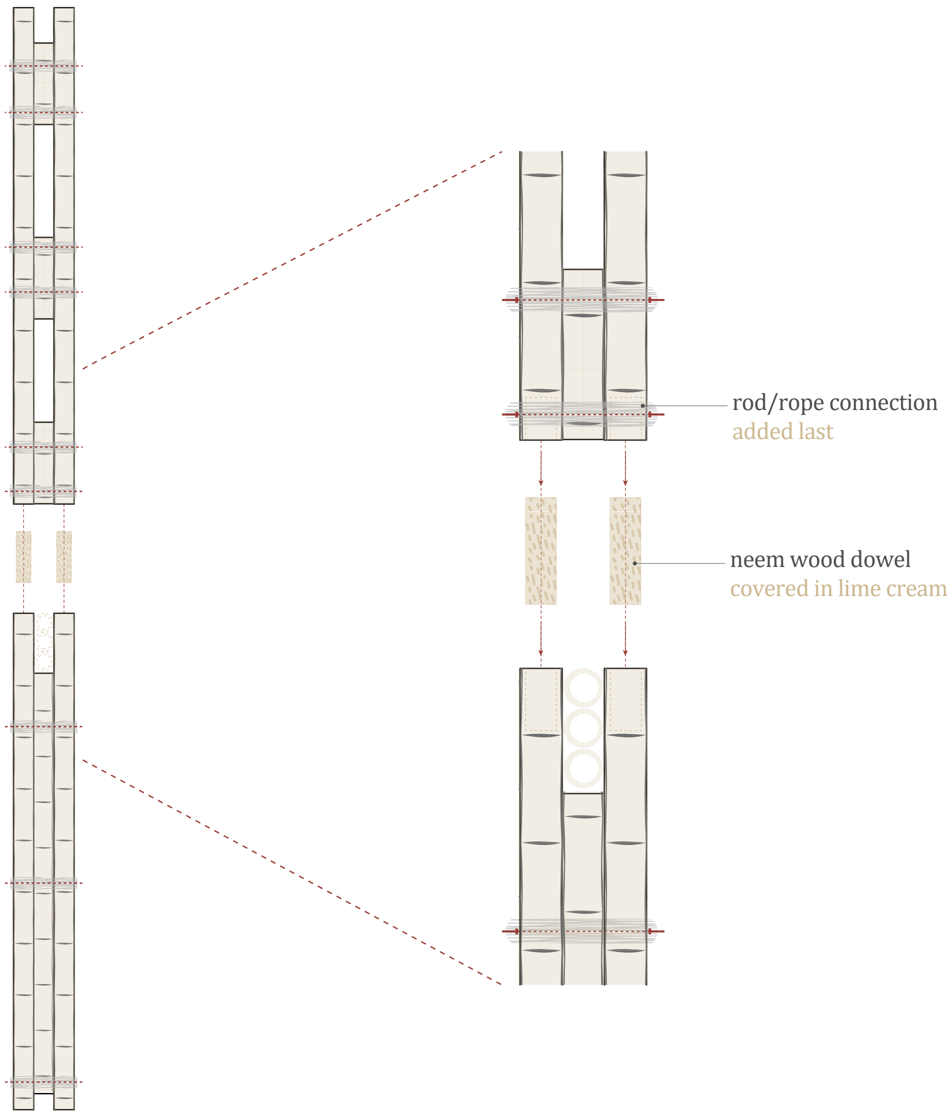


Figure 76.
Connection columns

Wall system | The hempcrete wall is positioned in front of the bamboo bearing structure, instead of on the same axis. This separation of the Skin and Structure layers allows for easy access to the connections (recommendation *2.1.3 Connections are independent*). The thickness of the wall is 15 cm, which is based on calculations for achieving comfortable temperature in Sindh (Appendix B).

The hempcrete wall is made of three sizes of panels (modules) seen in Figure 77. They can be arranged in several configurations, allowing for the integration of doors and windows (recommendation *2.2.1 Catalogue the modules and the possible combinations*). Even when already assembled in the THU, the modules can later be exchanged if the need for more privacy or additional openings arises (recommendation *2.5.4 Allow for façade reconfiguration*).

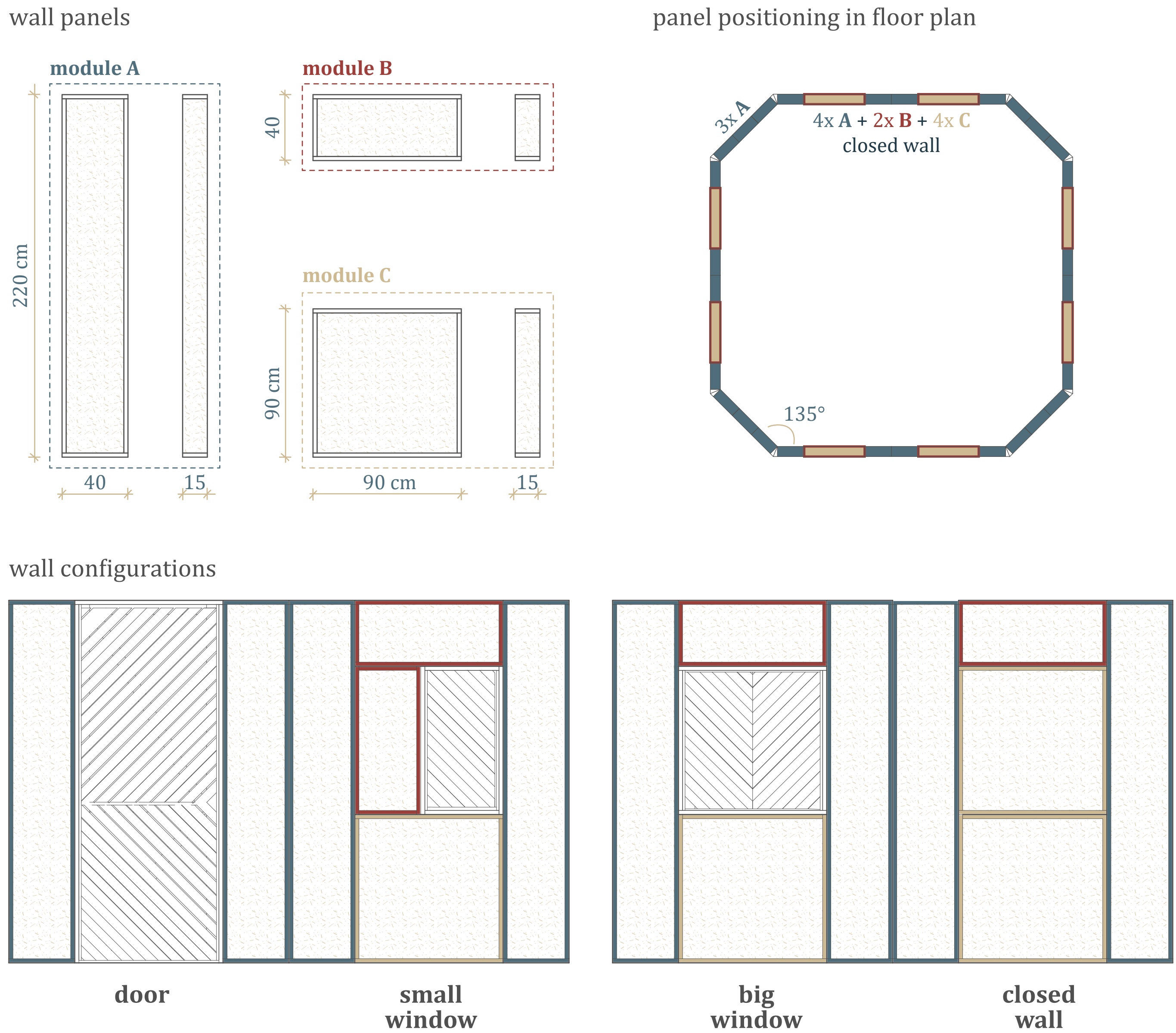


Figure 77.
Wall panels and configuration

Wall system: assembly and connections | The panels have a frame made of Neem wood. The frame remains from the casting process, allowing for easier handling on site. Through the use of big panels, the assembly process is faster compared to hempcrete brick layering. Furthermore, none of the modules is heavier than 55 kg, so it can be carried by 2-3 people.

The corners of the THU have an angle of 135°. To achieve this connection a piece of 15 x 6 cm Neem wood is cut diagonally. One of the halves is then flipped around and screwed to the other, which creates a corner piece with the correct dimension.

The connections between the panels are made with standardised straight plate stainless-steel brackets and 50-60 mm long wood screws. To avoid cracking, pilot holes can be pre-drilled or self-drilling screws can be used. At the corner connection, stainless-steel 135° angle brackets are used. The positioning of the brackets can help compensate for tolerances. All connections are easily accessible from the veranda or the interior of the THU (recommendation *2.1.2 Connections are easily accessible*).

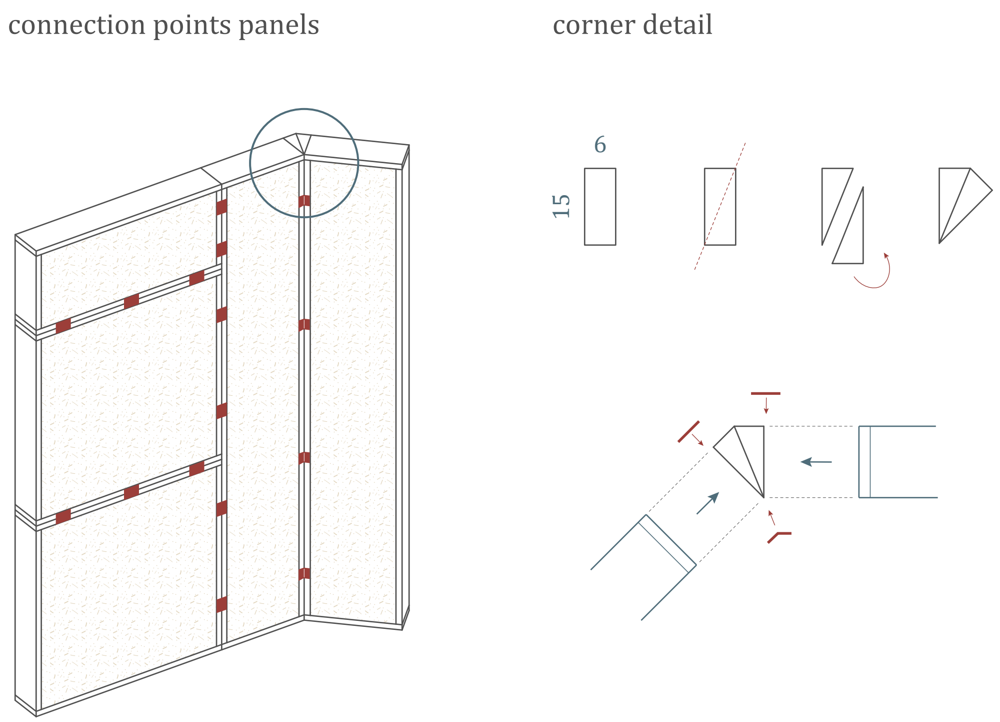


Figure 78.
Wall panels connection points and corner detail

Wall system: end of service life | Once the end of service life of the THU is reached, the wall panels can be disassembled. They could be directly reused with the wood frame in another project, or the materials of the modules can be separated (recommendation *2.7.1 Materials within a component can be separated*). The hempcrete could then be incorporated in a new wall with the current dimensions. Alternatively, it can be cut to brick size with a simple hand saw. The most common hempcrete brick measurements are 30 x 60 cm with varying thickness. With 35 cm width, this panel is slightly bigger, but this can be used as tolerance, in case the hempcrete gets damaged in the process of removing the wood frame. Any damaged hempcrete can be recycled into aggregate for the production of new hempcrete.

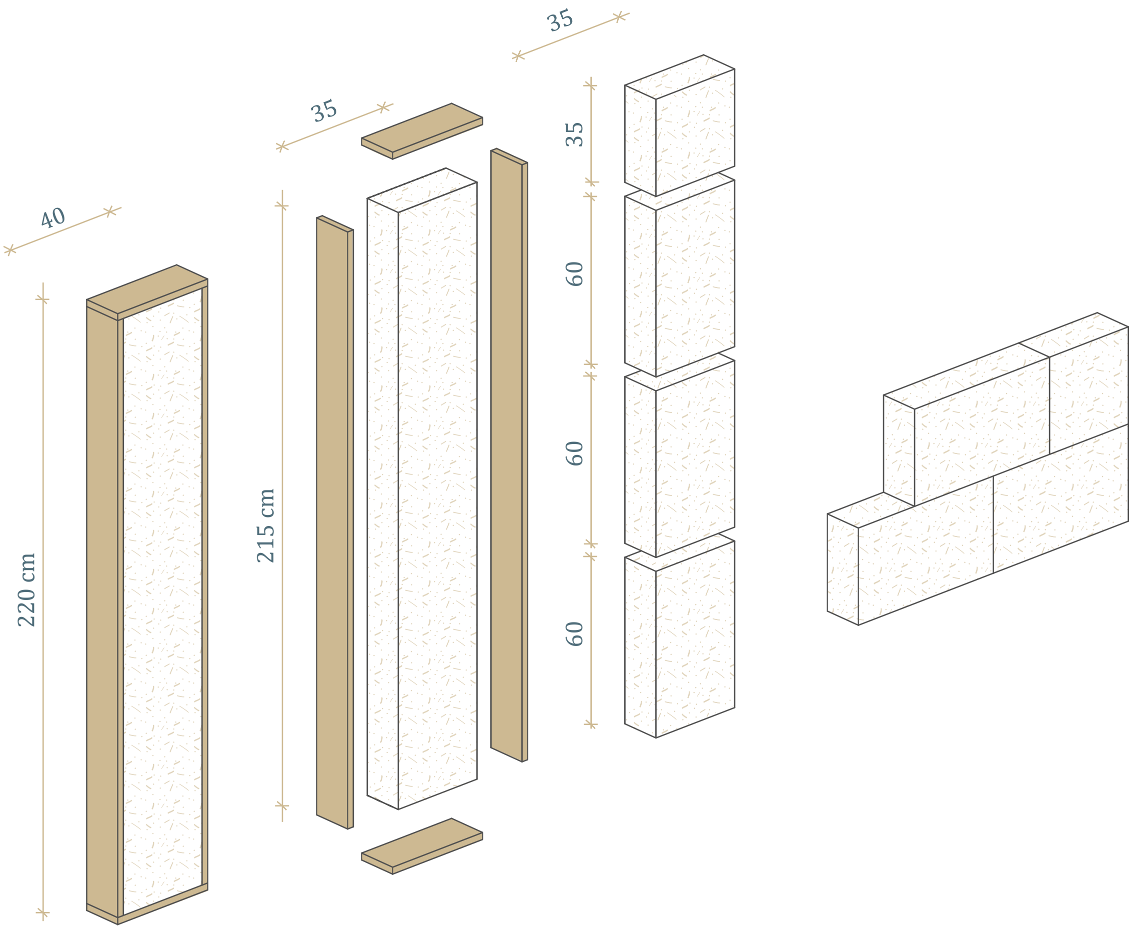


Figure 79.
Wall panels end of service life

Layout | The THU has an area of 24,5 m^2 and an additional veranda of about 22 m^2. Considering the analysis of vernacular rural houses and existing shelter projects, the unit will provide (at first) only one enclosed room, however, it is possible to add partitions from lightweight materials like bamboo panels or curtains. The hempcrete wall system allows the addition of a second door, so the unit could be separated in two rooms with separate entrances. This flexibility allows the unit to be adapted to the beneficiaries needs, as well as accommodate other functions (recommendation *2.3.3 Multifunctional spatial layout*).

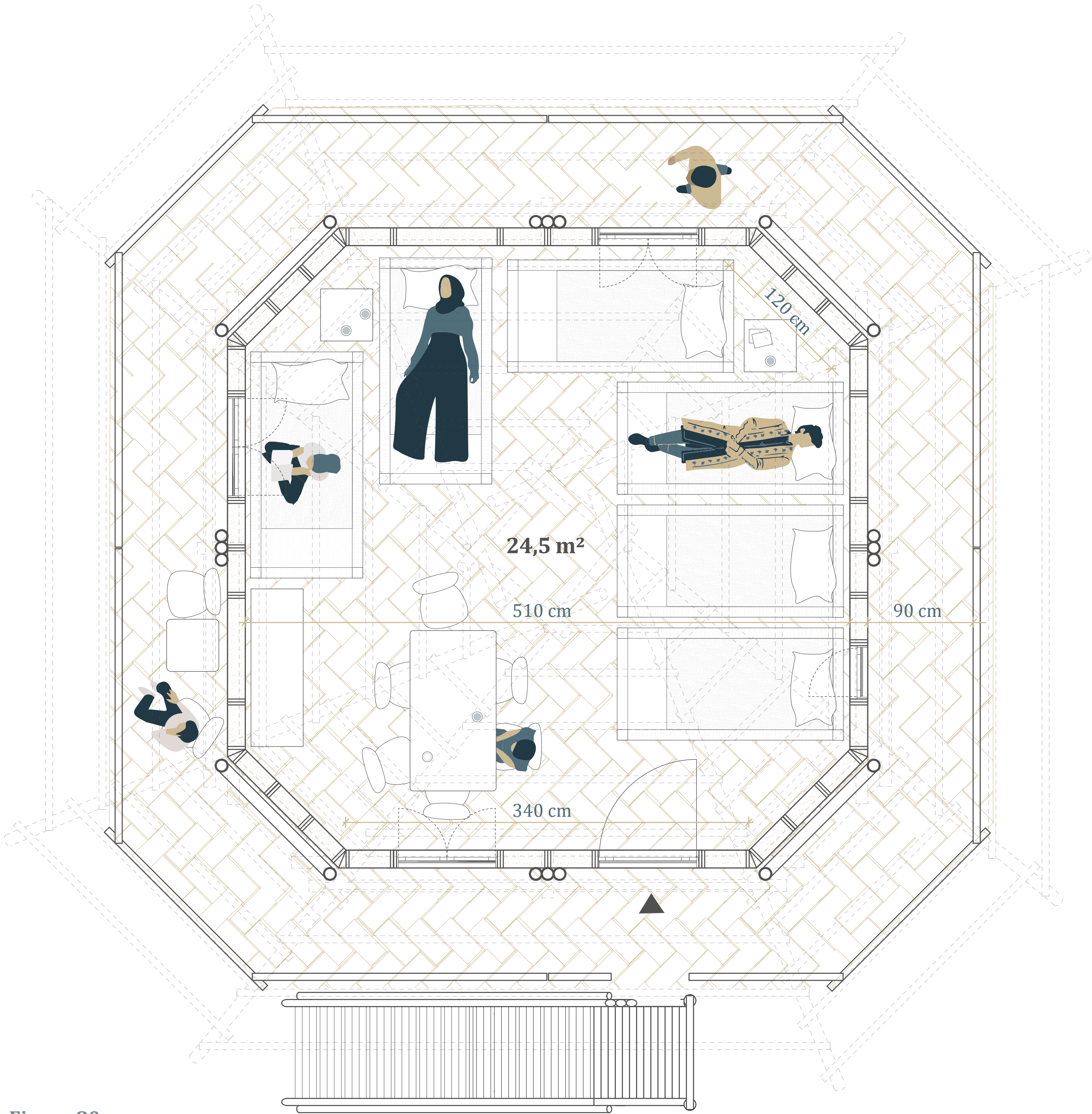


Figure 80.
Floor plan 1:50

Future scenarios | The common practise after disaster in Pakistan is to go straight to permanent reconstruction and support beneficiaries with core shelters. This is in line with the government's PDNA (Ministry of Planning Development & Special Initiatives. 2022). To make the transitional housing proposal a more desirable option it should have the opportunity to be transformed into a semi-permanent shelter (if land with secure tenure is available) with small adjustments, such as a stronger foundation. The open space on the ground floor can then be enclosed with walls made of hempcrete or the more traditional mud and lime. Thus an additional room can be created.

