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BUILDING MATERIALS
IN THE HUMANITARIAN SECTOR

YEMEN

GUIDELINES FOR SUSTAINABLE RESOURCE MANAGEMENT OF BUILDING MATERIALS

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CRAterre

UNHCR
The UN Refugee Agency

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Foreword

Following the production of a Shelter Response Profile for Yemen in 2022, this document presents reflections and recommendations for the sustainable management of construction materials in habitat, housing and shelter projects in Yemen.

The term sustainable can be understood in different ways in the construction sector. In this document, we propose to provide an integral perspective that considers social, cultural, environmental, and economic aspects.

The construction of shelters, housing and other infrastructure is essential to the quality of life and dignity of communities. Beyond that, construction is a driver of recovery and development, through the activity it will generate locally. But it can also have an impact on the land, its resources, and the wider environment.

In order to encourage building practices that have the greatest possible positive impact on the local area and communities, and also to consider contributing to the overall effort that needs to be made to reduce greenhouse gas emissions, it is necessary to be able to assess these different aspects. To what extent will the local economy benefit from the project? What will the project's environmental footprint be?

Questions relating to the appropriateness of the use of construction materials in different contexts, recycling, reuse, and reduction in the use of materials are at the origin of this guidance document, produced by CRAterre and the Shelter Cluster in Yemen, with the support of UNHCR, ECHO and the Global Shelter Cluster.

This document is not exhaustive but suggests avenues to be explored in greater depth, particularly in the light of local conditions, for more sustainable construction projects.

CAUTION

The recommendations presented here for Yemen response are not intended to replace local analyses in specific contexts. It remains essential to supplement the information gathered in this document with field surveys that will enable discussions with local stakeholders and residents on the constraints and potential of their territories in terms of land tenure, lifestyles, material and human resources, practices, knowledge and capacities for implementing construction work.

↘ FOR MORE INFORMATION

ENGLISH VERSION:
Detailed Shelter Response Profile for Yemen: Local Building Cultures for sustainable and resilient habitats

ARABIC VERSION:
Arabic -Detailed Shelter Response Profile for Yemen: Local Building Cultures for sustainable and resilient habitats

PUBLISHED IN SEPTEMBER 2022 WITH CONTRIBUTIONS FROM CRATERRE, YEMEN SHELTER CLUSTER, GLOBAL SHELTER CLUSTER, UNHCR, UNITÉ DE RECHERCHE AE&CC - ENSAG - UNIVERSITÉ GRENOBLE-ALPES, IFRC, ECHO AND BHA-USAID

Cover photos :
Raw earth bricks plants, Aden ©CRAterre
Local Wood sticks for building, water, and chopped straw, Marib ©YFCA
Stones for masonry, Aldhalea Gov., Damt District ©YFCA
Cement blocks, Shabwa Gov., Rodhom district ©YFCA
Cob walls, Al Jawf Gov., Almtoon district ©YFCA
Stone masonry, rural area, Al Jawf Gov., ©YFCA

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Glossary

Biobased construction materials: Biobased construction materials are materials that are partially or wholly derived from biomass, such as wood (timber and related products), hemp, rapeseed, rice husk, straw, flax shives, cork, corncob, reed, sheep's wool, etc.[1]

Circular economy: The circular economy is a production and consumption model that involves sharing, renting, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible. In this way, the life cycle of products is extended. In practice, this means reducing waste to a minimum. When a product reaches the end of its life, its materials are retained in the economy, as far as possible, through recycling. These materials can be reused productively, creating additional value[2].

Geologic construction materials: Geologic construction materials are materials derived from mineral resources, such as raw earth or dry stone[3].

Habitat: Habitat is the place, in a general sense, where people and communities live[4].

Infrastructures[5] : There are two types of infrastructure: networked and non-networked. Networked infrastructure includes energy, transport, water, waste treatment, and digital communications. Non-networked infrastructures include housing and shelters, health centers, schools, markets, industrial facilities, community centers, courts and prisons, public buildings, etc.

Local and minimally processed materials: When they are local and minimally processed, biobased and geologic construction materials generally have a low environmental footprint[6].

Local building cultures (LBC): A building culture is an intangible dimension of what is produced by humans to live, work, thrive, etc. It includes assets related to each phase of the building life cycle: design, construction, use(s), maintenance, replacement, extension, adaptation, etc., that are linked to social, economic, environmental, and cultural aspects. The genesis and evolution of building cultures are closely linked to their environment and the specific history of each territory. This is why they are so diverse worldwide and why several building cultures can co-exist within a single territory.

Recycling: The recovery of waste materials for conversion into new products, materials, or substances, whether at origin or for other purposes. This includes the reconditioning of organic materials but does not include energy recovery or reconditioning into materials for use as fuel or for landfill operations[7].

Reduction: Increasing the efficiency of the manufacture or use of products by consuming fewer natural resources and materials[7].

Reuse of a product that is still in good condition and fulfills its original function (and is not waste) for the same purpose for which it was designed[7].