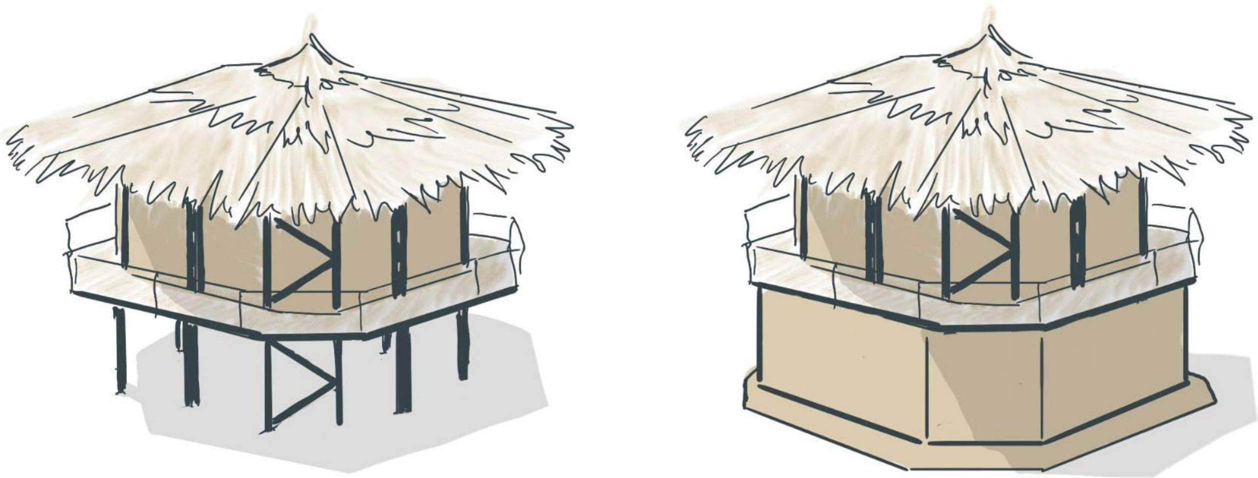


Figure 81.
Transition from THU to permanent housing

The THU proposal should, therefore, be easy to relocate and flexible enough to allow strategies for direct reuse at the end of the displacement period. The unit can become a social or rental housing. Alternatively, the function can change to a community space. Social centres, which provide safe space for women or children, can contribute largely to permanent settlements (recommendation *2.5.1 Analyse end-of-life scenarios*).

6.5. Manufacturing

Figure 82.
Circularity principles in the domain 'Manufacturing' implemented in the circular THU design proposal

For the THU design proposal for Pakistan, two Manufacturing circularity principles are followed: *3.1 Prefabrication* and *3.5 Vernacular building techniques*. The other three options – additive manufacturing, robotics, and CNC milling, are not suitable for the context of Sindh due to the high initial investment and special machinery required.

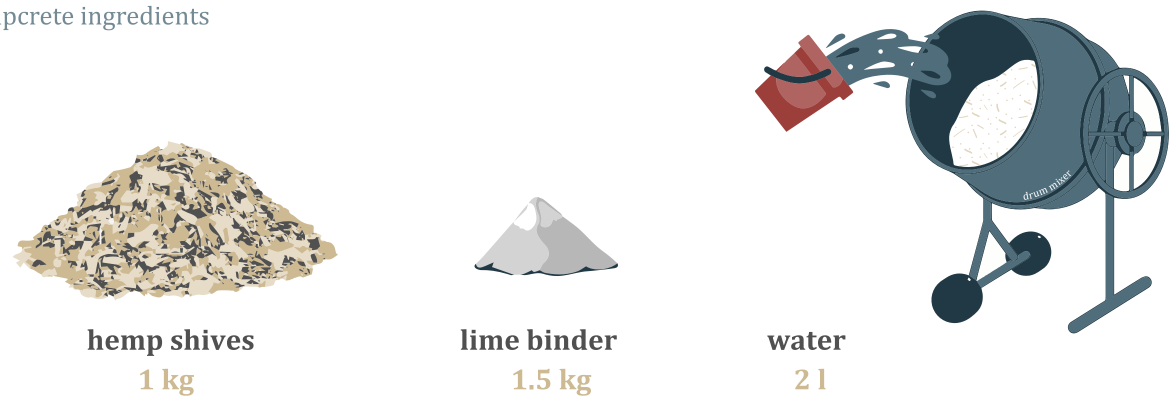
Wall panels | The hempcrete panels can be prefabricated either off or on site. With the legalisation of industrial hemp in Pakistan, it can be expected that hempcrete factories will be set up. In controlled conditions the mixture and the drying process can be kept consistent. The transitional housing can thus be supported by available manufacturers in the affected region (recommendation *3.1.2 Utilise existing prefabrication infrastructure*). Alternatively, manufacturers of clay bricks might have the necessary facilities like a drying chamber.

The prefabrication on site can allow the participation of the beneficiaries in the process. Through construction workshops, they can learn how the hempcrete mixture is made, how to work with the material safely, and how it can be used in a later stage (recommendation *3.2.3 Train beneficiaries*).

Hempcrete mixing | Three elements are needed for the creation of hempcrete: hemp shives, lime binder, and water. The woody core of the hemp plant is chopped to pieces of 5 – 25 mm. The proportions of the mixed ingredients is crucial for the performance of the composite material. A few tests might be necessary to find the optimal measurements but a ratio of 1:1.5:2 of hemp shives, binder and water in weight is a good start.

The hempcrete is usually mixed in a large pan mixer. If this is not available, a drum mixer can also be used. In the case that no such tools can be brought to the prefabrication site, the material can also be mixed by hand, which is more labour intensive. For safety reasons, working gloves need to be used as the lime can irritate the skin. A mask and goggles are also advised due to the dust during mixing.

Figure 83.
Hempcrete ingredients



Firstly, the binder and water are mixed until they form a homogeneous liquid. Then the hemp shives are added. After several minutes of mixing the material can be tested by making a ball with your hands – it should stick together and start to crumble under small pressure.

The ready hempcrete can then be added to the premade framework of neem wood. It needs to be pressed down and flattened, for example with a wooden trowel or tamper. The panel is then left to air-dry, which can take up from a few days to 2-3 weeks depending on the climatic conditions. Once dry, the panels can be assembled directly with the wooden frame.

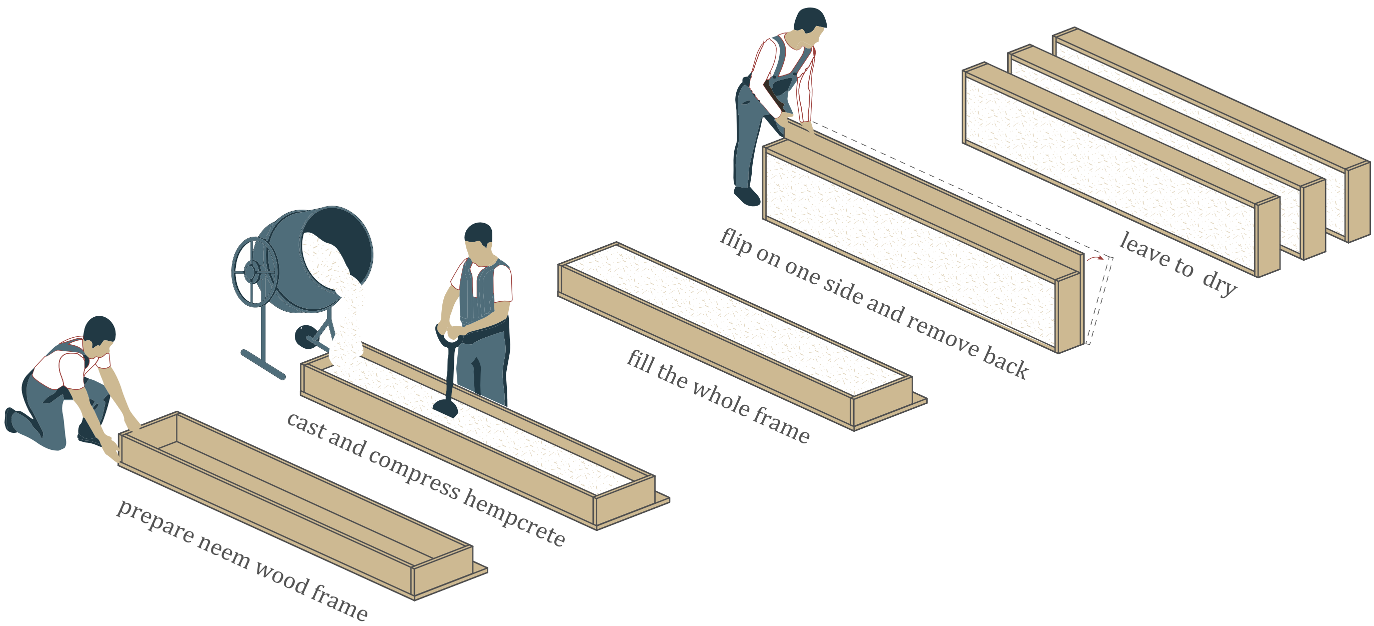


Figure 84.
Hempcrete panel manufacturing

Vernacular building techniques | For the proper bamboo preparation and connections local experts should be contacted as they know the available bamboo species best. Local knowledge and expertise can further be utilised in the roof construction. The THU has a thatched roof, similar to the huts found in the Thar desert (subchapter 4.2). Local craftsmen can help adapt the vernacular technique to the proposed transitional housing design. Women can further help in the weaving of grass for the roofing (recommendation *3.5.1 Understand the existing vernacular building techniques and construction skills*).

6.6. Management

The proposed transitional housing unit follows the concept of *4.7 Building as material banks - BAMB*. The units are, therefore, seen as an investment and the used materials and components can be of a higher quality, as they will be returned to the local economy after the displacement period. To enable this strategy, *4.6 Material passports* are prepared for the components and *4.2 Take-back agreements* with suppliers are made even before a crisis occurs. *4.3 Scenario planning* is implemented as preparation for the future. Finally, beneficiaries are informed about the construction, maintenance and EoL options of their units through *4.1 Create guidelines*.

In the Preparedness phase, before a disaster has occurred, governmental agencies, in collaboration with humanitarian organisations, are preparing a '*Strategic plan for action in case of a crisis*' for every region of Sindh. Incorporated in this plan is a section for transitional housing units. After an analysis of the available resources and a study of the local material suppliers, a list of diversified contractors (supplier pool) is set up. Agreements and contracts can now be set up, assuring a swift reaction when a disaster strikes and the need for THU materials arises (recommendation *4.2.2 Set agreements with suppliers*). The agreements portray the basis for a take-back business model, in which the suppliers will provide materials to beneficiaries for exchange of government-issued material vouchers. At the end of the displacement (or by damage of the components) the materials can be returned to the suppliers for further processing. The suppliers can get reimbursed through the vouchers.

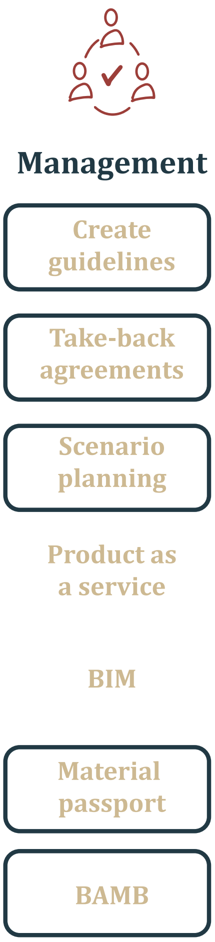


Figure 85. Circularity principles in the domain 'Management' implemented in the circular THU design proposal

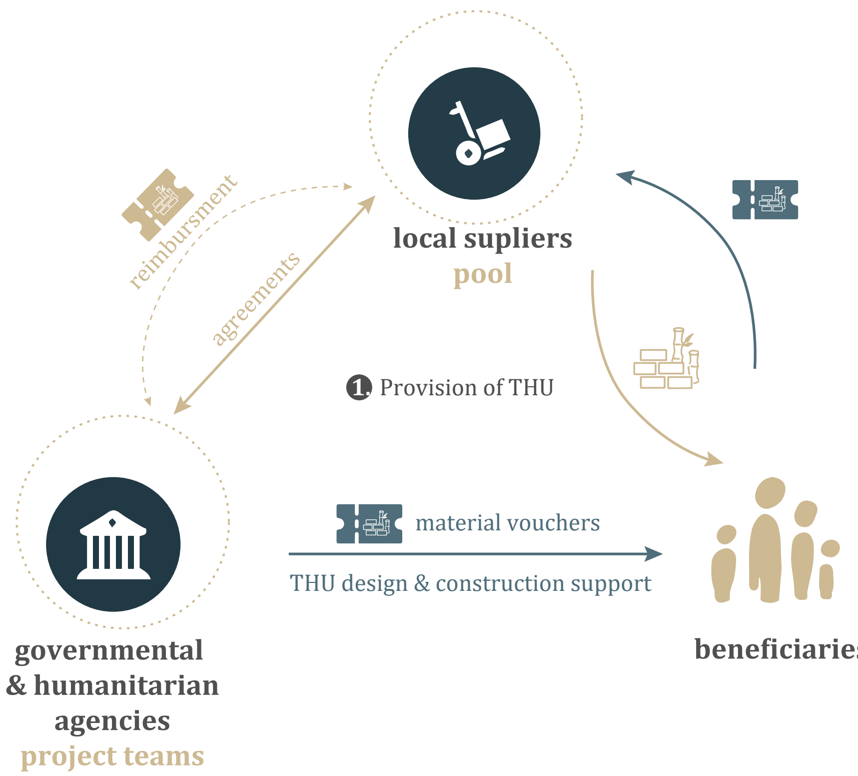


Figure 86. Management strategy for THU proposal: Step 1. Provision of THU

NGOs and governmental agencies will provide those government-issued vouchers to beneficiaries after the need for a THU has been determined and a unit design consultation has been made. The beneficiaries can then choose any contractor from the previously determined supplier pool. The service might include only delivery of the materials to the building sight or construction assistance as well. The THU construction should be supervised by appointed members of the agencies.

With the acquired components, the THU can be constructed, and the beneficiaries can move in for the duration of the displacement period. At this moment the beneficiaries are the owners of the unit. At the end of this period there are several possible scenarios (recommendation *4.3.1 List potential future uses for the transitional housing unit*).

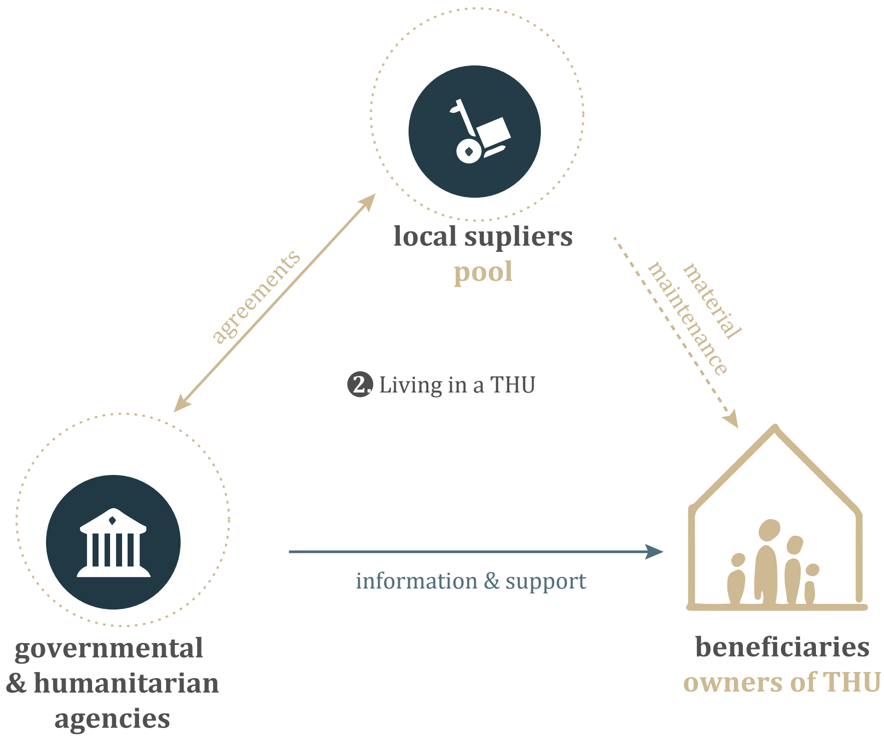


Figure 87.
Management strategy for THU proposal: Step 2. Living in a THU

Scenario 1: Exchange for cash - In this case the beneficiaries do not want to keep any of the materials used in the shelter. Due to the agreements previously made between the government and the contractors, the beneficiaries can return the materials to the suppliers for cash exchange. Alternatively, they can also give the whole unit to the local government (or a new party), again for a monetary compensation. In that case the THU can be directly reused with the same or another function like social housing or a community centre.

Scenario 2: Partial exchange for cash - Sometimes the beneficiaries might want to take only some of the materials with them, the bearing structure for instance. They could then still return the rest of the materials, for example the hempcrete panels, to the suppliers and get some refund, which can be invested in reconstruction.

Scenario 3: Keeping the unit - If the beneficiaries own land nearby or if they can afford the moving cost, they are free to keep the whole unit. It can be relocated, reinforced, and turned into a permanent dwelling.

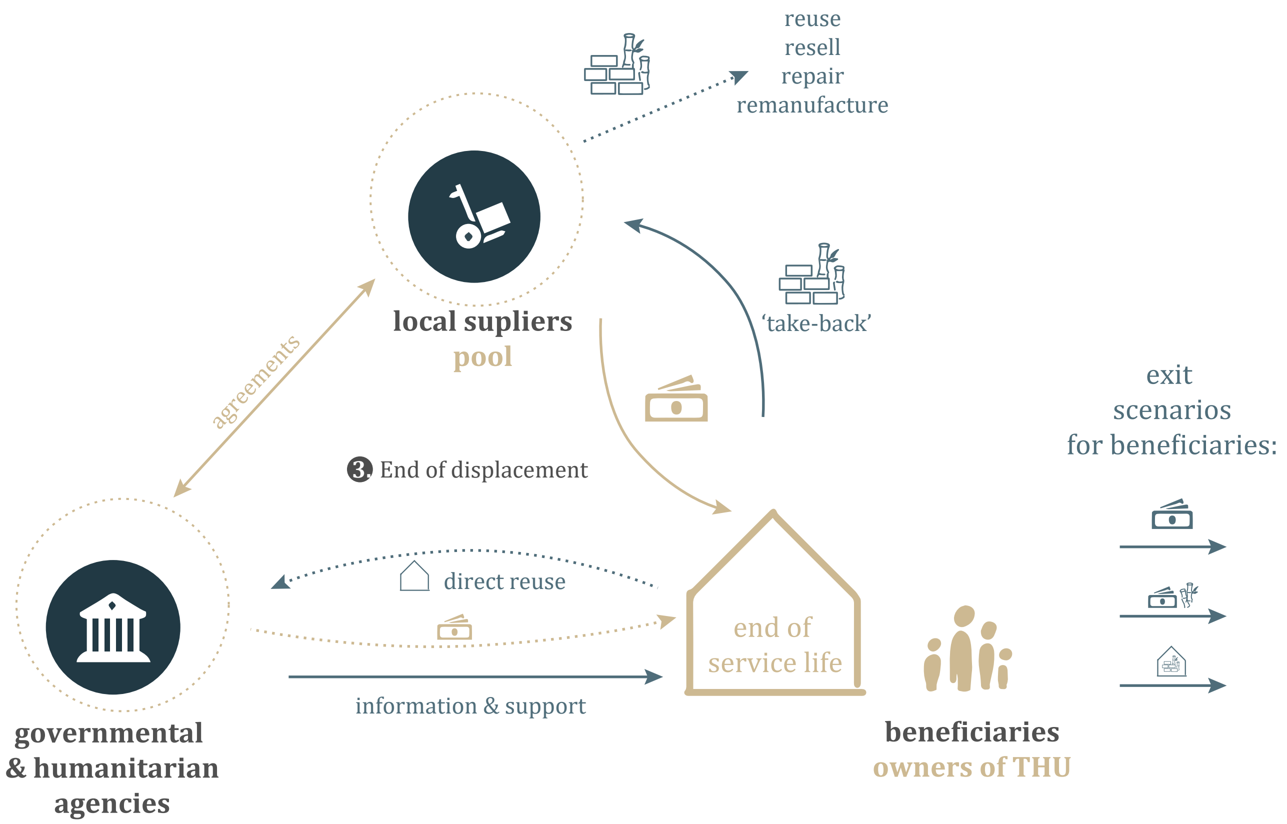


Figure 88. Management strategy for THU proposal: Step 3. End of displacement

As the THU is seen as a BAMB, it is important to retain information about the quantity and quality of the materials and components used. The agencies can thus prepare Material passports with identification codes for each unit (recommendation *4.7.1 Provide material passports to building components*). The use of Material passports can support the take-back business model and the reintroduction of the building components in the local economy.

Benefits and risks for each party | The governmental agencies and HOs benefit by setting up a strategic plan before a disaster occurs and thus they can be faster, more prepared and more efficient. Furthermore, by having set the agreements with suppliers in advance, they can be more secure about the material quality, which will be provided. The government needs to be prepared to reimburse the material vouchers of the suppliers. The overall investment might thus be higher as compared to tent provision, but the provided shelter will be more durable. By relying on local suppliers rather than international ones, the economy of the region can be pushed to recover quickly.

There are also several benefits for the contractors. For instance, they can have a greater security that they will get paid as the vouchers will be reimbursed by the government. They will also have a continuing work in the aftermath of the crisis, provided they have not had severe damages. Knowing that a percentage of the distributed materials will be returned, the contractors have the incentive to make more durable and repairable components, pushing innovation of their products. Once the materials are returned, they can be refurbished (if necessary) and resold.

In all the described scenarios, the beneficiaries do not end empty handed after the displacement is over. They will either receive a monetary compensation to invest in reconstruction or keep the housing unit. It is important to make beneficiaries aware of those options (recommendation *4.1.1 Include necessary information for material recovery*) and make this information accessible (recommendation *4.1.3 Provide access*). They are also receiving support from the governmental agencies for the design, construction and throughout the whole displacement period, including assistance for returning the materials to the suppliers.

6.7. Evaluation of the design proposal

Material	Design	Manufacturing	Management
Local material	**Design for disassembly**	**Prefabrication**	**Create guidelines**
Biobased material	**Modular design**	Additive manufacturing	**Take-back agreements**
Waste material	**Design for longevity**	CNC milling	**Scenario planning**
Recyclable material	Design for standardisation	Robotics	Product as a service
Secondary streams	**Design for adaptability**	**Vernacular building techniques**	BIM
	Material optimisation		**Material passport**
	Design for recycling		**BAMB**

Table 11.
All circularity principles implemented in the proposal for a transitional housing unit in Sindh, Pakistan

The proposal for a circular transitional housing unit for the extreme climatic conditions of upper Sindh province in Pakistan follows 15 out of the 24 circularity principles introduced in Chapter 3 (Table 11). The design decisions were based on the recommendations developed in the Design support tool (Chapter 5). Overall, it can be concluded that the design proposal has a high circularity potential according to the Design evaluation tool, seen in Table 12 (next page). The score is predominantly green in all four domains: Material, Design, Manufacturing and Management, which indicates that the design has taken multiple variables in consideration. The full evaluation sheet with the selected performance indicators can be seen in Appendix E.

> *Overall, it can be concluded that the design proposal has a high circularity potential according to the Design evaluation tool.*

No	Category	Principle		Evaluation overview		
I.	**Material**					
		1.1	Local materials	green	yellow	green
		1.2	Biobased materials	green	green	green
		1.3	Waste materials	green		
		1.4	Recyclable materials			
		1.5	Secondary streams			
II.	**Design**					
		2.1	Design for disassembly	green	green	
		2.2	Modular design	green		
		2.3	Design for longevity	green		
		2.4	Design for standardisation			
		2.5	Design for adaptability	green		
		2.6	Material optimisation			
		2.7	Design for recycling	green		
III.	**Manufacture**					
		3.1	Prefabrication	yellow	green	green
		3.2	Additive manufacturing			
		3.3	CNC milling			
		3.4	Robotics			
		3.5	Vernacular building techniques	green	green	
IV.	**Management**					
		4.1	Create guidelines	green	green	
		4.2	Take-back agreements	green		
		4.3	Scenario planning	yellow	green	
		4.4	Product as a service			
		4.5	Building information model (BIM)			
		4.6	Material passport	green		
		4.7	Building as material banks (BAMB)	green		

Table 12. *Evaluation overview for the circularity potential of the THU proposal for Sindh, Pakistan; based on the visual evaluation tool*

Detailed evaluation | In the following section the chosen performance indicators will be explained in more detail. The materials used in the THU are all locally available in Pakistan. While Bambusa bamboo and Neem wood can be found in the Sindh region, hemp production is yet to be developed. For now, there is not enough information available to assume that hempcrete can be manufactured in the province. Based on this uncertainty the second option in the performance indicator (yellow) is chosen: *THU non-structural materials are abundantly available in the **host country*** rather than *THU non-structural materials are abundantly available in the **affected region***.

Bamboo, hempcrete and Neem wood are the main biobased materials used in the unit. All of them can be returned to the biological material loop through anaerobic digestion. However, if a high amount of material is piled up and thrown away simultaneously, the biodegradation process can be impacted.

As hemp shives are a byproduct of hemp fibre production, its use in the production of hempcrete is considered a utilisation of an existing wastestream. The sourcing of the product, however, needs to be further investigated.

Both, the connections used for the bamboo bearing structure and the hempcrete wall panels, can be easily accessed and are fully demountable without damaging the components. Based on that the score of both performance indicators for *2.1 Design for disassembly* is green. Principle *2.2 Modular design* relates to the construction of the hempcrete wall. The panel system allows modules to be exchanged and for openings to be created or closed.

The lifespan of hempcrete can be very long with little maintenance. Possible damages can occur during disassembly. The panel system takes this into account, making the dismantling process easier. The hempcrete panels can then be easily cut to building blocks. It can then be assumed that the material can be reused in consecutive projects. The bamboo stems can also prove to be very durable if treated against termites. The extended roof offers additional protection against rain. Consequently, *the materials used in the THU are durable enough to survive the planned lifespan of the unit and also consecutive uses with little maintenance*. At the end of their useful life, all *Components can be fully separated to their base materials and returned in the biological or technical loop.*

After serving as a transitional housing, the unit can be easily transformed into a dwelling. Besides that, it can also serve as a community centre, workshop, store, or a classroom. Internal transitions can be added if required, as well as an extension of the closed living space through enclosing the ground floor.

The prefabrication process is used both for the bamboo components as well as the hempcrete wall modules. While the former material is known to the local population, the latter is yet to be introduced in Pakistan. For that reason, the option: *Prefabricated components use some materials known to the beneficiaries; the beneficiaries know how to maintain and repair them*, is chosen. As the beneficiaries can participate in workshops, explaining the properties and handling of hempcrete, they will learn how to maintain the material and to utilise it in reconstruction. The THU utilises vernacular building techniques for the bamboo connections and roofing. The chosen methods use low emission materials and have a low environmental impact.

The management section is most difficult to evaluate at this stage as it involves decisions and actions from multiple stakeholders. For the purpose of the design proposal it is assumed that the relevant actors are on board with the suggested circularity principles.

Figure 89.
THU Visualisation street view

7. Discussion

7.1. Role of circularity and innovation in the humanitarian construction

Architecture: now vs before | Today's architecture is changing rapidly. If several decades ago, a building has continued to maintain the function it was designed for throughout its lifetime, nowadays buildings need to be flexible enough to accommodate an everchanging and swiftly developing environment. Inflation, globalisation, economic instability, pandemics, politics, global warming, migration, war. All those elements and many more are shaping the world's dynamic state, to which architecture must respond.

In a sense, the architecture of today is in a state of constant change. A designated function might remain in a building for only a year or several months. Some modern architects try avoiding obsolescence of their designs, with other words their work becoming no longer useful, by planning ahead for a variety of space uses. Flexible floor plans, movable walls and demountable connections are only a few examples of the approaches followed to allow architecture to change and adapt. Those are also some of the principles making the built environment more circular. However, this interest in momentary function is in direct contrast with the old perception of architecture as permanent or eternal.

The idea of 'building to last' common in the past, for example in the pyramids or castles, is seemingly becoming alien today. Yet, for a long time, permanence in construction had been sought out as it is associated with prestige or wealth whereas a temporary use or structure is often linked to a lack of financial resources and uncertainty. This clash of reality and perception has led to obsolete buildings and demolition of perfectly in-tact structures. Perhaps this phenomenon and a look at the cyclic and transitional essence of nature may question the meaning of 'permanence' in general.

Transitional housing as a miniature of modern architecture | Based on that, transitional housing for displaced people can be seen as a small-scale reflection of modern architecture. It presents the elements of a rapid change, need for adaptability and increased flexibility in a context of extremes. These harsh circumstances can push experimentation and innovation. Ideas, developed in the aftermath of emergency situations, can prove to be very beneficial not only for the humanitarian sector but for the challenges modern architecture faces on a bigger scale as well.

Architecture and circularity | The principles of circularity are connected to the ability of nature to regenerate. In its perfect form it sees the use of materials as momentary assembly before they can be returned to the technical or biological loop. By acknowledging this idea, modern architecture can create buildings, which have a low impact on the environment and can adapt to the changing functional requirements, while allowing the return of valuable resources to the nature or economy.

In the humanitarian setting, circularity principles can improve the utilisation of resources, while minimising the environmental impact of shelter construction. By enabling transitional housing units to be reused or repurposed rather than thrown away, affected communities can be supported in their recovery.

7.2. Implementation of the developed tool in the humanitarian sector

The recommendation set and visual evaluation tool was created to help humanitarian project team members make circularity informed decisions when designing transitional housing units. Though it seems as a good start for introducing the concept of circularity in the humanitarian sector, it needs to be further developed in collaboration with the user, for it to become a truly functional and helpful tool.

Principle hierarchy | There are several elements of the tool that might require further adjustments or improvements. For instance, the perceived hierarchy of the circularity principles. Currently, a number is assigned to each of the explored domains and to each circularity principle. Though this has been done solely for organisational purposes, it might wrongly convey that the tool should be used in this particular order. On the contrary, the tool should be seen as a map of options. In any particular situation and context, the most relevant principles can differ. To resolve this issue the numbers could be fully removed or exchanged for letters or forms, but the efficiency of this action needs to be further explored.

Preknowledge | The recommendations included in the tool are based on the research conducted in this thesis. Consequently, there are concepts and terminology used, which might not be fully familiar to the user group. To avoid confusion and misinterpretation, a glossary explaining the circularity specific terms can be added as an additional sheet. It can include all necessary information, including sources for further reading. In addition to that, another 'Introduction' sheet, where the structure of the tool and how it can be used is explained, can make the overall user experience easier.

Context specific decisions | As mentioned earlier, the context plays a very important role in the decision-making process and the choice of relevant circularity principles. However, in some cases, the design of transitional housing units begins before the location or magnitude of a crisis is known. For that reason, it might be beneficial to indicate which principles are more reliant on context information than others. For instance, choosing the concrete local materials and suppliers requires knowing where the project will be situated. Design decisions based on modularity or design for standardisation on the other hand, can be taken into account even without a specific location in mind.

Interpretation of evaluation score | The visual evaluation score gives an indication of the circularity potential of existing design proposals. By highlighting a specific area (Material, Design, Manufacturing, Management) with red or orange, the user can see that there is a need for improvements. The evaluation tool does not take into account economic constraints, which might influence certain choices, especially in the humanitarian sector. Therefore, each small improvement (eg. from red to orange) can be seen as a move towards a more circular design.

7.3. Hempcrete as a circular material for humanitarian projects

The use of hempcrete in the proposed THU in Pakistan aimed to explore how this relatively new material can be introduced in humanitarian projects to improve their circularity potential. Though the combination of hemp and lime can be found many centuries ago, nowadays this biobased composite is being revived and used in more and more projects around the world. It's many positive properties, as seen in subchapter 6.3, make it very interesting for humanitarian settings. Not only is it easy to work with, but it is often much cheaper than other commonly used in construction materials. It is made from a byproduct, and, at the end of its service life, it can be directly reused or fully recycled into new hempcrete, showing its circularity potential.

This thesis explores the possibility to make large panels due to the easy and fast installation on site and the ability to cover big portions of the walls at once. There are, however, other hempcrete construction methods that can also be utilised for humanitarian projects, such as precast building blocks or casting.

Building blocks | Hempcrete blocks are a common building component, which can be installed similar to concrete blocks. Due to their lightweight they are easy to transport and to assemble. Additionally, using building blocks allows for standardised wall dimensions and can result in consistent quality. The blocks are laid with a lime-hemp mortar, which makes them difficult to disassemble but keeps the recyclability of the wall. Alternatively, the blocks could be cut out from the wall, but this might damage the components.

Interlocking blocks | Some manufacturers explore interlocking hempcrete blocks. This is a very interesting option, which could be integrated in transitional housing projects. The dry connections make disassembly and reuse possible. The geometry of those blocks can be quite complex, which would make production on site challenging. Nonetheless, if such manufacturers are available in the affected area, this can approach can be interesting to investigate.

Casting | The probably most common method to construct hempcrete walls is casting. It involves pouring the hemp-lime mixture into formwork on-site, allowing it to harden and form solid walls. Casting provides flexibility in terms of wall shape and size, allowing for customisation. However, it can be time-consuming and labour-intensive, requiring skilled workers and careful supervision. Furthermore, the house cannot be directly inhabited as the hempcrete needs to dry out first, which can take several weeks. In a displacement scenario, time and resources may be limited, making this method more suited for reconstruction rather than temporary housing.

Overall, hempcrete is an affordable material with great thermal and acoustical qualities, which can be crucial in humanitarian settlements. Furthermore, the ability to make monomaterial walls makes the construction (and dismantling) easier and faster. With the shift of the legal image of hemp in many countries, like Pakistan, it can be valuable to investigate how this material can benefit housing and shelters while promoting circularity principles.

8. Conclusions

In this chapter the main research question and the subquestions are being answered. The research limitations are discussed and future research topics are suggested. Lastly, a reflection on the work process is added.

8.1. Answering the research question

The presented research aimed to investigate how circular building principles can be integrated in the planning of humanitarian transitional housing units for a rising amount of displaced population. By doing so negative environmental, economic, and social impacts, associated with transitional housing, can potentially be mitigated. Transitional housing units were selected for this research, because they offer a structurally sound shelter for an interim use, which has a high potential to be relocated, reused and integrated in the local community. To contextualise the study, the extreme climatic conditions of the upper Sindh province in Pakistan were investigated as a case study. This ultimately led to the main research question: ”*How can transitional housing for displaced people in the extreme conditions of upper Sindh province in Pakistan be made using circular building principles?*”. To answer this question first the five sub-questions are resolved.

SQ1.
What are the existing transitional housing options and their end-of-life scenarios?

Transitional housing today | To gain a better insight on transitional housing, an analysis of the humanitarian shelter typologies was made. It gave an understanding of the shelter sector and the basic terminology used. This highlighted the characteristics of emergency, transitional, and core (semi-permanent) shelters, as well as the importance of the settlement. Essentially, transitional housing provides enough comfort to displaced people for them to return to daily activities until a permanent accommodation is available, usually for a period of 1-3 years. It was found that transitional housing projects cover a great variety of options, including rental and shared dwellings. For the purpose of the research nuclear housing units were further investigated, of which three typologies, based on the used materials, were identified: steel framed prefab units, timber/bamboo framed units and units of combined materials.

It was found that there isn’t one universal approach to provide post-crisis housing units. This inevitably has an influence on the lifecycle of the units. Given the urgency of the situation, end-of-life scenarios are rarely considered during the design phase of THUs, rather the disposal becomes a problem. Some recommendations for reusing components exist, but there are rarely any legal frameworks set in place. This can be due to a lack of appointing a responsible party.

Though there is no numerical data, based on the available literature, several EoL scenarios, which are most likely, were mapped out. Those included:

- Units getting abandoned due to cultural and climatic inconsideration.
- Units are used for an prolonged period of them, deteriorating with time and posing health risks to the inhabitants
- Units get demolished and materials are burned or buried (landfill)
- Units are upgraded to permanent shelters
- Units are donated to local NGOs

SQ2.
Which principles of circularity can be applied? How can they inform design decisions about transitional housing?