Revalorization: Some materials are derived from the reuse of waste, by-products, and co-products, such as cellulose wadding, recycled textiles, pallet wood, cardboard, etc. These materials are part of a circular economy[8].

Shelter: The term shelter is used to refer to both the basic definition of shelter— a 'habitable covered space providing a secure and healthy environment with privacy and dignity for those residing in the dwelling'— and the process through which this habitable space evolves from emergency shelter to durable solutions, which may take years[9].

Sustainable construction: The term sustainable can be understood in different ways in the construction sector. In this document, we propose to bring a perspective of integral sustainability in the sense of sustainable development, which considers social and cultural aspects as well as environmental, economic, and governance aspects. The VerSus project (Lessons from vernacular heritage to sustainable architecture) integrates these aspects into three main areas of sustainability[10]:

- **Environmental:** the capacity of human intervention to reduce and even avoid the adverse impacts of construction on the environment, which is very sensitive to changes. Human intervention integrates nature and

[1] République française (n.d.)
[2] European Parliament (2023)
[3] République française (n.d.)
[4] Association Sphère (2018)
[5] Thacker et al (2018)
[6] République française (n.d.)
[7] EIB (2020)
[8] République française (n.d.)
[9] Inter-Agency Standing Committee (2015)
[10] Guillaud et al. (2014)

bioclimatic features, controls the production of pollution and waste, preserves health, and prevents natural hazards impacts.

- **Socio-cultural:** the sense of belonging, identity, and personal and community development. This scope tries to gather all social and cultural positive impacts observed on vernacular heritage. It concerns the protection of cultural landscapes, the transmission of construction cultures, the capacity to stimulate creativity, the recognition of cultural values (tangible and intangible), and the reinforcement of social cohesion.

- **Socio-economic:** the capacity to reduce the efforts invested during the construction process, the building performance, the maintenance of buildings, and all the impacts that contribute to improving living conditions. Here, the concept of effort and work replaces the idea of cost, especially in contexts where no capital-intensive systems were implemented. Vernacular solutions encourage autonomy and local activity, optimize construction efforts, extend the lifetime of the building, and save resources.

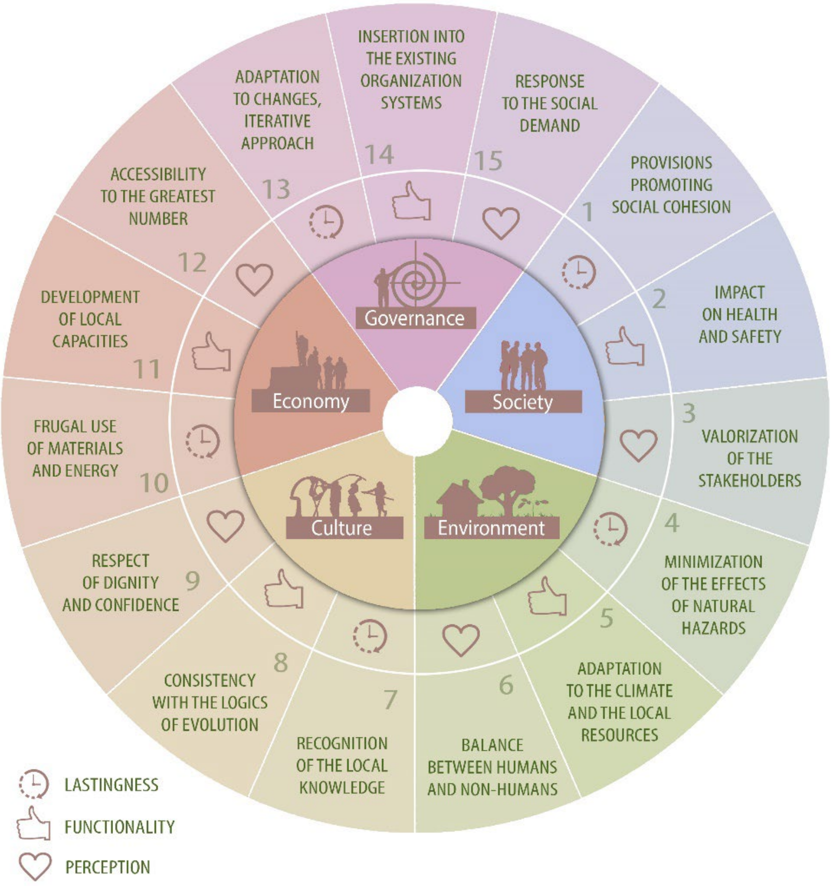
CONTEXTUALIZATION OF SHELTER PROJECTS AND SUSTAINABILITY

This document intends to help improve shelter projects' contextualization and sustainability. They can help to limit the management of industrial or toxic waste and the recycling or reuse of materials that are difficult for local people to use.

These guidelines are also a way of improving the cultural appropriation of dwellings or shelters, respect for the local and global environment, and promoting the climatic adaptation of buildings and maintenance by their inhabitants, who will have the knowledge, know-how, and means to undertake these tasks.