Circularity principles | Circularity is a broad and complex topic. In this research circularity principles in the built environment were specifically analysed as they can be applied directly to transitional housing units. A comprehensive literature review, including scholarly articles, reports, and relevant literature from various sources, was conducted. Based on that circularity principles were identified and could be categorised into four main topics: Materials, Design, Manufacturing, and Management. The 21 sources and their contribution to the topic areas are shown in Table 1, ensuring transparency in the literature review process.

The compiled circularity principles were further structured and described in four additional tables (Table 2-5) with respect to the four domains. It is important to note that each of the circularity principles has benefits and risks associated with implementing them, which need to be considered during the design process. The principles can further be used separately or in various combinations. A single recipe for a circular building does not exist, which allows THU projects to adapt to the contex and specific circumstances. As humanitarian crises are connected to a lot of uncertainty, material availability for instance, some principles might not even be applicable.

SQ3.
Who are the existing stakeholders? How are they currently entangled in the management?

Stakeholders and procurement | The stakeholders and their involvement may vary depending on the country, context, and the severity of the situation. In some cases projects are planned and executed on national level, in others international support is present as well. The main actors include: the government (local and national), members of the affected community, HOs and NGOs, donors, civil and voluntary associations, private sector (designers, builders, and suppliers), academic institutions and media.

Two main procurement approaches can be identified: top-down and bottom-up. The former one is associated with concentrated decision making of a smaller group of people, usually without the direct participation of the affected population. It is often resulting in identical housing models, distributed to beneficiaries. While this approach allows for cross-sector collaboration and efficient manufacturing through prefabrication, it can lead to culturally and environmentally insensitive designs or high transportation costs. Additionally, it may result in settlements in less desirable areas, with limited infrastructure and job opportunities, potentially alienating beneficiaries.

The bottom-up approach emphasises community participation, self-resilience, and creativity, often leading to more sustainable and economic results. Crisis affected people are thus invited to the decision-making table and have an active role in determining the THU design. Results are usually more diversified and adapted to the beneficiaries needs.

A combination of both approaches, involving DP in the planning of their own units, while utilising standardised components, can bring economic and social benefits to the project. Nevertheless, one of the biggest challenges when it comes to the provision of units in a post-crisis situation is the lack of timely planning.

Including THU design in the preparedness phase, as part of an overall strategic action plan, can prevent problems and ensure locally suitable designs. Crises can further be seen as opportunities for improvement of the conditions rather than returning to the previous standard. Ultimately, severe climatic events will continue to happen, but they only turn into a disaster when the coping mechanisms fail to deal with the impacts. Strategic planning, as part of disaster preparedness and mitigation, is particularly important in disaster-prone areas.

SQ4.
How do the extreme conditions of repeated flooding and high temperature in upper Sindh, Pakistan affect the design of transitional housing?

Extreme conditions in Pakistan | Pakistan is one of the countries most affected by climate change with natural disasters striking on an annual basis. The Sindh province regularly suffers many damages. By the last severe flooding in 2022 over 1.7 million houses were partially or fully destroyed. At the same time, the already high temperatures reach new records with over 50°C. Those extreme conditions pose a strain on the local population. In addition, a high percentage of the people, especially in rural areas, are living in poverty.

All those elements need to be considered for a successful transitional housing project. Extreme temperatures can be, at least partially, mitigated through an integration of economical low-tech passive cooling techniques. The choice of durable and appropriate materials can further contribute to the structure's resilience.

Finally, the THUs should not contribute to the negative impacts of the extreme conditions. The extraction of the material as well as its eventual disposal needs to be considered in the initial planning process. A lack thereof might lead to deforestation and ground degradation which in turn might heighten the risk of floods, storms, or landslides. Incorporating circularity principles, in consideration of existing and potential hazards, can help reduce the negative environmental impact of THUs and thus contribute to future disaster resilience.

SQ5.
How can THU planners be assisted in taking circularity informed design decisions?

Suggestive tool | The integration of circularity principles in the planning of transitional housing units can be supported through a dual suggestive tool. The developed tool can provide *Design support* for new projects and *Design evaluation* for already existing ones. The goal is to assist THU planners in taking circularity informed design decisions.

The catalogue is divided into two main parts: recommendation set and visual evaluation. The recommendation set provides more information on the circularity principles across the topics of material, design, manufacturing, and management. It can be used proactively during the design phase.

The visual evaluation gives an indication of the circularity potential of the examined design, using a qualitative approach and a traffic light score system. Performance indicators provide the user with statements, from which they can choose the most relevant one. Automatically the score is indicated with green being the best and red the worst. In the uncertain and complex context of humanitarian construction, it might be challenging to achieve a high score across all categories. However, by visualising the weaker areas, small changes, like turning from orange to yellow, can be implemented towards a more circular design.

How can transitional housing for displaced people in the extreme conditions of upper Sindh province in Pakistan be made using circular building principles?

In the design of a circular transitional housing unit in Sindh several circularity principles have been implemented by following the recommendation set in the suggestive tool. Those will be discussed in regard of the four domains: Material, Design, Manufacturing and Management.

Materials | The two main building materials are bamboo and hempcrete. Both are local and biobased. As organic materials, they absorb carbon from the atmosphere while growing. Hempcrete further absorbs CO_2 through the process of carbonation. This turns the whole THU into a carbon bank, thus helping to reduce emissions in the region. Bamboo is durable enough to withstand the general displacement period of two years even without treatment. However, natural coating with lime can prolong its service life drastically. At its EoL it can be turned into secondary materials and eventually let to biodegrade or used for heating. Hempcrete can also be directly reused or recycled into a new hempcrete mixture, before returning to the biological cycle.

Design | The design of the unit follows the strategies of design for disassembly, modular design, design for longevity, design for adaptability and design for recycling. The structure can be relocated and turned into a permanent dwelling or its individual components can be potentially used in reconstruction. By enclosing the ground floor, additional living space is created. The symmetrical octagonal form provides less amount of "unique" components, making assembly and reuse easier. All connections are reversible and easly accessible. The hempcrete wall systems is made of three modules. They are compatible and easily exchangeable. This system allows the openings to be adapted according to the need. For instance, an additional door can be installed or a window can be made bigger. This is important, as it enables the unit to be reused for another function.

Manufacturing | The manufacturing methods of additive manufacturing, CNC milling, and robotics have a lot of potential for circularity. However, in the rural context of Sindh they are out of place due to the high investment and specific machinery needed. Nevertheless, prefabrication and vernacular building techniques are utilised. Hempcrete will potentially become a more common construction material in Pakistan with the recent legalisation of industrial hemp. Being made with a byproduct from fibre production, the fabrication of hempcrete blocks and panels is likely to spread around the country.

Prefabrication of the panels is done onsite. This is used as an oppurtunity to introduce the material and its positive properties to the beneficiaries and teach them how to use it. Vernacular building techniques are implemented in the bamboo handling and tatched roof construction.

Management | The circular transitional housing units follow the concept of BAMB (Building as Material Banks), where materials and components are seen as an investment, which can be returned to the local economy. In the preparedness phase, a strategic plan is developed in collaboration between governmental agencies and humanitarian organisations, which includes a section for transitional housing units. EoL scenarios for the units are considered in the planning. Agreements are made with diversified contractors, establishing a take-back business model where materials are provided to beneficiaries in exchange for government-issued vouchers. The beneficiaries can choose contractors from a pre-determined supplier pool, and at the end of the displacement period, they have the option to exchange materials for cash, partially exchange materials, or keep the entire unit for relocation and permanent use. This approach benefits the government and contractors through preparedness, material quality assurance, and economic recovery, while beneficiaries receive support throughout the process and retain value from the materials or the housing unit.

A circular transitional housing proposal | Overall, the thesis provides an example of a circular transitional housing unit design proposal for the extreme conditions in Sindh, Pakistan. This proposal shows one of many options to integrate circular building principles in humanitarian construction. The thesis further provides a suggestive tool for THU planners, which can enable them to take circularity informed decisions.

Circularity provides an alternative to the throwaway model, by considering the value of materials and providing strategies to retain this value. In humanitarian construction, where the availability and quality of materials can be a challenge, utilising circular building principles can combat economic struggles through a return of investment, while minimising the environmental impact of shelters, and increasing community resilience.

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8.2. Research limitations

The thesis researched investigates how circularity principles can inform design decisions of transitional housing units for displaced population. Due to the defined timeframe, several limitations were encountered:

The design proposal is conceptual. It is crucial to assess the feasibility of the implemented concepts by conducting physical tests on models and prototypes.

The design of shelter for displaced population can be very sensitive and is extremely location specific. Therefore, input form the affected community into the THU design and settlement development is very important for the success of any shelter project. Unfortunately, a field study in Pakistan was not possible in the thesis timeframe, limiting the access of cultural information to desk research.

Some aspects of the design proposal are based on assumptions, especially in regard to the development of the hemp industry in Pakistan and the 'management' strategies.

Economic analysis of the design proposal is not included. The feasibility of shelter projects can be strongly related to their price. However, this was outside of the scope of this project.

The EoL mapping of current and alternative scenarios is based on the literature review. An official dataset portraying the probability of each option is non-existent.

8.3. Future research

The topic of circularity is gaining more friction in the building industry but is still very new and underexplored in the humanitarian sector. Nevertheless, there is the recognition of the benefits more sustainable construction practices can bring to the post-disaster architecture. More awareness, information and communication on the topic are needed to make a shift in the sector. Research in the following topics can be helpful for the further steps:

End-of-life scenarios of THU – What happens to transitional housing units after their service life remains partially a mystery. There is very scarce data as humanitarian organisations often don't have the funds or capacity to gather it. The feasibility and benefits of alternative end-of-life scenarios can also be explored further. More detailed research on this topic is needed for the potentials of circularity to be utilised.

BAMB and material passports – These concepts are still being developed in the construction industry but they can prove to be beneficial for humanitarian shelters as well. A shared database, mapping out the availability of materials (stored in THU) can improve availability and foster the reuse of secondary materials. For this to work material passports need to become part of the THU project developments.

Circular business models for THU – the proposed strategies in the Management part of the design proposal are based on some assumptions about the stakeholders. A further study into those business models and the viability of introducing them in humanitarian projects is necessary.

The suggestive tool is not exhaustive. It can be extended and verified with further research developments and implementation in other projects. It can further be analysed if the tool does have an influence on incorporating circularity principles in the design of transitional housing projects. Potentially, it can be adapted to other shelter typologies as well.

8.4. Reflection

Relation between the graduation topic, the Building Technology (BT) master track and the master programme MSc AUBS | The graduation topic “Circular Transitional Housing for displaced people in extreme conditions: the case of Pakistan” is directly connected with the topic of the Building Technology graduation studio “Circular Building Design” as it aims to explore the potentials of incorporating circularity principles in humanitarian construction. Transitional Housing in particular, provides an intriguing setting for investigating circular building principles. These housing units face challenges related to technical, social, environmental, and economic aspects, compounded by their temporary nature. Critiques include high resource consumption and waste generation, leading to environmental damage in an already vulnerable area.

The research aims to address these challenges by proposing recommendations to help THU planners take circularity informed design decisions, aligning them with circular building principles. As part of the Building Technology track, the thesis will incorporate both architectural and engineering design skills in order to contribute to the development of more sustainable building practices in the humanitarian, and by extension the Architecture, Engineering, and Construction, sector.

Humanitarian architecture requires a holistic approach as it often has major restraints like limited funding, short timeframe, and resource availability. Innovations, developed in such restrained circumstances, can prove to be beneficial for the built environment in general. The added element of setting the context of the thesis in extreme climatic conditions is directly related to the exploration of low-tech, affordable, and local building techniques and their influence on and transferability to a circular built environment. By having an interdisciplinary approach and by incorporating elements from environmental, social, and economic sustainability the topic fits in the MSc AUBS programme.

Research method and results | The research methodology followed a five-step approach: background research, literature review, design research, end products, and discussion. The initial study aimed to provide clarity on the relation between humanitarian shelters and circularity and establish the context for the thesis. The outcome showed that there is a high interest in the humanitarian sector towards more sustainable practices. However, the topic of circularity in this context is foreign.

In the second step extensive research was conducted in the fields of humanitarian sheltering and circularity. To gain a better perspective, additional sources such as online courses and informal conversations with people from the field were done. It was found that due to the high amount of uncertainty and actors involved it is difficult to map a clear design process and lifecycle of Transitional Housing Units. Although there are humanitarian shelter guidelines available, governmental agencies, national and international non-profit organisations, and local communities may follow different approaches. Due to this and the urgency of natural or man-made crises, there is a big gap in the data, especially related to the THU end-of-life phase. Based on the available literature, the existing EoL scenarios were mapped in order to bring more clarity to the THU lifecycle. Bringing this idea further, alternative EoL scenarios, based on circularity principles, were also drawn and visualised.

To contextualise the research, and as part of the design assignment, a specific location had to be chosen for further analysis. After a careful consideration of multiple areas, the chosen case study for extreme conditions was the upper part of Sindh province in Pakistan. The decision criteria included climatic and economic parameters, natural and man-made crises, amount of displaced people, and vulnerability to climate change. This gave further a direction for the research.

The initial idea of the graduation research was to come up with a holistic design roadmap, which can help the integration of circularity principles in the THU design process. However, due to the many diverse factors in play, such as crisis intensity, material availability, funding, climate etc., this was not feasible. Instead, a set of recommendations and a visual evaluation tool were developed. Based on the literature review, circularity principles in the built environment were identified. They were then assessed on their applicability in transitional housing projects by a careful consideration of the possible benefits or risks they might bring. This resulted in the suggestive tool, which could ideally be used by shelter team members for making more circularity informed design decisions.

Circularity is difficult to quantify, rather it can be seen as a spectrum. To provide a visual indication of this spectrum, a traffic light system was used in the evaluation part of the tool. The result is, therefore, evaluated by the user and is thus subjective to interpretation. However, it can be used to give a general indication to whether certain design decisions will contribute to the circularity potential of the transitional housing unit or not.

The design of the THU in the setting of Sindh, Pakistan, is based on the research and follows the recommendation set introduced as design support. It does, however, take certain assumptions into account. For instance, it is assumed that the hemp industry in the country is likely to develop in the upcoming years, based on the recent legalisation of industrial hemp and the willingness of the government to push the economy. This assumption allowed the use of hempcrete in the design. Hempcrete has a high circularity potential, as it is natural, local, serves as a carbon bank, possesses multiple positive qualities and can be sustainably disposed of.

Another assumption was the feasibility of the proposed business model. It provides an idea of how circularity can be integrated in the management of transitional housing projects, however, this depends on the cooperation of multiple stakeholders.

Overall, the design proposal shows an example of how circularity principles can be applied in the design process of transitional housing units in the context of Sindh province in Pakistan.

Strengths	Weaknesses	Opportunities	Threats
EoL scenario mapping; composing a tool for the shelter sector; implementation example in Sindh, Pakistan	scarce data on circularity in the humanitarian sector (emerging field)	introducing circularity in the humanitarian sector; further development in collaboration with partners	some proposals are based on assumptions

Table 13.
SWOT analysis

Social impact | Humanitarian aid is crucial for the survival of millions of people annually. Working with people who have suffered from trauma requires sensitivity and empathy. The health and safety of people becomes first priority. This needs to be considered in any project regarding humanitarian assistance. It also becomes evident that the do-no-harm principle, followed by HOs, should be extended further to the overall environment and long-term recovery. In some cases, the provision of emergency aid, if not done in consideration of the context, can be harmful for the affected population. For that reason, a holistic approach is needed. The provision of shelters can have a particularly high impact on the surrounding. For that reason, sustainable alternatives are sought out from within the sector.

Circularity is becoming more relevant on a global scale, making its way in national and international legislations and regulations. With raising concerns about the emissions produced by the AEC sector, circular building principles are being further developed and integrated in modern projects. Construction in the humanitarian sector can also benefit from those developments. By introducing ways to keep materials and resources in the loop, environmental, as well as social and economical benefits can be brought to the calamity-hit areas.

The end products of this thesis – the recommendation set and visual evaluation tool for circularity informed design decisions, and the circular transitional housing design proposal – can contribute to the emerging field of circularity in the humanitarian sector, and in particular, to transitional housing. The tool can be used to inform design choices in similar projects. The design proposal serves as an example of the implementation of those recommendations.

Bibliography

A

Alshawawreh, L., Pomponi, F., D'Amico, B., Snaddon, S., & Guthrie, P. (2020). *Qualifying the Sustainability of Novel Designs and Existing Solutions for Post-Disaster and Post-Conflict Sheltering.* Sustainability, 12(3). https://doi.org/ARTN 890 10.3390/su12030890

Antonini, E., Boeri, A., & Giglio, F. (2020). *Emergency Driven Innovation: Low Tech Buildings and Circular Design.*. Springer Cham. https://doi.org/https://doi.org/10.1007/978-3-030-55969-4_2

Arslan, H. (2005). *Re-design, re-use and recycle of temporary houses*. Building and Environment 42, 400-406. https://doi.org/10.1016/j.buildenv.2005.07.032

Arslan, H., & Cosgun, N. (2008). *Reuse and recycle potentials of the temporary houses after occupancy: Example of Duzce, Turkey.* Building and Environment, 43(5), 702-709. https://doi.org/10.1016/j.buildenv.2007.01.051

Arup & EMF. (2022). *d.Hub Circular Buildings Toolkit*. https://ce-toolkit.dhub.arup.com/

Askar, R., Rodrigues, A. L., Bragança, L., & Pinheiro, D. (2019). *From Temporary to Permanent; A Circular Approach for Post-disaster Housing Reconstruction* IOP Conf. Ser.: Earth and Environ. Sci. 225 012032,

Atmaca, N. (2017). *Life-cycle assessment of post-disaster temporary housing.* Building Research and Information, 45(5), 524-538. https://doi.org/10.1080/09613218.2015.1127116

Azcarate Aguerre, J. F. (2023, April 20). *Biological and Technical Materials* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/biological-technical-materials/

B

Bakker, CA., den Hollander, MC., van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models.* TU Delft Library.

BAMB. (2019, February 28). *D14 – 4 pilots built & feedback report – Testing BAMB results through prototyping and pilot projects* [Report]. BAMB 2020. https://www.bamb2020.eu/wp-content/uploads/2019/03/20190228-BAMB-D14.pdf

Betts, A., & Bloom, L. (2014). *Humanitarian innovation: The state of the art, occasional policy series.* UN OCHA.

Biswas, N., Sorange, S. & Ojha, G. (2015). *Ajrakh and dhabla of kutch, rajasthan* [PowerPoint Slides]. National Institute of Fashion Technology - Gandhinagar. Slideshare. https://www.slideshare.net/NooraniBiswas/ajrakh-and-dhabla-of-kutch-rajasthan

Boix-Cots, D., Pardo-Bosch, F., Blanco, A., Aguado, A., & Pujadas, P. (2022). *A systematic review on MIVES: A sustainability-oriented multi-criteria decision-making method.* Building and Environment, 223. https://doi.org/ARTN 109515

Brancart, S. (2023a, April 20). *Design for Adaptability, Longevity and Disassembly* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/design-for-adaptability-longevity-and-disassembly/

Brancart, S. (2023b, April 20). *Design Scenarios* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/design-scenarios/

Brand, S. (1994). How Buildings Learn: What Happens After They're Built. Penguin.

Brangeon, S. & Crowley, F. (2020). *Environmental footprint of humanitarian assistance - scoping review. https://www.urd.org/wp-content/uploads/2020/09/Groupe-URD-Inspire-studypublic.pdf*

C

CBE Hub. (2022). *Planning for change: a methodological framework for integrating circularity into TU Delft's faculty of architecture and the built environment's curricula.* Serbian Journal of Architecture, 12(3), 234-269. DOI: 10.5937/saj2003234I

Circle Economy. (2022). *The Circularity Gap Report 2022.* Amsterdam: Circle Economy.

Circle Economy. (2023). *The circularity gap report 2023* (pp. 1-64, Rep.). Amsterdam: Circle Economy.

CDP. (2023). *2022 Pakistan Floods*. Center for Disaster Philanthropy. https://disasterphilanthropy.org/disasters/2022-pakistan-floods/

D

Dev, D. D., Shanta Pragyan (2022). *An Investigative Study on Material and Its Performance of Intermediate Disaster Relief Shelters* Virtual Conference on Disaster Risk Reduction, VCDRR 2021,

Dunkelberg, K., Fritz, J., Gaß, S., Greiner, S. Hennicke, J., Otto, F., Reiner, R., Schaur, E., & Voigt, H. (1985). *IL 31 Bambus - Bamboo*. Institute for Lightweight Structures, University of Stuttgart. Karl Kramer Verlag Stuttgart 1992. ISBN 3-7828-2031-2

E

Eckstein, D., Künzel, V. & Schäfer, L. (2021). *Global Climat Risk Index 2021.* Germanwatch e.V. https://www.germanwatch.org/en/19777

Ellen MacArthur Foundation (2017). *The Circular Economy In Detail.* https://archive.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail.

F

Faragallah, R. N. (2021). *Fundamentals of temporary dwelling solutions: A proposed sustainable model for design and construction.* Ain Shams Engineering Journal, 12(3), 3305-3316. https://doi.org/10.1016/j.asej.2020.11.016

Felix, D., Branco, J. M., & Feio, A. (2013). *Temporary housing after disasters: A state of the art survey.* Habitat International, 40, 136-141. https://doi.org/10.1016/j.habitatint.2013.03.006

Felix, D., Monteiro, D., Branco, J. M., Bologna, R., & Feio, A. (2015). *The role of temporary accommodation buildings for post-disaster housing reconstruction.* Journal of Housing and the Built Environment, 30(4), 683-699. https://doi.org/10.1007/s10901-014-9431-4

G

Global Shelter Cluster (Producer). (2014). *More Than Just a Roof – Introduction to shelter and settlement.* [Online Course]. https://ifrc.csod.com/ui/lms-learning-details/app/course/78e12c9b-4354-4b9e-84f0-c73433d42de3

Global Shelter Cluster. (2021). *Shelter Projects Essentials*. www.shelterprojects.org

H

Heritage Foundation of Pakistan. (2013, June 22). *Build Back Safer with Vernacular Methodologies* [Final Narrative Report].

Heritage Foundation of Pakistan. (2020). *Green KaravanGhar: GKG & Beyond for Disaster Risk Reduction, Darya Khan Shaikh & Uthero District Khairpur, Sindh*. https://www.heritagefoundationpak.org/Page/2020/green-karavanghar-and-beyond

Hosseini, S. M. A., Farahzadi, L., & Pons, O. (2021). *Assessing the sustainability index of different post-disaster temporary housing unit configuration types.* Journal of Building Engineering, 42. https://doi.org/ARTN 102806 10.1016/j.jobe.2021.102806

H&P Architects. (2013). *Bb Home / H&P Architects*. Archdaily. https://www.archdaily.com/431271/bb-home-h-and-p-architects

I

ICRC & IFRC (2023). *The climate and environment Charter for Humanitarian Organizations.* In.

IFRC. (2011). *Transitional shelters: Eight designs.* http://shelterprojects.org/tshelter-8designs/files/8transitionalshelters.pdf

IFRC. (2013). *Post-disaster shelter: Ten designs.* http://shelterprojects.org/tshelter-8designs/10designs2013/2013-10-28-Post-disaster-shelter-ten-designs-IFRC-lores.pdf

IFRC. (2022). *PAKISTAN: IFRC country plan.* https://www.ifrc.org/sites/default/files/2022-02/Pakistan_Country_Plan_2022.pdf

Ioannou, O. (2023a, April 20). *Design for Standardization & Modular Design* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/design-for-standardization-modular-design/

Ioannou, O. (2023b, April 20). *Design Principles* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/design-principles/

Ioannou, O. (2023c, April 20). *Systems Theory: An Introduction* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/systems-theory-an-introduction/

Ioannou, O. (2023d, April 20). *The R Strategies: An Introduction* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/the-r-strategies/

K

Khalid, A. (2020). *Passive Design, Urban-Rural Architectural Morphology for Subtropics*. European Journal of Sustainable Development (2020), 9(3), 376-399. Doi: 10.14207/ejsd.2020.v9n3p376

Klein, T., Bilow, M., Sabbe, A., Smit, M., Wandl, A., Leclercq, E., Konstantinou, T., Hackauf, U. & Ioannou, O. (2019). *Circular Economy for a Sustainable Built Environment* [MOOC]. Delft University of Technology (Producer). https://online-learning.tudelft.nl/courses/circular-economy-for-a-sustainable-built-environment/

Klein, T. & Ioannou, O. (2022). *AR0145 Technoledge Circular Product Design* [Class handout]. Façade & Product Design, Chair Building Product Innovation, Delft University of Technology.

Klein, T. (2023, April 20). *The 'Scales to Aspects' Model: Framing Circularity in the Built Environment* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/the-scales-to-aspects-model-framing-circularity-in-the-built-environment/

Kuittinen, M. (2016). *Carbon footprinting in humanitarian construction.* Aalto University School of Arts, Design and Architecture.

Kuittinen, M., & Winter, S. (2015). *Carbon Footprint of Transitional Shelters.* International Journal of Disaster Risk Science, 6(3), 226-237. https://doi.org/10.1007/s13753-015-0067-0

L

Lalwani, S. (2020). *Treating Bamboo In Your Backyard*. Bamboo U. https://bamboou.com/treating-bamboo-in-your-backyard/

Lari, Y. (2021, March 11). *Pre-Fab Bamboo Panels* [Video]. YouTube. https://www.youtube.com/watch?v=uwTAtnr06y4&t=387s

Lizarralde G., Johnson, C. & Davidson, C. (2010). *Rebuilding after disasters: from emergency to sustainability.* Spon Press

M

Malazartes, N. (2016). *Una construcción pionera de cáñamo y bambú* [A pioneering hemp and bamboo construction]. Canamo. https://canamo.net/cultivo/exterior/una-construccion-pionera-de-canamo-y-bambu

Marques, A. C. (2014). *Teaching Sustainability Design of Products to Engineering Students.* International Journal of Performability Engineering, 10(6), 589-604.

Ministry of Planning Development & Special Initiatives. (2022, December). *Pakistan Floods 2022: Post-Disaster Needs Assessment (PDNA)* (Supplemental report). UNDP. https://www.undp.org/pakistan/publications/pakistan-floods-2022-post-disaster-needs-assessment-pdna

Mughal, H., Ahmed, S.A., Mumtaz, H., Tanwir, B., Bilal, S. & Stephenson, M. (2015). *Kashmir Earthquake 2005: Learning from the Shelter Response and Rural Housing Recovery*. IOM. https://sheltercluster.s3.eu-central-1.amazonaws.com/public/docs/shelter_in_recovery._kashmir_eq_2005.pdf

Mumtaz, K. K. (1978). *Traditional forms of rural habitat in Pakistan*. Human settlements and socio-cultural environments UNESCO.

N

Niazi, Z., Singh, A. & Sen, I. (2020). *State of play for circular built environment in Asia*. TARA, Development Alternatives and United Nations One Planet Network Sustainable Buildings and Construction Programme.

Nunez, P. M. (2017). *Prefabricated Dwelling in Transitional Shelter Processes for Unprecedented Displacement.* Boletin Academico-Revista De Investigacion Y Arquitectura Contemporanea(7), 115-134. https://doi.org/10.17979/bac.2017.7.0.1853

O

OCHA. (2022a). *Pakistan: 2022 Flood response plan.*

OCHA. (2022b). *Global Humanitarian Overview 2023*. https://reliefweb.int/report/world/global-humanitarian-overview-2023-enaresfr

OCHA. (2023). *Pakistan: 2022 Monsoon Floods - Situation Report No. 13* (As of 6 January 2023)

P

Pakistan Bureau of Statistics. (2017a). *Housing census: Table - 27 Type of housing units, population by sex and rural/urban*. https://www.pbs.gov.pk/content/final-results-census-2017-0

Pakistan Bureau of Statistics. (2017b). *Housing census: Table - 33 Housing units by tenure, material used in outer walls, roofs and rural/urban*. https://www.pbs.gov.pk/content/final-results-census-2017-0

Perez-Valcarcel, J., Muniz, S., Mosquera, E., Freire-Tellado, M., Aragon, J., & Corral, A. (2021). *Modular Temporary Housing for Situations of Humanitarian Catastrophe.* Journal of Architectural Engineering, 27(2). https://doi.org/Artn 05021004 10.1061/(Asce)Ae.1943-5568.0000471

Perrucci, D., & Baroud, H. (2020). *A Review of Temporary Housing Management Modeling: Trends in Design Strategies, Optimization Models, and Decision-Making Methods.* Sustainability. https://doi.org/https://doi.org/10.3390/su122410388

Pezzica, C., Cutini, V., & de Souza, C. B. (2021). *Mind the gap: State of the art on decision-making related to post-disaster housing assistance*. International Journal of Disaster Risk Reduction, 53. https://doi.org/ARTN 10197510.1016/j.ijdrr.2020.101975

Pintos, P. (2022). *Circular Tiny House CTH*1 / Faculty Design / Coburg University Germany.* Archdaily. https://www.archdaily.com/982824/circular-tiny-house-cth-star-1-faculty-design-coburg-university-germany

Preston, L. (2017). *A wider circle? The circular economy in developing countries*. Chatham House: The Royal Institute of International Affairs. ISBN 978 1 78413 256 9

R

Rathnasinghe, A., Sirimewan, D., Shandraseharan, A., Thurairajah, N., Thayaparan, M. and Waidyasekara. (2021). *Towards long-term sustainable performance of post-disaster housing reconstruction: Second life for temporary housing.* 9th World Construction Symposium, WCS 2021, http://dl.lib.uom.lk/bitstream/handle/123/16624/Towards%20long-term%20sustainable%20performance%20of.pdf?sequence=1

Roser, M., Ritchie, H., Ortiz-Ospina, E. & Rodés-Guirao, L. (2013). *World Population Growth.* OurWorldInData. https://ourworldindata.org/world-population-growth

S

Safiruddin, M. (2005). *Folk houses in Sindh: a study in cultural geography*. [Doctoral thesis]. University of Karachi

Salvalai, G., Imperadori, M., Lumina, F., Mutti, E. & Polese, I. (2016). *Architecture for refugees, resilience shelter project: A case study using recycled skis*. iHBE 2016. doi: 10.1016/j.proeng.2017.04.271

Schires, M. (2021, April 15). *Hempcrete: Creating Holistic Sustainability With Plant-Based Building Materials*. Archdaily. https://www.archdaily.com/955176/hempcrete-creating-holistic-sustainability-with-plant-based-building-materials

Shahzad, A. (2020). *Pakistan approves first industrial hemp production - minister.* Reuters. https://www.reuters.com/article/pakistan-drugs-pharmaceuticals-idUSL8N2FZ481

Shelter Centre (Publisher). (2012). *Transitional Shelter Guidelines*. https://reliefweb.int/report/world/transitional-shelter-guidelines

Smit, M. (2023, April 20). *Locally Harvested Materials* [Video]. Circularity for Educators. https://circularityforeducators.tudelft.nl/article/locally-harvested-materials/

Sphere. (2018). *The Sphere Handbook: Humanitarian charter and minimum standards in humanitarian response*. https://handbook.spherestandards.org/en/sphere/#ch001

T

Turk, B. (2022). *Quantifying the potential of overheating countermeasures on a humanitarian shelter through measurements and building performance simulations.* [Master's thesis]. Eindhoven University of Technology. https://research.tue.nl/en/studentTheses/quantifying-the-potential-of-overheating-countermeasures-on-a-hum

U

UNEP. (2022). *Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.*

UNHCR. (2022). *Global Forced Displacemen*t. https://www.unhcr.org/globaltrends

V

van der Lugt, P. (2017). *Booming Bamboo: The (re)discovery of a sustainable material with endless possibilities.* Materia.

W

Wagemann, E. (2017). *Need for adaptation: transformation of temporary houses.* Disasters, 41(4), 828-851. https://doi.org/10.1111/disa.12228

Widyarko, K. F. A., Nisrina Dewi Salsabila, Linda Firlie, & Pratiwi. (2021). *Material Loops Potential in post-disaster Transitional Shelter: Learning from 2010 Mepari Eruption.* architecture&ENVIRONMENT, 20(Apr 2021), 13-30.

Wikipedia contributors. (2023, May 1). *Ajrak*. In Wikipedia, The Free Encyclopedia. Retrieved 10:39, June 11, 2023. https://en.wikipedia.org/w/index.php?title=Ajrak&oldid=1152559978

Wimberly, T. A., Salman; Khalfan, M.; Ulhaq, I.; Maqsood, T.; . (2021). *Temporary Homes in Disaster Hit Areas.* In S. M. A. P. H. S. A. A. D. Saul; (Ed.), Advances in Science, Technology & Innovation (pp. 367 - 374). https://doi.org/10.1007/978-3-030-48465-1_62

Y

Yadav, M. & Saini, A. (2022). *Opportunities & challenges of hempcrete as a building material for construction: An overview*. Materials Today: Proceedings 65. https://doi.org/10.1016/j.matpr.2022.05.576

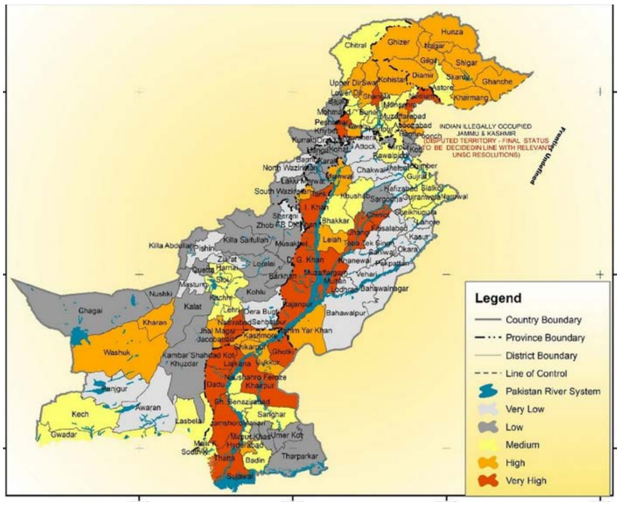
Yau, N. J., Tsai, M. K., & Yulita, E. N. (2014). *Improving efficiency for post-disaster transitional housing in Indonesia An exploratory case study.* Disaster Prevention and Management, 23(2), 157-174. https://doi.org/10.1108/Dpm-04-2013-0071

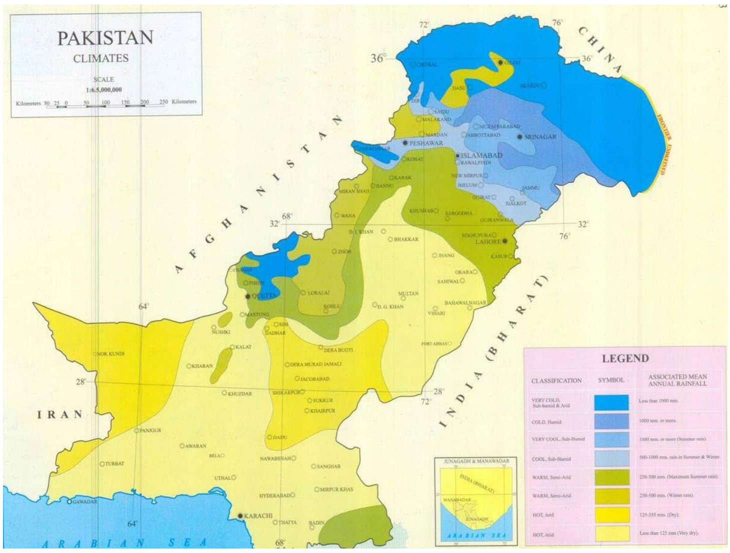
Z

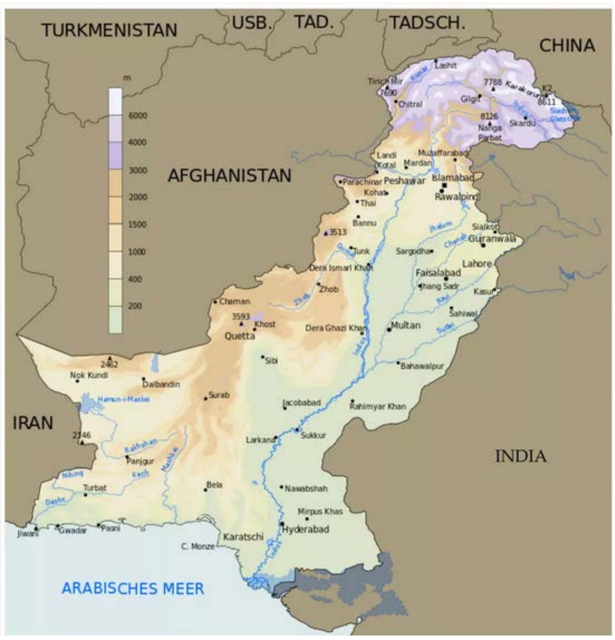
Zimmann, R., O'Brien, H., Hargrave, J., & Morrell, M. (2016). The Circular Economy in the Built Environment. ARUP. https://www.arup.com/perspectives/publications/research/section/circular-economy-in-the-built-environment