[1] Introduction: sustainability in a broad sense

[1.1] TOWARDS CONTEXTUAL APPROACHES IN SEARCH OF GLOBAL SUSTAINABILITY



Wheel for criteria for a sustainable architecture[11] ©CRAterre, Joffroy T. & Sánchez Muñoz N.

> **SUSTAINABLE MANAGEMENT OF CONSTRUCTION MATERIALS IN THE HUMANITARIAN SECTOR IN YEMEN**
>
> Sustainability cannot be understood in a partial way by looking only at one of the aspects of the wheel of sustainability principles.

Organizations such as CRAterre have been working for several years to identify construction dynamics in different contexts, including local building cultures (LBCs), to propose appropriate responses to today's major environmental, social, and economic challenges. The aim is to make it easier to identify the strengths and weaknesses of construction dynamics and LBCs and the opportunities they offer to promote them (in an adapted version if necessary) in projects to build, rebuild, rehabilitate, or improve housing or shelters.

It is important to consider that households and communities live in transforming environments due to factors such as climate change, urbanization processes, globalization, changing social attitudes where local practices are being challenged, and the security and humanitarian context.

> **↘ PEOPLE AT THE CENTER**
>
> Over the years, the people of Yemen have developed numerous strategies for preserving the environment, their living environment, and their livelihoods and for minimizing the impact of natural hazards in the places where they live.
>
> Some of these practices are parallel to housing or shelter and are not necessarily linked to producing materials or housing but are essential to its existence.
>
> All these practices show that people must be at the heart of the analysis of the situation and the decision-making process, as they are at the origin of solutions adapted to their context.

[11] This wheel is an adaptation of the VerSus project "Lessons from vernacular heritage for sustainable architecture" https://www.esg.pt/versus/pdf/versus_booklet.pdf widely used in the TCLA+ project in Haiti https://www.youtube.com/channel/UCjNV3BOfxauJDag7m_hfepg

[1.2] STRATEGIES TO MINIMISE THE EFFECTS OF NATURAL HAZARDS AND REDUCE THE ENVIRONMENTAL IMPACT OF CONSTRUCTION

►LOCAL BEST PRACTICES TO PROTECT THE ENVIRONMENT/MINIMISE THE EFFECTS OF NATURAL HAZARDS

- ➔ Frugal and sustainable use of local tangible and intangible resources and adaptation of buildings and lifestyles to climatic and cultural conditions. Historically, the people of Yemen have been able to make the most of their immediate environment without endangering it.
- ➔ In the *wadi*, the former practice of annually cleaning the water channel allowed removing overgrown vegetation. However, concrete constructions in flood-prone areas today act as barricades, so the floodwater and its rebounding effect push the flood toward more vulnerable buildings[12].
- ➔ Tree planting. Planting trees is an essential strategy against erosion and drought, as they help to bind water in the soil and prevent soil erosion with their roots. Some trees are also a source of building materials and food.
- ➔ Areas prone to flash floods are commonly known, and construction is avoided in these areas: camouflaged earth brick cities and villages are perched along the escarpments, contrasting with the verdant swathes of date palm groves and cultivated fields that line the valley floor. This pattern allows for the maximum use of arable land and protects against occasional flash floods[13].
- ➔ Steep, narrow streets also act as spillways during flash floods, with dry stonework to retain the hillside and break the force of the cascading water.
- ➔ Wood structures (joists or beams) are often covered with earth plasters, ensuring good fire resistance.

↘ DON'T FORGET STRATEGIES THAT COME WITH LOW IMPACT TECHNIQUES

There is a renewed interest in local, low-processed materials, short supply chains, local economic development, environmental impact, and sustainable development. These approaches are putting the spotlight back on construction techniques. But beyond construction, local populations in Yemen have developed strategies for the sustainable management of their environment.

↘ FOR MORE INFORMATION

SEVERAL DOCUMENTS, STANDARDS AND PUBLICATIONS DEAL WITH REDUCING THE ENVIRONMENTAL IMPACT OF CONSTRUCTION.