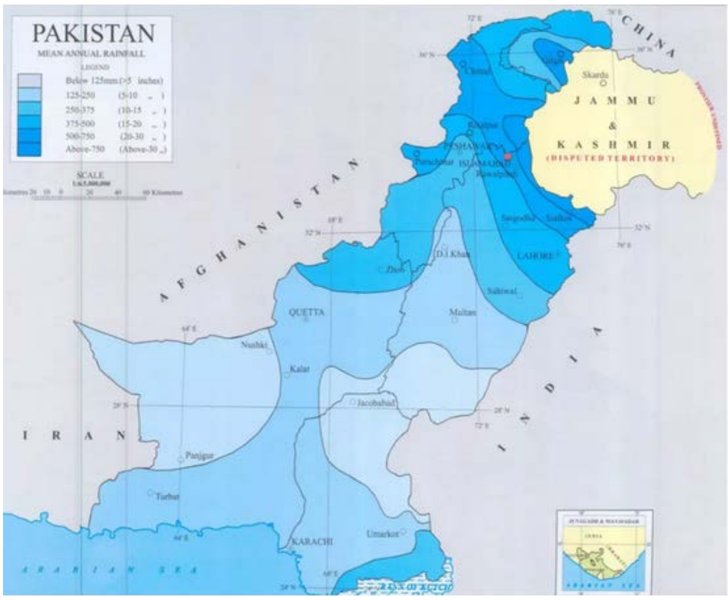
Appendix

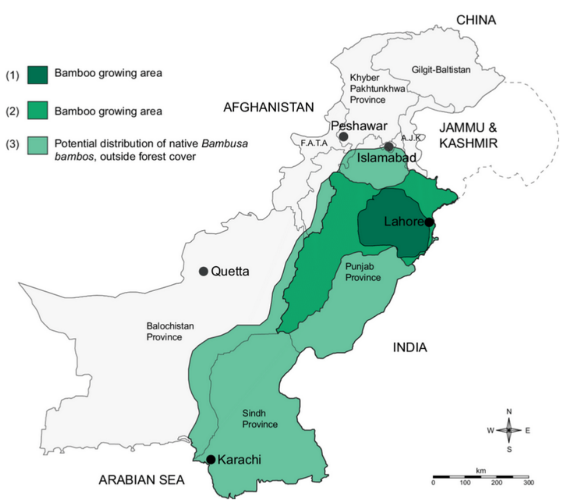
Appendix A - Pakistan maps



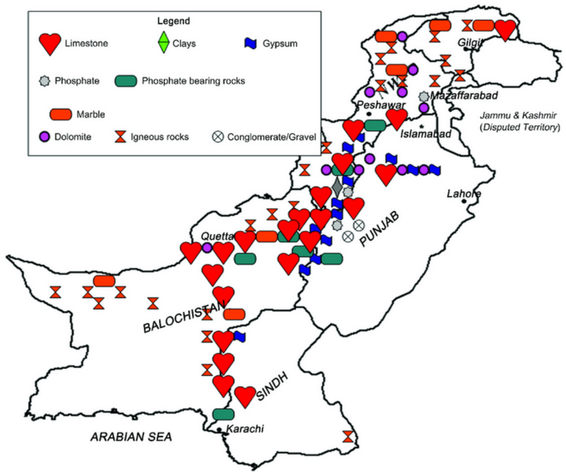






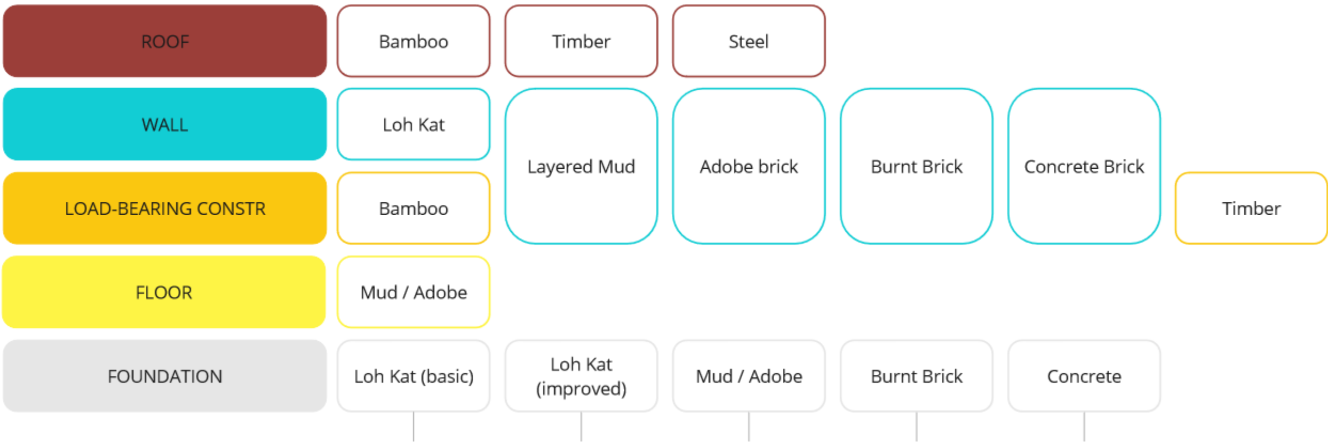


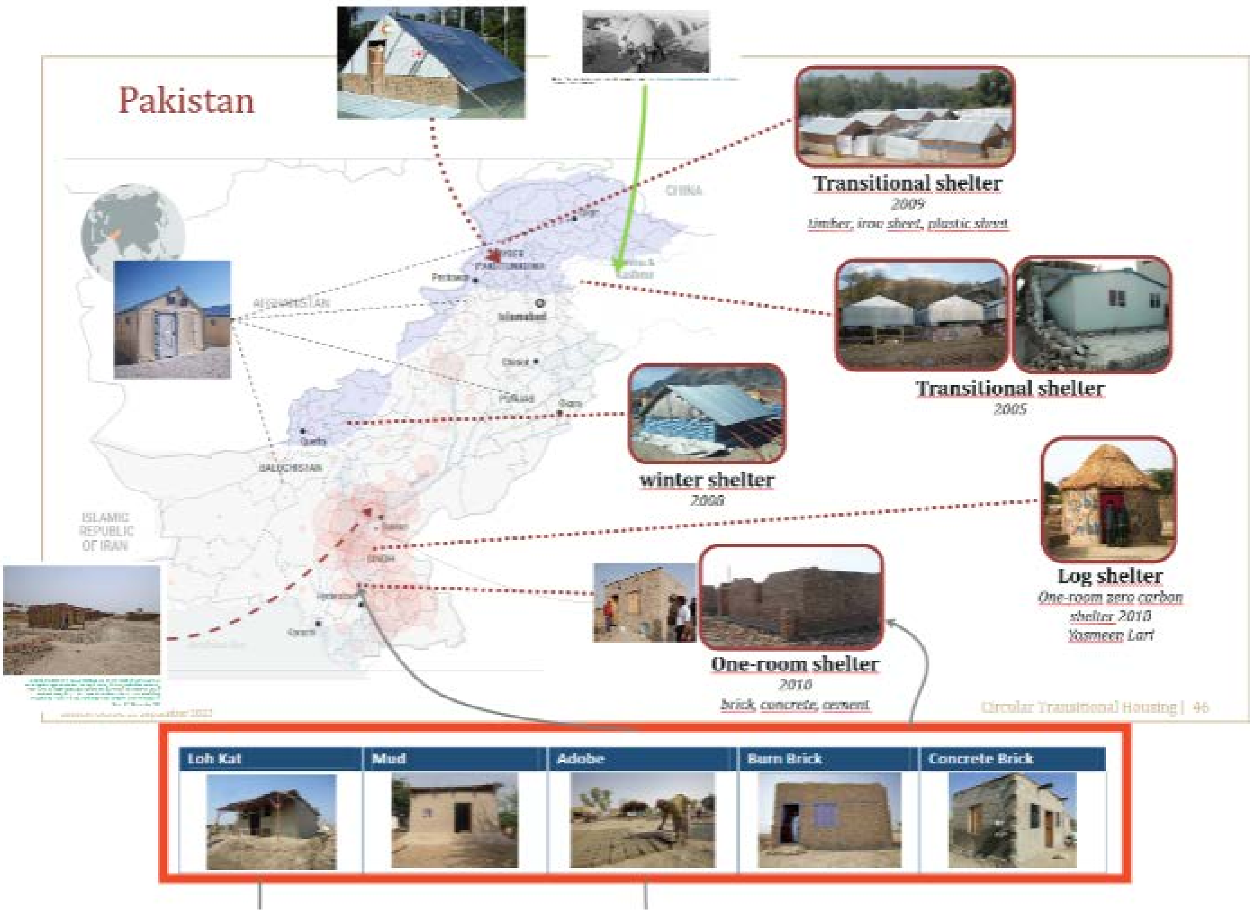
Map of bamboo growing areas in Pakistan. Sources: Based on information from (1) Suleman (2005), (2) Karim Alm-Ns (2016) and (3) Bystriakova et al. (2003)



Map of Pakistan showing main cement raw resources (limestone, shale/clay, gypsum), agrominerals (rock phosphate, gypsum), marble, construction, dimension and décor stone resources (marble, dolomite, conglomerate and gravels, igneous rocks) of Pakistan.

Construction materials | Based on the analysis of vernacular architecture in the different regions of Pakistan, a map depicting the local biobased construction materials has been compiled.


ROOF
Bamboo
Timber
Steel
WALL
Loh Kat
Layered Mud
Adobe brick
Burnt Brick
Concrete Brick
LOAD-BEARING CONSTR
Bamboo
Timber
FLOOR
Mud / Adobe
FOUNDATION
Loh Kat (basic)
Loh Kat (improved)
Mud / Adobe
Burnt Brick
Concrete


Pakistan
Transitional shelter
2009
timber, iron sheet, plastic sheet
Transitional shelter
2005
winter shelter
2008
Log shelter
One-room zero carbon
shelter 2010
Yasmeen Lari
One-room shelter
2010
brick, concrete, cement
AFGHANISTAN
CHINA
BALOCHISTAN
SINDH
ISLAMIC REPUBLIC OF IRAN
Circular Transitional Housing | 46
Loh Kat
Mud
Adobe
Burn Brick
Concrete Brick

Appendix B - Comfortable temperature calculations for Sindh, Pakistan

For the estimation of the hempcrete wall tickness, the weather data of Sukkur, Pakistan has been examined. Data has been taken from the webpages *Meteoblue* and *Weatherspark*. The temperature difference between the day and night is quite big, allowing for nighttime cooling.

TEMPERATURES SUKKUR Pakistan												
average °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MAX	28	33	39	44	48	49	47	45	43	41	35	30
	24	27	32	40	44	45	43	42	41	37	31	26
AVR	15	18	24	30	35	36	35	34	32	28	22	16
	8	10	16	21	25	28	29	28	25	20	14	9
MIN	2	3	9	14	20	25	27	25	21	15	9	4
SUNRISE	7:15 AM	7:11 AM	6:49 AM	6:15 AM	5:45 AM	5:29 AM	5:32 AM	5:47 AM	6:03 AM	6:17 AM	6:35 AM	6:57 AM
SUNSET	5:40 PM	6:04 PM	6:24 PM	6:41 PM	6:58 PM	7:15 PM	7:24 PM	7:14 PM	6:46 PM	6:11 PM	5:41 PM	5:29 PM
DAYTIME	10.6	11.2	12	12.8	13.5	13.9	13.7	13.1	12.3	11.5	10.8	10.4
sol en KWh/m²	4.2	5.1	6.1	7.1	7.7	7.7	6.9	6.7	6.5	5.6	4.5	3.9
sol en W/m²	396.23	455.36	508.33	554.69	570.37	553.96	503.65	511.45	528.46	486.96	416.67	375.00

The experience of thermal comfort is different for every person. It is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55). It depends on amount of clothing, metabolism and personal preference. The indoor comfortable temperature also varies in relation to the outdoor temperature. There are different methods to calculate that. For the purpose of theis thesis two are used: Humphrey (1978) - Model 1, and the model followed on Ashrae 55 - Model 2. The models are applied to the maximum, average and minimum temperatures found in Sukkur. Their average is taken as the indication for comfortable indoor temperature (average Ti). This average is used to determine the temperature difference (ΔT) between the outdoors and the desirable indoor comfort. The colour red indicates the need of cooling and the colour blue - the need of heating, to reach *comfort.*

COMFORTABLE TEMPERATURE												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Model 1	26.9	29.5	32.7	35.4	37.5	38.1	37.0	35.9	34.9	33.8	30.6	27.9
Model 2	26.5	28.0	29.9	31.4	32.7	33.0	32.4	31.8	31.1	30.5	28.7	27.1
Model 1	19.9	21.5	24.7	27.9	30.6	31.1	30.6	30.1	29.0	26.9	23.6	20.4
Model 2	22.5	23.4	25.2	27.1	28.7	29.0	28.7	28.3	27.7	26.5	24.6	22.8
Model 1	13.0	13.5	16.7	19.4	22.6	25.3	26.3	25.3	23.1	19.9	16.7	14.0
Model 2	18.4	18.7	20.6	22.1	24.0	25.6	26.2	25.6	24.3	22.5	20.6	19.0
average Ti	**26.7**	**28.8**	**31.3**	**33.4**	**35.1**	**35.5**	**34.7**	**33.8**	**33.0**	**32.2**	**29.6**	**27.5**
average Ti	**21.2**	**22.4**	**25.0**	**27.5**	**29.6**	**30.0**	**29.6**	**29.2**	**28.4**	**26.7**	**24.1**	**21.6**
average Ti	**15.7**	**16.1**	**18.6**	**20.8**	**23.3**	**25.4**	**26.2**	**25.4**	**23.7**	**21.2**	**18.6**	**16.5**
ΔT	-1.3	-4.2	-7.7	-10.6	-12.9	-13.5	-12.3	-11.2	-10.0	-8.8	-5.4	-2.5
ΔT	6.2	4.4	1.0	-2.5	-5.4	-6.0	-5.4	-4.8	-3.6	-1.3	2.1	5.6
ΔT	13.7	13.1	9.6	6.8	3.3	0.4	-0.8	0.4	2.7	6.2	9.6	12.5

Model 1 - Humphrey 1978 **Tn = 11.9 + 0,534*To**
Tn - preferred temp
To - mean outside

Model 2 - Ashrae 55 **Tn = 0.31*To + 17.8**

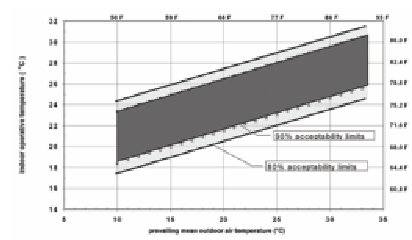
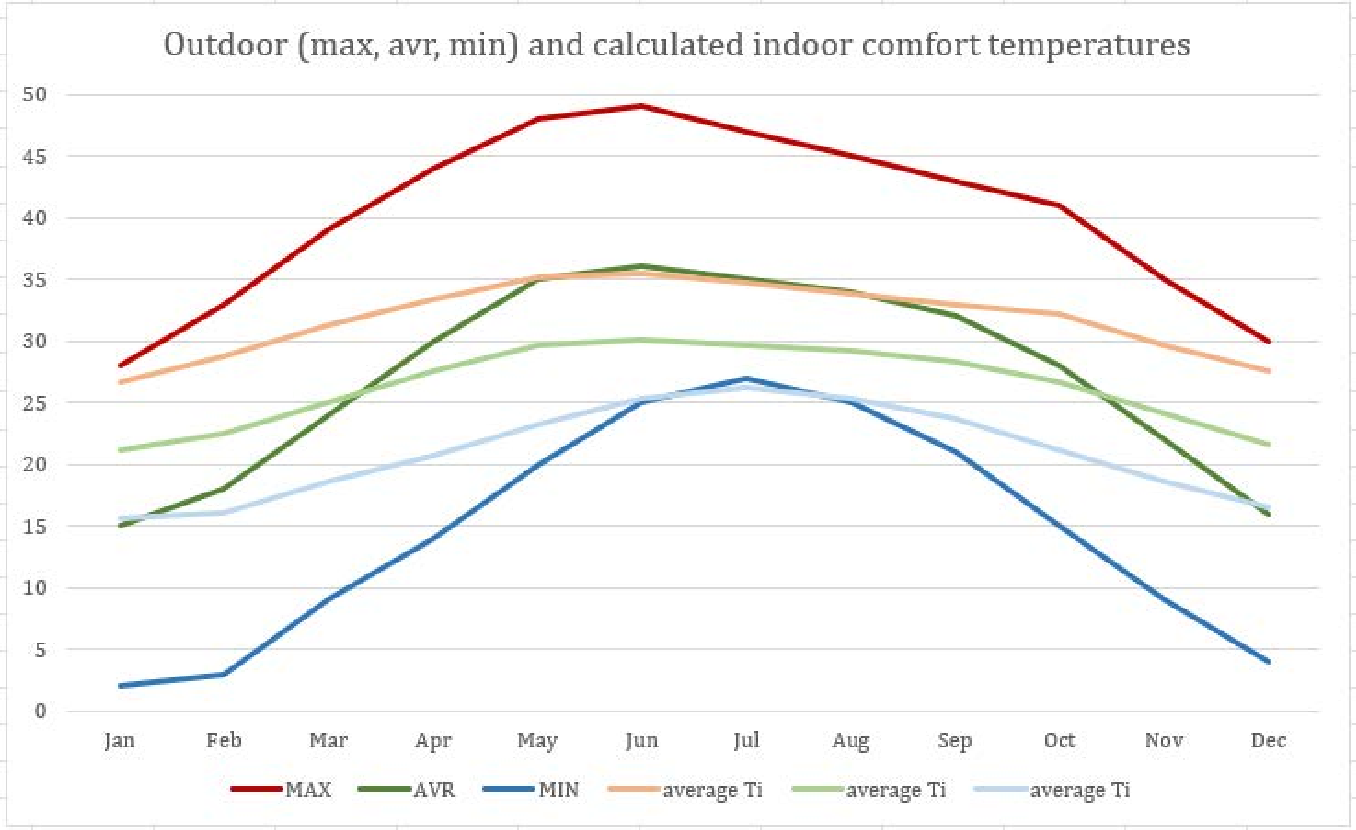


FIG. 2.2 Acceptable operative temperature ranges for naturally conditioned spaces (ANSI/ASHRAE, 2017)



The planned THU is for a household of six persons. To calculate the internal heat gains two adults and four children are assumed. Based on that and the amount of average heat production in rest, a rough estimate of the internal heat gains is made. This number is taken as a baseline and does not include heat production of lamps, heaters or other electronics.

HEAT GAINS										
heat production in rest			**THU**		**total**		**people**	520	W	
adult	100	W	2		200	W	lamps	0	W	
child	80	W	4		320	W				
					520	**W**	**total**	**520**	**W**	

For the hempcrete wall, basic calculations of the weight and U-value are made based on average thermal conductivity (λ) and density hempcrete values.

WALL CONSTRUCTION					
material	**d (m)**	**R (m²K/W)**	**λ (W/mK)**	**α**	**U (W/m²K)**
hempcrete brick	0.15	2.30769231	0.065		0.43

wall height	2.5	m
wall perimeter	17.7	m
Wal volume	5.97375	m³
density	400	kg/m³
wall weight	**2389.5**	**kg**
	23417.1	N
	23.4171	kN

The heat transmission is calculated with the formula: Qtr = U*A*ΔT (U - U-value; A - wall area; ΔT - temperature difference between indoor and out). Based on that and the previously defined ΔT for comfortable indoor temperature and the wall area (with 10% assumed window area), the heat transmission is calculated. The result show that in the coldest moments, **assuming a hempcrete wall of 15 cm**, only 240W will be needed to keep the indoors comfortable. Taken the internal heat gain of 520W, the indoor of the THU will remain comfortable without additional heating.

HEAT TRANSMISSION														
wall height	2.5	Qtr = U*A*ΔT						glass are	4.425	m²	room are	24	m²	
wall perimeter	17.7	area wall -	44.25	m²	Glas/Wall	10%		wall area	39.825	m²				
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	ΔT	-1.3	-4.2	-7.7	-10.6	-12.9	-13.5	-12.3	-11.2	-10.0	-8.8	-5.4	-2.5	°C
	ΔT	6.2	4.4	1.0	-2.5	-5.4	-6.0	-5.4	-4.8	-3.6	-1.3	2.1	5.6	°C
	ΔT	13.7	13.1	9.6	6.8	3.3	0.4	-0.8	0.4	2.7	6.2	9.6	12.5	°C
	Qtransm	-23.0215	-72.89568	-132.7447	-182.61887	-222.52	-232.49	-212.54	-192.59	-172.644	-152.69	-92.845	-42.971	W
	Qtransm	106.6514	76.726845	16.87784	-42.971175	-92.845	-102.82	-92.845	-82.871	-62.92085	-23.022	36.8275	96.6765	W
	Qtransm	236.3242	226.34937	166.5004	116.626185	56.7772	6.903	-13.047	6.903	46.80234	106.651	166.5	216.375	W

This calculation is just meant to give a basic orientation for the necessary wall thickness. The heat transmission through the roof and the floor are not calculated. Furthermore, heat gains and loss through ventilation and infiltration is not yet taken into account. For the implementation of this design proposal a more elaborate calculation of the indoor thermal comfort will be necessary.

Appendix C - Recommendation set and visual evaluation tool for circularity informed design decisions

Recommendation set:

Design Principles							
	Category	**Principle**		**Recommendation**			
I.	**Material**						
		1.1	Local materials	1.1.1	Identify possible local building materials (area, region, country)	The material demand is often very high after a crisis occures. To respond to possible overconsumption of local resources, an overview of the locally available materials at all three scales can provide alternatives, which can be easily sourced.
			Biological or technical materials, which can be (sustainably) sourced and processed from the area, region or country	1.1.2	Diversify suppliers if possible	By using several local suppliers a monopol on the materials can be avoided. This can further help the local economy and possibly provide livelihood opportunities for the locals.
				1.1.3	Environmental impact of materials' sourcing and processing	Each material has carbon emissions connected to its extraction, procurement and manufacturing. Materials with a lower environmental impact should be preferred. Transportation usually has a minor influence on the overall emissions compared to the material sourcing, so materials which are a bit further away but have a lower impact, might be a better choice.
				1.1.4	Consider ease of maintenance	Repair and maintenance of transitional housing units can be encouraged by use of materials known to the community.
		1.2	Biobased materials	1.2.1	Identify suitable disposal options and their availability	Biobased materials might not always be biodegradable, especially if they are part of a composite material. Suitable disposal options should be considered to avoid waste generation at the end-of-life phase.
			Materials, which can be returned to the ecosystem through composting or anaerobic digestion.	1.2.2	Avoid toxic chemicals	Biobased materials need to be protected against fire, rot and insects. Coatings, which will impact the recyclability or compostability of the product, should be avoided. Passive protection alternatives like roof overhangs and suitable distances between units should be implemented whereever possible.
				1.2.3	Favor sustainable sourcing of materials	Give preference to suppliers, who manage material extraction is a sustainable way.
				1.2.4	Consider the harvest season	Seasonal material limitations should be considered during the preparation phase.
		1.3	Waste materials	1.3.1	Identify waste materials (area, region, country)	Different industries might provide a useful waste material, which can be integrated in the shelter. For example old car tires might be used as foundations ot textile waste can be used as insulation.
			Materials, which are considered waste or are a byproduct from another process or industry	1.3.2	Check if the material or product meets the functional requirementss	The functionalities of the material (or product) should be respected
				1.3.3	Check if quantity of the material is sufficient for the intended use	Availability might be limited (due to market, infrastructure damage, seasonal change, etc.). Timely limitations need to be considered.
		1.4	Recyclable materials	1.4.1	Map recycling infrastructure (area, region, country)	Recyclable materials should be in consideration of the country's capacity. Materials should be brought to the respective recycling facility for processing. Export to a facility in another country is possible but logistics, funding and transportation need to be considered.
			Materials, which can be recycled into new components with the same properties	1.4.2	Favor monomaterial products	To allow for recyclability, the components should be easy to separate into basic materials. Some coatings, dyes and glues can influence the disposal method.
		1.5	Secondary streams	1.5.1	Identify secondary materials and components (area, region, country)	Demolition projects or harvest maps can be explored as a source for secondary materials or components such as used windows, doors, etc.
			Materials and components that have been reclaimed and reused.	1.5.2	Check if the material or component meets the functional requirementss	The functionalities of the material (or component) should be respected
				1.5.3	Check if quantity of the material is sufficient for the intended use	Availability might be limited (due to market, infrastructure damage, seasonal change, etc.). Timely limitations need to be considered.
II.	**Design**						
		2.1	Design for disassembly	2.1.1	Connections are reversible	Screws, ropes or plugs should be preferred over adhesives or nails. Dismantling of connections should not result in damage of components.
			Enabling the dismounting of components at the buildings end-of-service-life without damaging them in order to recover value. Possible reassembly. Some elements can be reused in another system.	2.1.2	Connections are easily accessible	Enough space for a connection to be reached in a safe manner should be provided. Space for necessary tools (eg. screwdriver) should be available.
				2.1.3	Components are independent	Components are kept independent in consideration of the 'Shearing layer of change' theory. Systems, requiering a change earlier, can be removed without damaging the rest.

	2.2 Modular design A system with several parts (modules), which can be independently created, combined and exchanged.	2.2.1	Catalogue the modules and the possible combinations	Information on the flexibility and variation options should be provided to ensure the full potential of the modular system. Detailed specifications, assembly instructions, and maintenance procedures should be included.
		2.2.2	Standardise modules	Dimensions, connections, and interfaces for the modules should be defined to ensure compatibility and interchangeability.
	2.3 Design for longevity Life of components is extended (through durable materials or flexible spacial layout), so that they can survive the expected service life (wear and tear) and even beyond that, in order to utilise reuse strategies.	2.3.1	Prioritise durable materials	Strong materials, which are resistant to wear and tear, should be preferred.
		2.3.2	Minimise the amount of parts in components	The amount of parts in components should be reduced to prevent breaking. Fragile pieces should be avoided.
		2.3.3	Multifunctional spatial layout	A multifunctional spatial layout increases the reuse potential of units. Scenario planing can help determine the potential future uses.
	2.4 Design for standardisation Components are designed following (inter)national norms and rules (standards), making them compatible and interchangeable with elements from other systems	2.4.1	Identify product standards followed in the host country	Relevant local product standards should be identified as a preparation.
		2.4.2	Compatibility of components	Components should be compatible with existing systems or infrastructure. Interface and connection points should be easy to integrate with other standardised elements or equipment commonly used in the host country.
	2.5 Design for adaptability Adapting to changing function requirements during the use phase (or in a second life) through spacial layout reconfigurations, extensions or partial dismantling	2.5.1	Analyse end-of-life scenarios	Visualising the most plausible end-of-life scenarios (check principle 4.3), such as reuse, can provide indications of what might be necessary in the future and thus be included in the design from the beginning. Changes might include reconfigurations, extensions or partial dismantling.
		2.5.2	Utilise sensible dimensions	Providing a good room height and a sensible structural grid can positively influence the ease of the unit to be adapted to another function.
		2.5.3	Allow for flexible dimensions (secondary streams)	Secondary components might differ in their dimensions. A flexible design or construction method can accommodate those differences, thus allowing for a wider implementation.
		2.5.4	Allow for façade reconfiguration	The façade should accommodate change in the openings requirements due to light, ventilation, circulation and privacy necessities.
	2.6 Material optimisation Optimisation of components and thus reduction of the necessary material; reduction of material waste and packaging	2.6.1	Consider building material dimensions	The design should be adapted to the standard construction materials or components to minimise waste from cutting and processing
	2.7 Design for recycling Keeping materials separated (pure) in order to make recycling possible	2.7.1	Materials within a component can be separated	Components can be dismanteld to their basic materials. Adhesives or coatings which could negatively influence the reciclability should be avoided.
III. Manufacture	**3.1 Prefabrication** Components or units are prepared and assembled usually in controlled conditions, before reaching the building site	3.1.1	Consider transportation vehicle sizes in host country	Off-site prefabricated components need to be transported to the building location. Vehicle size restrictions should be considered to save time and investment.
		3.1.2	Utilise existing prefabrication infrastructure	Prefabrication might already be known as a manufacturing method in the host country. Facilities and skilled labour might thus be available.
		3.1.3	Train beneficiaries	Organising workshops to teach beneficiaries how to prefabricate components can help them contribute to the shelter construction and find livelihood opportunities in the long term.
	3.2 Additive manufacturing The process of building up components by continiously adding material (layering)	3.2.1	Ensure the availability of machinery in area	This process requires special machinery. Make sure it is available in the affected region. This may require setting up new partnerships
		3.2.2	Ensure the availability of skilled labour	This process requires specific know-how on how to use the machinery. Make sure it is available in the affected region.
		3.2.3	Train beneficiaries	Organising workshops to teach beneficiaries how to participate in the process can help them contribute to the shelter construction and find livelihood opportunities in the long term.

	3.3 CNC milling	3.3.1	Ensure the availability of machinery in area	This process requires special machinery. Make sure it is available in the affected region. This may require setting up new partnerships
	Computer-controlled machines carve out material to form components, substractive manufacturing	3.3.2	Ensure the availability of skilled labour	This process requires specific know-how on how to use the machinery. Make sure it is available in the affected region.
		3.3.3	Train beneficiaries	Organising workshops to teach beneficiaries how to participate in the process can help them contribute to the shelter construction and find livelihood opportunities in the long term.
	3.4 Robotics	3.4.1	Ensure the availability of machinery in area	This process requires special machinery. Make sure it is available in the affected region. This may require setting up new partnerships
	Robot executes specific tasks with great precision. Following a computer profram the machine can run continiously in repetitive cycles	3.4.2	Ensure the availability of skilled labour	This process requires specific know-how on how to use the machinery. Make sure it is available in the affected region.
		3.4.3	Train beneficiaries	Organising workshops to teach beneficiaries how to participate in the process can help them contribute to the shelter construction and find livelihood opportunities in the long term.
	3.5 Vernacular building techniques	3.5.1	Understand the existing vernacular building techniques and construction skills	Contact with local experts can give insights on available manufacturing methods. The vernacular techniques can be further developed and adapted with technical modifications for better hazard preparedness and durability.
	Utilising local knowledge on construction. Vernacular architecture is often accommodated to the local climate and culture	3.5.2	Favor sustainable modifications	Modifcations made to the traditional building techniques should support the ability of the material to be returned to the biological or technical material loop (butterfly diagram).
IV. **Management**				
	4.1 Create guidelines	4.1.1	Include necessary information for material recovery	The guidelines should contain information on how to assemble and dismantle the THU in a safe manner without damaging the components. Further information on separating materials and their proper disposal or other end-of-life scenarios should be included. Depending on the concept, options for the end-of-life of the unit can be included as well.
	The lack of information is one of the biggest challenges when it comes to circularity. By providing manuals, the owners will be able to recover value and reuse materials safely.	4.1.2	Keep guidelines simple and understandable	Visual representation and simple explainations should be preferred. All langueges spoken by the affected population should be included.
		4.1.3	Provide access	Beneficiaries should know where and how to find the necessary guidelines. Additional assistance for questions should be provided.
	4.2 Take-back agreements	4.2.1	Identify local suppliers following this business model	Suppliers offering the take-back business model should be taken in consideration.
	Suppliers / producers provide a take-back service; they collect their products at their EoL stage (or free or an agreed fee) or if they are being damaged	4.2.2	Set agreements with suppliers	THU are needed for a limited amount of time. This period can be agreed upon and the used components can later be returned to the supplier, where they can reenter the economy or be recycled.
	4.3 Scenario planning	4.3.1	List potential future uses for the transitional housing unit	Possible future developments for the transitional housing units should be examined. This may include the existing situation getting better or worse, conesequent hazards, change in cotext, etc. Think about likely, unplanned and unexpected scenarios. "what if" statements can be helpful.
	Planning for possible future (EoL) scenarios for the units as part of the design process thus testing the efficiancy of the design concept	4.3.2	Consider the necessary changes in each scenario	Changes can include reconfiguration of space, change of components, change of openings and more.
		4.3.3	Design for the new scenarios	This step can help improve the existing design by making it future-proof. It can provide information about the size of the structural grid, the circulation or the services.
		4.3.4	Discuss possible scenarios with the stakeholder team	In order to define the most probable scenarios and the necessary adapations, discussion with all relevant stakeholders, including authorities and the affected population is recommended.
	4.4 Product as a service	4.4.1	Identify suppliers who follow this business model	Suppliers offering the product-as-a-service business model should be taken in consideration. Might be connected with principle 4.2.
	Suppliers lease out products rather than selling them, or offer an additional service with the product, thus remaining responsible for the quality and maintenance.	4.4.2	Set agreements with suppliers	THU are needed for a limited amount of time. This period can be agreed upon and the used components can later be returned to the supplier, where they can reenter the economy or be recycled.
	4.5 Building information model (BIM)	4.5.1	Ensure input quality	The BIM software needs to be used by all stakeholders involved in the design. Team members should have the know-howon how to use it.
	Digital representative 3D model (twin) of the physical building. Includes data of all elements, cost and systems.			

4.6	Material passport A document, containing information on the origin, composition, and characteristics of construction materials	4.6.1	Gather enough information	All necessary information on the materials should be gathered to complete the material passports.
4.7	Building as material banks (BAMB) EU funded project, aiming to make a systemic shift in the BE towards CE. Materials and components are temporarily assembles in a building, but are easy to be reused in another through BIM and material passports	4.7.1	Provide material passports to building components	The components should be easy to identify to utilise the potential of transitional housing units as a stock of valuable materials. A database of the used components with material passports should be easily accessible a to ensure information flow and quality. Could be linked to principle 4.5.

Performance indicators for evaluation:

Material

1.1 Local Material

material availability in host country
THU structural materials are abundantly available in the affected region
THU structural materials are abundantly available in the host country
THU structural materials are partialy available in the host country
all THU structural materials are imported
not applicable

Materials used in THU
THU non-structural materials are abundantly available in the affected region
THU non-structural materials are abundantly available in the host country
THU non-structural materials are partialy available in the hostcountry
all THU non-structural materials are imported
not applicable

Materials environmental impact
Materials are sourced sustainably (certified supplier)
Materials are sourced sustainably (uncertified supplier)
Materials are sorced sustainably, but procured with unsustainable transportation
Material sourcing is unsustainable or unknown
not applicable

1.2 Biobased Material

biodegradable structural
Biobased structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae)
Biobased structural materials will break down in a compost environment
Biobased structural materials will break down in an industrial compost environment
Biobased structural materials can pollute the environment during degredation due to toxic additives
not applicable

biodegradable non-structural
Biobased non-structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae)
Biobased non-structural materials will break down in a compost environment
Biobased non-structural materials will break down in an industrial compost environment
Biobased non-structural materials can pollute the environment during degredation due to toxic additives
not applicable

Design

2.1 Design for disassembly

Reversible connections
connections are fully reversible; components do not get damaged
connections are reversible; components get ligthly damaged
some connections are reversible; components get damaged
connections are not reversible; components get damaged
not applicable

Accessible connections
connections are easily and safely accessible; if necessary, tools can be used without an issue
most connections are easily and safely accessible; if necessary, tools can be used without an issue
connections are difficult to access; tools may cause damage to other components
connections are not accessible; using tools causes damage or issues
not applicable

2.2 Modular design

Spalte1
Modules can be very easily interchanged or replaced within the system
Modules can be interchanged or replaced within the system with some difficulties
Modules can be interchanged or replaced within the system but it is a difficult and complicated process
Modules cannot be interchanged or replaced within the system
not applicable

Manufacturing

3.1 Prefabrication

Spalte1
Prefabricated components use materials known to the beneficiaries; the beneficiaries know how to maintain and repair them
Prefabricated components use some materials known to the beneficiaries; the beneficiaries know how to maintain and repair them
Prefabricated components use some materials known to the beneficiaries; the beneficiaries do not know how to maintain and repair them
Prefabricated components use materials unknown to the beneficiaries; the beneficiaries do not know how to maintain and repair them
not applicable

Spalte1
Beneficiaries have received training in prefabrication of components, which they can employ in their shelter and reconstruction
Beneficiaries have received training in prefabrication of components, which they can employ only in their shelter
Beneficiaries have received training in prefabrication of components, which is unsufficient to employ in their shelter and reconstruction
Beneficiaries have not received training in prefabrication of components
not applicable

Spalte1
Prefabricated components can be easily dismantled, reused, recycled, or repurposed, minimizing waste generation
Prefabricated components can be easily dismantled, recycled, but not directly reused
Prefabricated components can be dismantled with difficulty, then recycled, but not directly reused
Prefabricated components cannot be easily dismantled, recycled, or repurposed
not applicable

3.2 Additive manufacturing

material efficiency
The amount of material needed for THUs is significantly less compared to conventional construction. Consider material waste during printing like leftovers and offcuts.
The amount of material needed for THUs is less compared to conventional construction. Consider material waste during printing like leftovers and offcuts.
The amount of material needed for THUs is equal to conventional construction. Consider material waste during printing like leftovers and offcuts.
The amount of material needed for THUs is higher compared to conventional construction. Consider material waste during printing like leftovers and offcuts.
not applicable

material recycling
Materials can be easily recycled or reused at the end-of-life stage, for example for other 3D printed projects
Some of the materials can be easily recycled or reused at the end-of-life stage, for example for other 3D printed projects
Materials can be recycled or reused at the end-of-life stage but it is difficult to do
Materials can not be recycled or reused at the end-of-life stage, for example for other 3D printed projects
not applicable

Manegement

4.1 Create guidelines

Spalte1
Guidelines are provided to the beneficiaries and other relevant stakeholders; Information includes the (dis)assembly of THU, maintenance, end-of-life scenarios and proper material disposal
Guidelines are provided to the beneficiaries and other relevant stakeholders; Information is incomplete
Guidelines are provided to the beneficiaries and other relevant stakeholders; Information is wrong or incomplete
Guidelines are not provided to the beneficiaries and other relevant stakeholders; Information is wrong or incomplete
not applicable