See bibliography

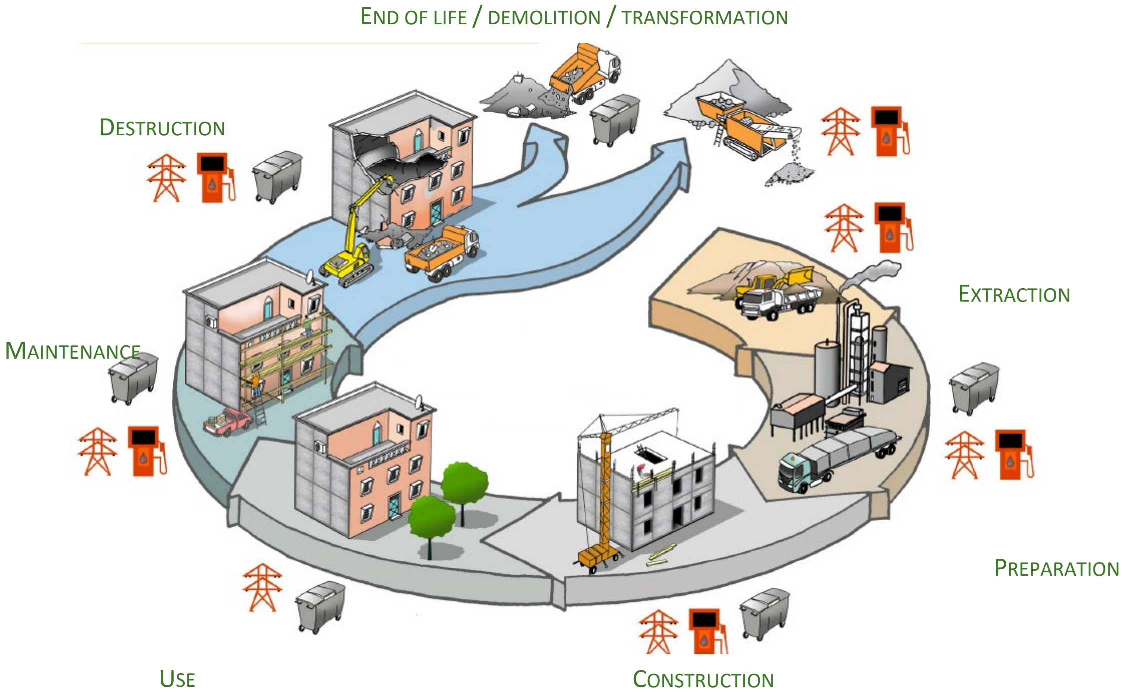
►STRATEGIC RECOMMENDATIONS: ENVIRONMENTAL LEVEL

- ➔ **Understand local environmental management systems** to contribute to the sustainability of projects.
- ➔ **Use local and minimally processed materials to avoid fuel costs and emissions** due to transport and over-consumption of energy during production and processing. Moreover, in remote areas that are difficult to access (due to insecurity or the poor state of the road network), local materials represent an undeniable competitive advantage over transport and site supply issues.
- ➔ **Use local, minimally-processed materials, which often offer good thermal comfort**, compared with concrete and sheet metal solutions, which offer poorer hygrothermal comfort. Local biobased and geologic materials are usually the source of energy savings during the construction phase, as they are better adapted to local climates.

[12] (Jerome, 2010)
[13] (Varanda, 1994), (Jerome, Chiari, & Borelli, 1999)

- ➔ **Design for efficient use of materials**[14]; refuse to build if not essential; reduce the use of resources; reuse materials; recycle materials; repair existing infrastructure, think about waste treatment, etc.;
- ➔ **Design for the climate with a bioclimatic approach** that takes into account orientation, site, insulation, thermal mass, ventilation, shading, and various issues related to the local climate[15];
- ➔ Design for energy efficiency[15].

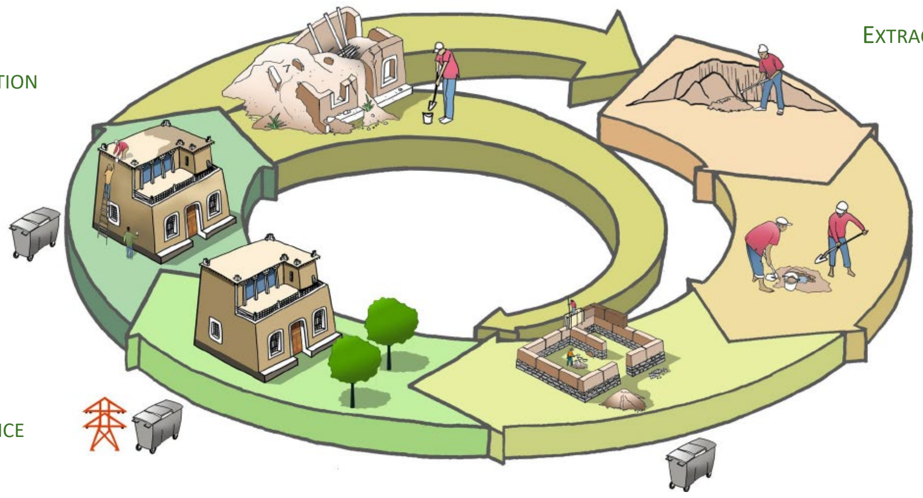
►ACCUMULATION OF WASTE AND OVER-CONSUMPTION OF ENERGY



Vicious circle of building with industrial and processed materials ©CRAterre - Sébastien Moriset & Arnaud Misse

[14] The "*Green recovery and reconstruction Training Toolkit*" (World Wildlife Fund, Inc. & American Red Cross, 2010) contains recommendations, some of which are in line with sustainable use of material resources.
[15] World Wildlife Fund, Inc. & American Red Cross, 2010

► ENERGY AND WASTE REDUCED TO THE MINIMUM



Virtuous circle of building with local, minimally processed materialS ©CRAterre - Sébastien Moriset & Arnaud Misse

[1.3] SOCIO-CULTURAL STRATEGIES THAT PROMOTE RESILIENCE

► SOCIO-CULTURAL STRATEGIES OF YEMENI POPULATIONS THAT PROMOTE RESILIENCE

Solidarity mechanisms

➔ The Yemeni people have created a unique architecture based on their deep cultural roots. In small settlements, the principle of mutual aid is inherent to the community. All its members are bound to participate in any aspect of public welfare, from constructing or repairing terraces to the erection of a school, mosque, or other community facilities.