Spalte1
Guidelines are easily accessible; information is presented visually and in all relevant languages
Guidelines are difficult to find; information is presented visually and in all relevant languages
Guidelines are easily accessible; information is presented not visually or relevant languages are missing
Guidelines are difficult to find; information is presented not visually or relevant languages are missing
not applicable

4.2 Take-back agreements

Spalte1
There are take-back agreements between the THU provider and the supplier in place; components will be returned after displacement
There are take-back agreements between the THU provider and the supplier in place; some components will be returned after displacement
There are unofficial take-back agreements between the THU provider and the supplier in place; some components will be returned after displacement
There are no take-back agreements between the THU provider and the supplier in place; components cannot be returned after displacement
not applicable

biobased material sourcing
Biobased materials are sourced sustainably (certified supplier)
Biobased materials are sourced sustainably (uncertified supplier)
Biobased materials are sorced sustainably, but procured with unsustainable transportation
Biobased material sourcing is unsustainable or unknown
not applicable

1.3 Waste Material

Source
Existing wastestreams are utilised in the THUs
Existing wastestreams are utilised in the THUs but transportation to site is resource-intensive
Waste not complient with product requirements is used in the THUs, requiring early replacement
New resources are sold as "waste" in order to be utilised in THUs
not applicable

2.3 Design for longevity

Spalte1
The materials used in the THU are durable enough to survive the planned lifespan of the unit and also consecutive uses with little maintenance
The materials used in the THU are durable enough to survive the planned lifespan of the unit and also consecutive uses with some repairs and maintenace needed
The materials used in the THU are durable enough to survive only the planned lifespan of the unit
The materials used in the THU are not durable enough to survive the planned lifespan of the unit and will require repair or exchange before the end of displacement
not applicable

3.3 CNC milling

material efficiency
The amount of material needed for THUs is significantly less compared to conventional construction. Consider material waste during milling like leftovers and offcuts.
The amount of material needed for THUs is less compared to conventional construction. Consider material waste during milling like leftovers and offcuts.
The amount of material needed for THUs is equal to conventional construction. Consider material waste during milling like leftovers and offcuts.
The amount of material needed for THUs is higher compared to conventional construction. Consider material waste during milling like leftovers and offcuts.
not applicable

material recycling
The CNC milled materials can be easily recycled or reused at the end-of-life stage
Some of the the CNC milled materials can be easily recycled or reused at the end-of-life stage
The CNC milled materials can be recycled or reused at the end-of-life stage but it is difficult to do
The CNC milled materials can not be recycled or reused at the end-of-life stage
not applicable

4.3 Scenario planing

Spalte1
Several future scenarios (likely and unexpected) are explored and the design can accommodate the necessary changes they may require
Several future scenarios (likely and unexpected) are explored and the design can accommodate the necessary changes some of the scenarios may require
Few future scenarios (likely and unexpected) are explored but it is unknown if the design can adapt
No future scenarios (likely and unexpected) are explored and the design can not accommodate the necessary changes they may require
not applicable

Spalte1
Possible scenarios and adaptations are discussed with all relevant stakeholders (affected population, government authorities..)
Possible scenarios are discussed with all relevant stakeholders (affected population, government authorities..) but not the necessary adaptations
Possible scenarios and adaptations are discussed with some of the relevant stakeholders
Possible scenarios and adaptations are not discussed with relevant stakeholders (affected population, government authorities..)
not applicable

1.4 Recyclable Material

material separation
Materials can be fully separated and returned in the biological or technical loop
Materials can be almost fully separated and returned in the biological or technical loop. Small amount of waste is generated.
Materials can be only partially separated and returned in the biological or technical loop. Big amount of waste is generated.
Materials can NOT be fully separated and returned in the biological or technical loop. Waste is generated.
not applicable

recycling facility
Recycling infrastructure is present in the project area of the host country
Recycling infrastructure is present in the host country
Recycling infrastructure is present in the neighbouring countries and disposal agreements are made
Recycling infrastructure is not present in host country; materials need to be exported abroad (beyond neighbouring countries)
not applicable

2.4 Design for standardisation

Spalte1
The design and its components follow national and international building standards; the components are compatible with other systems
The design and some of its components follow national and international building standards; some components are compatible with other systems
The design and some of its components follow national and international building standards; few components are compatible with other systems
The design and its components do not follow any national nor international building standards; the components are not compatible with other systems
not applicable

3.4 Robotics

material efficiency
The use of robotics enables precise and automated construction processes, minimising errors and material waste. Material is used more efficiently compared to conventional construction
The use of robotics enables precise and automated construction processes, minimising errors and material waste. A small amount of material is slightly less compared to conventional construction
The use of robotics enables precise and automated construction processes, minimising errors and material waste. Equal amount of material is used compared to conventional construction
Errors and material waste are present. Material is used less efficiently compared to conventional construction
not applicable

material recycling
Robotics can assist to efficiently dismantle THUs, enabling the recovery of valuable components and materials for recycling and reuse
Robotics can partialy assist to efficiently dismantle THUs, enabling the recovery of valuable components and materials for recycling and reuse
Robotics can not assist to efficiently dismantle THUs, but valuable components and materials can still be reclaimed for recycling and reuse
Robotics can not assist to efficiently dismantle THUs, valuable components and materials cannot be recycled and reused or only with great difficulty
not applicable

4.4 Product as a service

Spalte1
Products for the THU are provided as a service (leased / rented) by the supplier; components are maintained and will be returned after the displacement.
Some of the products for the THU are provided as a service (leased / rented) by the supplier; those components are maintained and will be returned after the displacement.
Some of the products for the THU are provided as a service (leased / rented) by the supplier; components are not maintained and will not be returned after the displacement.
Products for the THU are not provided as a service (leased / rented) by the supplier; components are not maintained and will not be returned after the displacement.
not applicable

1.5 Secondary Streams

material separation
Existing components are reclaimed and utilised in the THUs
Existing components are reclaimed and utilised in the THUs but transportation to site is resource-intensive
Secondary components not complient with product requirements are used in the THUs, requiring early replacement
New resources are sold as "secondary" in order to be utilised in THUs
not applicable

2.5 Design for adaptability

Spalte1
The design has measurements, which are suitable for other functions (scenario planing) and allow the reconfiguration of the space layout
The design has measurements, which are suitable for similar functions and allow the reconfiguration of the space layout
The design has measurements, which are suitable for similar functions but the reconfiguration of the space layout is limited
The design has specific measurements, which are not suitable for other functions and the reconfiguration of the space layout is difficult
not applicable

3.5 Vernacular building techniques

Spalte1
Chosen vernacular building techniques support and enable other circularity principles like the dismantling and separation of materials
Chosen vernacular building techniques enable some circularity principles but prevent others
Chosen vernacular building techniques enable some circularity principles with some difficulty
Chosen vernacular building techniques contradict or prevent other circularity principles like the dismantling and separation of materials
not applicable

4.5 BIM

Spalte1
The BIM containes very detailed information about all parts of the THU and is updated on a regular basis.
The BIM containes some information about all parts of the THU and is updated on a regular basis.
The BIM containes some information about all parts of the THU but is not updated on a regular basis.
The BIM does not contain much information about all parts of the THU and is not updated on a regular basis.
not applicable

Spalte1
Chosen vernacular building techniques have a very low environmental impact compared to conventional construction
Chosen vernacular building techniques have less environmental impact compared to conventional construction
Chosen vernacular building techniques have the same environmental impact compared to conventional construction
Chosen vernacular building techniques have a high environmental impact compared to conventional construction
not applicable

2.6 Material optimisation

Spalte1
Design is adapted to the regular construction material sizes; little to none construction waste is generated
Design takes the regular construction material sizes in consideration; some construction waste is generated
Design takes some of the regular construction material sizes in consideration; construction waste is generated
Design is not adapted to the regular construction material sizes; a high amount of construction waste is generated
not applicable

4.6 Material passport

Spalte1
All components have material passports; information is sufficient
All components have material passports; information is partialy missing
Some components have material passports; information is sufficient
Few components have material passports; information is unsufficient
not applicable

2.7 Design for recycling

Spalte1
Components can be fully separated to their base materials and returned in the biological or technical loop
Components can be almost fully separated to their base materials and returned in the biological or technical loop. Small amount of waste is generated.
Components can be only partially separated to their base materials and returned in the biological or technical loop. Big amount of waste is generated.
Components can NOT be fully separated to their base materials and returned in the biological or technical loop. Waste is generated.
not applicable

4.7 BAMB

Spalte1
The components are available to be reused in other projects after the displacement. The information of the components and materials (material passports) is complete and easily accessible.
The components are available to be reused in other projects after the displacement. The information of the components and materials (material passports) is incomplete or not easily accessible.
Some of the components are available to be reused in other projects after the displacement. The information of the components and materials (material passports) is incomplete or not easily accessible.
Most components are not available to be reused in other projects after the displacement. The information of the components and materials (material passports) is incomplete or unaccessible.
not applicable

Appendix D - Implementation of evaluation on case studies

CTH*1

B.R.I.C.

BB house

No	Category	Principle	Design Principles	CTH*1 Evaluation: Performance	Score	B.R.I.C. Evaluation: Performance	Score	BB house Evaluation: Performance	Score
I.	Material								
		1.1	Local materials Biological or technical materials, which can be (sustainably) sourced and processed from the area, region or country	THU structural materials are abundantly available in the affected region THU non-structural materials are abundantly available in the affected region Materials are sourced sustainably (certified supplier)		not applicable not applicable not applicable		THU structural materials are abundantly available in the affected region THU non-structural materials are abundantly available in the affected region not applicable	
		1.2	Biobased materials Materials, which can be returned to the ecosystem through composting or anaerobic digestion.	Biobased structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae) Biobased non-structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae) Biobased materials are sourced sustainably (certified supplier)		Biobased structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae) Biobased non-structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae) not applicable		Biobased structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae) Biobased non-structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae) not applicable	
		1.3	Waste materials Materials, which are considered waste or are a byproduct from another process or industry	not applicable		not applicable		not applicable	
		1.4	Recyclable materials Materials, which can be recycled into new components with the same properties	not applicable not applicable		not applicable not applicable		not applicable not applicable	
		1.5	Secondary streams Materials and components that have been reclaimed and reused.	Existing components are reclaimed and utilised in the THUs		Existing components are reclaimed and utilised in the THUs		not applicable	
II.	Design								
		2.1	Design for disassembly Enabling the dismounting of components at the buildings end-of-service-life without damaging them in order to recover value. Possible reassembly. Some elements can be reused in another system.	connections are fully reversible; components do not get damaged connections are easily and safely accessible; if necessary, tools can be used without an issue		connections are reversible; components get ligthly damaged connections are easily and safely accessible; if necessary, tools can be used without an issue		not applicable not applicable	
		2.2	Modular design A system with several parts (modules), which can be independently created, combined and exchanged.	not applicable		Modules can be very easily interchanged or replaced within the system		Modules can be interchanged or replaced within the system with some difficulties	
		2.3	Design for longevity Life of components is extended (through durable materials or flexible spacial layout), so that they can survive the expected service life (wear and tear) and even beyond that, in order to utilise reuse strategies.	not applicable		The materials used in the THU are durable enough to survive the planned lifespan of the unit and also consecutive uses with little maintenance		The materials used in the THU are durable enough to survive the planned lifespan of the unit and also consecutive uses with some repairs and maintenace needed	
		2.4	Design for standardisation Components are designed following (inter)national norms and rules (standards), making them compatible and interchangeable with elements from other systems	not applicable		not applicable		not applicable	
		2.5	Design for adaptability Adapting to changing function requirements during the use phase (or in a second life) through spacial layout reconfigurations, extensions or partial dismantling	not applicable		The design has measurements, which are suitable for other functions (scenario planing) and allow the reconfiguration of the space layout		The design has measurements, which are suitable for other functions (scenario planing) and allow the reconfiguration of the space layout	
		2.6	Material optimisation Optimisation of components and thus reduction of the necessary material; reduction of material waste and packaging	not applicable		not applicable		not applicable	
		2.7	Design for recycling Keeping materials separated (pure) in order to make recycling possible	Components can be fully separated to their base materials and returned in the biological or technical loop		Components can be fully separated to their base materials and returned in the biological or technical loop		Components can be fully separated to their base materials and returned in the biological or technical loop	
III.	Manufacture								
		3.1	Prefabrication Components or units are prepared and assembled usually in controlled conditions, before reaching the building site	not applicable not applicable not applicable		not applicable not applicable Prefabricated components can be easily dismantled, reused, recycled, or repurposed, minimizing waste generation		not applicable not applicable not applicable	
		3.2	Additive manufacturing The process of building up components by continiously adding material (layering)	not applicable not applicable		not applicable not applicable		not applicable not applicable	
		3.3	CNC milling Computer-controlled machines carve out material to form components, substractive manufacturing	not applicable not applicable		not applicable not applicable		not applicable not applicable	
		3.4	Robotics Robot executes specific tasks with great precision. Following a computer profram the machine can run continiously in repetitive cycles	not applicable not applicable		not applicable not applicable		not applicable not applicable	
		3.5	Vernacular building techniques Utilising local knowledge on construction. Vernacular architecture is often accommodated to the local climate and culture	not applicable not applicable		not applicable not applicable		Chosen vernacular building techniques support and enable other circularity principles like the dismantling and separation of materials Chosen vernacular building techniques have a very low environmental impact compared to brick masonry and concrete construction	
IV.	Management								
		4.1	Create guidelines The lack of information is one of the biggest challenges when it comes to circularity. By providing manuals, the owners will be able to recover value and reuse materials safely.	not applicable not applicable		not applicable not applicable		not applicable not applicable	
		4.2	Take-back agreements Suppliers / producers provide a take-back service; they collect their products at their EoL stage (or free or an agreed fee) or if they are being damaged	There are take-back agreements between the THU provider and the supplier in place; some components will be returned after displacement		not applicable		not applicable	
		4.3	Scenario planing Planing for possible future (EoL) scenarios for the units as part of the design process thus testing the efficiancy of the design concept	not applicable not applicable		Several future scenarios (likely and unexpected) are explored and the design can accommodate the necessary changes they may require Possible scenarios and adaptations are discussed with all relevant stakeholders (affected population, government authorities.)		Several future scenarios (likely and unexpected) are explored and the design can accommodate the necessary changes they may require not applicable	
		4.4	Product as a service Suppliers lease out products rather than selling them, or offer an additional service with the product, thus remaining responsible for the quality and maintenance.	not applicable		not applicable		not applicable	
		4.5	Building information model (BIM) Digital representative 3D model (twin) of the physical building. Includes data of all elements, cost and systems.	not applicable		The BIM containes very detailed information about all parts of the THU and is updated on a regular basis.		not applicable	
		4.6	Material passport A document, containing information on the origin, composition, and characteristics of construction materials	not applicable		All components have material passports; information is sufficient		not applicable	
		4.7	Building as material banks (BAMB) EU funded project, aiming to make a systemic shift in the BE towards CE. Materials and components are temporarily assembles in a building, but are easy to be reused in another through BIM and material passports	not applicable		The components are available to be reused in other projects after the displacement. The information of the components and materials (material passports) is complete and easily accessible.		not applicable	

Appendix E - Implementation of evaluation on the THU proposal

Design Principles			Evaluation	
	Category	**Principle**	**Performance**	**Score**
I.	**Material**			
		1.1 Local materials	THU structural materials are abundantly available in the affected region	
		Biological or technical materials, which can be (sustainably) sourced and processed from the area, region or country	THU non-structural materials are abundantly available in the host country	
			Materials are sourced sustainably (certified supplier)	
		1.2 Biobased materials	Biobased structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae)	
		Materials, which can be returned to the ecosystem through composting or anaerobic digestion.	Biobased non-structural materials will break down quickly and safely into harmless compounds through naturally occurring microorganisms (bacteria, fungi, algae)	
			Biobased materials are sourced sustainably (certified supplier)	
		1.3 Waste materials	Existing wastestreams are utilised in the THUs	
II.	**Design**			
		2.1 Design for disassembly	connections are fully reversible; components do not get damaged	
		Enabling the dismounting of components at the buildings end-of-service-life without damaging them in order to recover value. Possible reassembly. Some elements can be reused in another system.	connections are easily and safely accessible; if necessary, tools can be used without an issue	
		2.2 Modular design	Modules can be very easily interchanged or replaced within the system	
		2.3 Design for longevity	The materials used in the THU are durable enough to survive the planned lifespan of the unit and also consecutive uses with little maintenance	
		2.5 Design for adaptability	The design has measurements, which are suitable for other functions (scenario planing) and allow the reconfiguration of the space layout	
		2.7 Design for recycling	Components can be fully separated to their base materials and returned in the biological or technical loop	
		Keeping materials separated (pure) in order to make recycling possible		

III. **Manufacture**

3.1	**Prefabrication** Components or units are prepared and assembled usually in controlled conditions, before reaching the building site	Prefabricated components use some materials known to the beneficiaries; the beneficiaries know how to maintain and repair them Beneficiaries have received training in prefabrication of components, which they can employ in their shelter and reconstruction Prefabricated components can be easily dismantled, reused, recycled, or repurposed, minimizing waste generation
3.5	**Vernacular building techniques** Utilising local knowledge on construction. Vernacular architecture is often accommodated to the local climate and culture	Chosen vernacular building techniques support and enable other circularity principles like the dismantling and separation of materials Chosen vernacular building techniques have a very low environmental impact compared to conventional construction

IV. **Management**

4.1	**Create guidelines** The lack of information is one of the biggest challenges when it comes to circularity. By providing manuals, the owners will be able to recover value and reuse materials safely.	Guidelines are provided to the beneficiaries and other relevant stakeholders; Information includes the (dis)assembly of THU, maintenance, end-of-life scenarios and proper material disposal Guidelines are easily accessible; information is presented visually and in all relevant languages
4.2	**Take-back agreements** Suppliers / producers provide a take-back service; they collect their products at their EoL stage (or free or an agreed fee) or if they are being damaged	There are take-back agreements between the THU provider and the supplier in place; components will be returned after displacement
4.3	**Scenario planning** Planning for possible future (EoL) scenarios for the units as part of the design process thus testing the efficiancy of the design concept	Several future scenarios (likely and unexpected) are explored and the design can accommodate the necessary changes some of the scenarios may require Possible scenarios and adaptations are discussed with all relevant stakeholders (affected population, government authorities..)
4.6	**Material passport** A document, containing information on the origin, composition, and characte-ristics of construction materials	All components have material passports; infurmation is sufficient
4.7	**Building as material banks (BAMB)** EU funded project, aiming to make a systemic shift in the BE towards CE. Materials and components are temporarily assembles in a building, but are easy to be reused in another through BIM and material passports	The components are available to be reused in other projects after the displacement. The information of the components and materials (material passports) is complete and easily accessible.