Mutual support in construction/access to housing

➔ At a more personal level, mutual aid is extended to the construction of individual houses or by offering assistance to those afflicted by disaster or misfortune. It partly explains why, in the past, even in the very low cash economy level of pre-revolutionary Yemen, deep poverty was virtually non-existent[16].

Building processes as an integral part of a community

➔ Anonymous master builders and workers formed an integral part of the community. They used only locally available building materials to fuse form and function in their creations. An elementary but effective organization for

CAUTION

The practices presented below are not exhaustive, represent only a sample of those that exist, and some deserve to be better documented. They are constantly evolving and need to be analyzed at the local site level.

↘ MUTUAL AID SYSTEMS

Mutual aid systems are known and practiced historically by the people of Yemen, including in construction, where help from mutuals and neighbors also exists. Building goes beyond the technical and becomes a social and cultural act.

[16] (Varanda, 1994)

construction existed. This construction industry model had many compelling merits, which survived and remained unchanged over the centuries. Foremost was the application of technology utilizing only available materials that could be transported easily to the site. Designs were to meet the environment's needs, never to violate it[17].

Self-reliance in building process

➔ The fact that the used methods of construction and concepts of design are part of the traditional discipline, and mastered by the local population, means that this population can run the process of design and construction self-sufficiently and without having to rely on material or technical aid from other sources[18].

Mutual support in construction/access to housing

➔ The farmer is also a builder. Farmers build their houses with the help of their families and neighbors. Outside help was called in for technical details such as wood or plaster carving and, more recently, plumbing and electric wiring[19].

↘ LOW-IMPACT CONSTRUCTION SKILLS

In Yemen, building industries with biobased (timber, thatch…) and geologic materials (earth, stone...) have existed for some time. Similarly, communities are often able to construct quality buildings using local techniques: in general, skills exist to guarantee a proper execution of works, providing good supervision and design of construction, as well as anticipated maintenance plans for low impact building.

►STRATEGIC RECOMMENDATIONS: SOCIO-CULTURAL LEVEL

➔ Facilitate local community involvement;

➔ Take cultural acceptance into consideration (local acceptance, community participation, and analysis of existing practices; construction techniques and knowledge sharing);

➔ Promote approaches that encourage the maintenance of mutual solidarity systems where they exist, given that they contribute to the weaving of strong social ties. However, we must consider that today's monetarization of society often favors the paid exchange of services over solidarity.

[1.4] SUPPORTING THE LOCAL ECONOMY

►STRATEGIC RECOMMENDATIONS: ECONOMIC LEVEL

➔ **Spend as much of the funds as possible at local level** to promote better living conditions for the target populations;

➔ **Inject resources into the local economy** so that the impact is felt not only by households whose housing has been improved but also by the entire population through the local construction sector;

➔ To address the issue of **creating and sustaining a market** capable of providing work for trained technicians and workers and retaining them in construction companies. It is, therefore, important to find mechanisms for sustaining this skilled workforce after their employment in the projects.

↘ CIRCULAR ECONOMY

Technical solutions favoring the circular economy and short circuits enable the bulk of project funds to be injected into local economies, thus promoting the recovery of populations and constituting an important step towards situations of material stability and improved living conditions in the medium and long term.

[17] (Kulkarni, 1983)
[18] (Damluji, 1992)
[19] (Varanda, 1994)

- ➔ Promote owner-drive approaches by providing IDPs with cash and/or materials in kind to build their houses. They may undertake the construction work by themselves, by employing family labor, local laborers, or by using a combination of these options. This approach is more empowering and dignified for households, and it is also often faster and cheaper[20].
- ➔ Increase self-reliance, dignity, and well-being by incorporating flexibility into the shelter design for livelihood opportunities and the potential for IDPs to adapt the shelter[21].

[1.5] TECHNICAL ASPECTS: SITE, DESIGN, IMPLEMENTATION, AND MAINTENANCE

►STRATEGIC RECOMMENDATIONS: TECHNICAL LEVEL

Choice of building site

- ➔ **Choose sites that do not involve particular risks** (flooding, strong winds, landslides, etc.) for safety reasons and also to reduce the environmental impact of construction, as limiting damage to housing limits the number of materials needed for shelter;
- ➔ Building in areas where communities will be able to establish themselves in the long term thanks to the **security of land tenure** is an important strategy for the sustainability of construction;
- ➔ Locate new buildings as close as possible to existing **basic services**. Be careful not to saturate them (health, education, water, etc.) or create these basic services;
- ➔ Locate camps **close to economic activity opportunities** to enable displaced people to access income.

↘ BUILDING SITE

The location of a building is essential to its sustainability. In the context of population displacement, the right choice of site also makes it possible to use buildings over the long term when conditions do not allow displaced people to return to their places of origin

Urban planning and site design

- ➔ **Check the general master plan** for the region, town or village, if one exists, to ensure compliance with its requirements;
- ➔ Take into consideration the density of houses, the orientation of houses on plots, and the layout of outdoor and indoor spaces in relation to socio-cultural requirements;
- ➔ Plan the location of infrastructure (pipes and other services), roads, and access to infrastructure;
- ➔ Plan the planting of suitable vegetation.

↘ SITE PLANNING

Once the construction site has been selected, site planning issues are essential to consider, especially for camps or sites created ex-novo by urban planners or architects.

UNEP & SKAT, 2007
After the tsunami. Sustainable building guidelines for South-East Asia

Design

[20] Koclejda et al (2022)
[21] Koclejda et al (2022)

- Use **simple, hazard-resistant house designs;**
- Emphasize the importance of the **replicability of shelter/housing projects**, bringing construction costs down to levels affordable to low-income households and making technical and spatial choices that take into account local know-how and construction knowledge and needs to make it possible to build projects on a larger digital scale within the limits of existing budgetary resources, but also through self-build strategies;
- Choose **construction models that residents can maintain** thanks to their know-how and the availability of the necessary materials and tools;
- **Consider the entire life cycle**: construction, maintenance, reuse, demolition, and recycling;
- **Consider flexible designs**, easy to adapt to families' changing needs (evolution, extension, etc.);
- Use designs and materials that enable easy **recycling and/or reuse**;
- Integrate **users' needs and aspirations** and take cultural factors into account.

↘ DESIGN AND TECHNIQUES

Techniques used in shelter and housing projects developed by humanitarian organizations have a major influence on the habitat built around them by households.

Techniques that are difficult for communities to appropriate should take a back seat to those that draw on local knowledge and know-how.

Construction

- **Identify needs in terms of supervision, training, and communication.**
- Develop and insist on the **pedagogical dimensions** of projects. **Proceed iteratively**, particularly when building with innovative techniques or those not commonly used in the humanitarian response to shelters or housing. Carry out **pilot and school constructions** to promote best practices and train the companies and workers in charge of the sites.
- **Upgrade the skills of local craftsmen and craftswomen** as part of the projects to achieve better results and also create the foundations for better overall building quality in a given area over the long term ;
- **Supervise the construction phase** to avoid unpleasant surprises once the buildings have been completed;
- Ensure that the materials and tools required for the chosen technique are **available**;
- **Take seasonal constraints into account** to assess the availability of inhabitants and materials;
- Analyze the **social organization of the act of build**ing, its short- and long-term efficiency, and its impact on community cohesion, and value traditional mutual aid systems;
- Promote local employment for a better impact on the community.

↘ QUALITY OF CONSTRUCTION

The quality of the workmanship ensures that buildings last longer and are safer in the event of a disaster.

In Yemen, construction is sometimes an activity developed by households, but it is generally carried out by masons from the informal sector who have learned on-the-job. These craftsmen and craftwomen sometimes have the knowledge and know-how to produce quality constructions, but this is not always the case.

Maintenance[22]

[22] Source principale : programme Africap2016. http://www.aimf.asso.fr/africap2016/

➔ **Raise residents' awareness of the importance of regular maintenance** for longer building life and reduced risk during a disaster.

➔ Ensure **regular inspection** to know the condition of the building, and to identify or anticipate possible deterioration.

➔ **Adapt uses to perpetuate the building** (for example, find new families for buildings no longer used by their **original occupants).**

➔ In the event of structural insecurity, **secure buildings** (temporary reinforcement of structures, prevention of damage, or limitation of access) for the well-being of users pending rehabilitation operations.

➔ **Care and maintenance of sensitive building elements: effective drainage around the building, foundation-wall-roof anchoring, bracing of the entire** structure, underpinning to limit water damage, protection of wooden post bases, protection of walls (plastering, pointing), waterproof roof and operational roof drainage system, etc.

↘ MAINTENANCE IS ESSENTIAL

Maintenance is essential to the life of a building. Good maintenance guarantees a longer useful life and reduces environmental impact.

[1.6] GOVERNANCE ASPECTS

► STRATEGIC RECOMMENDATIONS: GOVERNANCE LEVEL

➔ **Work in concert with the various stakeholders** present in a territory;

➔ Adapt **to local organizational systems**;

➔ Respect the **culture of dialogue and facilitate the expression and decision-making of the different groups of people** living in a community (women, children, men, minorities, the elderly, disabled people, displaced people, etc.);

➔ **Act iteratively**. Whenever possible, build a prototype first, whose participative evaluation will enable us to propose the necessary corrections and adjustments.

↘ GOOD GOVERNANCE

The *Labo de l'Economie Sociale et Solidaire* defines governance as "the set of rules and methods organizing reflection, decision-making and control of the application of decisions within a social body. Governance often evokes "good government" and therefore participatory and inclusive practices. Governance refers to the economic, social, and political spheres, etc".

https://www.lelabo-ess.org/gouvernance#:~:text=La%20gouvernance%20est%20l'ensemble,des%20pratiques%20participatives%20et%20inclusives

[2] Questions to ask when choosing building materials

[2.1] THE MAIN BUILDING MATERIALS IN YEMEN

Except for vegetal fibers used in the Tihama region, the traditional building materials in Yemen are raw or fired earth and stone for the wall structure; wood and earth for floors and roof structure; earth, lime, and gypsum plaster for the rendering of exteriors and interiors; wood, alabaster and colored glass for wall openings, and iron or brass for fittings. The used construction material is available in situ. Thus, earth construction is predominant in alluvial deposit areas and stone masonry on rocky slopes. Varied building solutions frequently occur in the same settlement or a single building[23]. Cement construction is now the most important construction material in the country.

MATERIAL CARD

The description of materials is presented in the tables called "Material card", which provide practical information: material, extraction, use/techniques, transport, lifespan, cost, know-how, informal/formal economy, urban/rural, large-scale potential, seasonality.

MATERIAL CARD	
Material	
Extraction	
Application/techniques	
Transport	
Service life	
Cost	
Know-how	
Informal/formal economy	
Urban/rural	
Large-scale potential	
Seasonality	

[23] (Varanda, 1994)

[2.2] SELF-QUESTIONNAIRE TO HELP IN THE CHOICE OF BUILDING MATERIALS

A table has been created to help self-ask the right questions when choosing building materials. The below table, "Self-questionnaire for material selection," covers issues relating to the extraction, production, transport, construction, use, and end-of-life of a material.

A critical analysis of the material resources needed for construction in a humanitarian operation, whether in terms of extraction, production, import, etc., is essential to understanding the impact of construction on the environment and society. Similarly, it is essential to analyze materials and techniques in terms of their constructive qualities, cost, lifespan, maintenance requirements, availability on the market, aesthetics, economic impact on communities, and the ecological footprint of a building with a given material.

↘ CASE-BY-CASE TABLE

Rather than a material-by-material basis, the proposal is to fill out the table on **a case-by-case** basis when setting up a shelter or housing project, so it can best decided on the appropriateness of using a specific material in a particular context. To complete this table, an analysis of impacts and advantages is carried out by building material in the following chapter.

SELF-QUESTIONNAIRE FOR MATERIAL SELECTION [24]

Questions	*Yes*	*No*	*Depends on context*
Extraction/production/transport			
Is the material produced locally?			
Are all or part of the material imported?			
Is it economical, abundantly available and/or easily renewable?			
Is it produced in a remote factory?			
Does production require special machinery and equipment?			
Can the material be produced on-site at low cost?			
Does production require much energy?			
Does production generate waste/pollution or other environmental problems?			
Is there an acceptable alternative material that eliminates any production problems? If yes, which one?			
Was production carried out under an environmental management plan?			
Was production carried out in compliance with decent working conditions?			
Are transport costs high?			

[24] Some questions are suggested by Wyss (2005). This table is to be adapted to each context and answered by organizations in the design phase of construction programs.

Construction/use			
Are the material and architectural design adapted to the climatic context?			
Are the material and architectural design sufficiently safe in the event of natural hazards in the area?			
Does the use require a lot of energy?			
Is there an acceptable alternative material that eliminates any problems during use? If yes, which one?			
Can the local population use and understand the material and technique without the need for specialized skill and experience?			
Can the material and architectural design be easily appropriated by a population that did not have access to assistance from the humanitarian sector?			
Is the material socially acceptable / is it associated with dignified housing?			
Can repair and maintenance be resolved locally?			
End of life			
Does end-of-life generate waste and pollution?			
Is the material recyclable?			
Is the material reusable?			

[3] Sustainable management of building materials in Yemen[25]

This chapter focuses on the impacts, advantages, and recommendations for the sustainable management of building materials most used in Yemen at different levels, environmental, socio-economic, cultural, etc., and for improving the management of materials from the environment point of view.

Recommendations are given for improving materials management regarding extraction, good socio-economic practices, design, construction, service life extension, reuse, and recycling.

DON'T REDUCE A CONSTRUCTION TO A SINGLE MATERIAL

It is not relevant to carry out only partial analyses that reduce the complexity of a construction to a given material, as constructions are always made with a combination of materials.

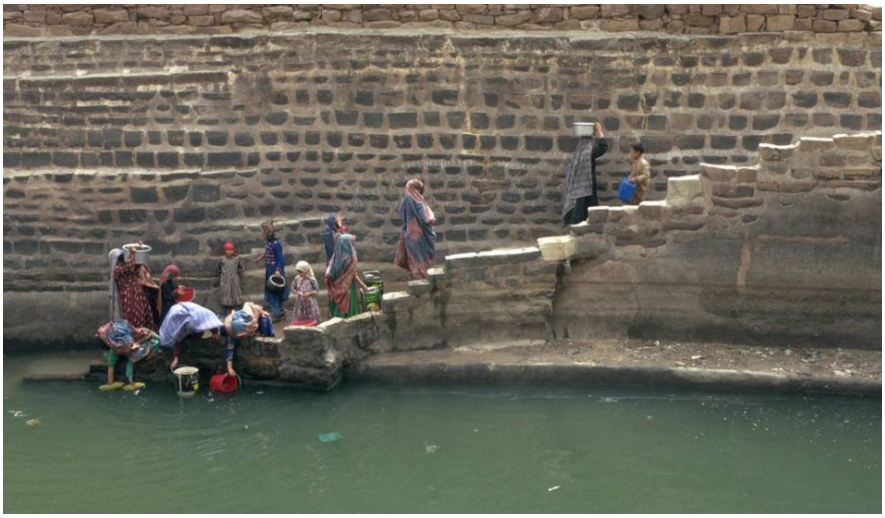
Solution of shelters upgrade where each material finds its place in the right part of the building (stone in the foundation and base, wattle and daub or earth bricks in the walls, thatch roofing), adding value and durability to it. © UNHCR, John Wain.

↘ BUILDING MATERIAL SELECTION

Intelligent, frugal combinations of low-processed local materials and industrial materials should be considered. To achieve this, materials need to be selected based on their availability, their contribution to the durability of structures, their technical and financial accessibility, their potential for reuse or recycling, and the environmental impact of their use for housing the greatest number of people.

[25] Main sources:
Detailed Shelter Response Profile for Yemen: Local Building Cultures for sustainable and resilient habitats (Cauderay, 2022)
Building Material Selection and Use An Environmental Guide 2nd Edition (Hettiarachchi, M., & al., 2021)
Green recovery and reconstruction Training Toolkit (World Wildlife Fund, Inc. & American Red Cross, 2010)
After the tsunami. Sustainable building guidelines for South-East Asia (UNEP & SKAT, 2007)

1 WATER



Yemeni Women getting water from a cistern © tbroughel, Flickr

IMPACTS AND DISADVANTAGES

Water scarcity

- → Rainwater harvesting systems are used as an alternative to groundwater and these include terraces, check dams, ponds, and spate irrigation. Spate irrigation is practiced in Yemen along wadi courses and in the plains. It has been practised for thousands of years. Besides providing irrigation, spates recharge shallow aquifers and filling cattle ponds. Rainwater amount and frequency has recently become erratic in Yemen because of climate change. Last year Yemen experienced a severe drought and flooding within the same season, which goes to illustrate the severity of climate change[26].
- → The traditional system for distributing drinking water and general use relied on reservoirs, wells, and dams. However, surface water now generally runs to waste. The construction and maintenance of storage and irrigation works are part of a forgotten craft.
- → The country is rapidly approaching an era where only renewable water resources (rain, surface and shallow groundwater) will be available[27]. Access to safe water and sanitation remains a high priority in Yemen, which has the lowest water availability per capita globally, coupled with increased water scarcity and WASH-related diseases that have reached critical levels.
- → Water sources do not necessarily coincide with the main concentrations of the population, requiring increasing supply for domestic and agricultural use[28].
- → The scarcity of water in the period preceding the rainy seasons makes it difficult to build in certain areas of the country with techniques that require much water for their production or implementation (for example, cement blocks and mortar, concrete, or adobe masonry).
- → Water collection is a burden that falls on women and girls, and 39% of households report more than 30 minutes of travel time[29].

[26] "Being the Change in Yemen: Improving Integrated Water Resources Management for Food Security", Dr Hussein Gadain, FAO, https://reliefweb.int/report/yemen/being-change-yemen-improving-integrated-water-resources-management-food-security-enar
[27] (UNDP,2022)
[28] (Damluji, 1992)
[29] (OCHA, 2021)

ADVANTAGES

- → N/A.

GOOD PRACTICES

Water collection

- → Interview the local population to find out what practices exist to access water, sometimes simpler than those introduced by humanitarian actors.

Management

- → It is recommended to choose different solutions to access water (for construction and life in human settlements), depending on the context: connection to the public water network, drilling, traditional well, boreholes, spring development with a gravity system, rainwater harvesting, or water transport by tanker truck. These systems should be chosen to supply the required water for construction and should be as close as possible to the construction site, ideally serving as a source of drinking water for the local population. The options are diverse: connect to the running water network if it exists, make a traditional well with a pump system where the water is closer to the surface, or drill a borehole where the water table would be deeper.
- → There is a need to consider the frequency and maintenance costs generated by each of the water access systems, in addition to the cost of purchasing the equipment, the human context, the hardness of the soil, the depth to reach the water table, and the availability of water throughout the year or not, as some of these systems may be difficult to implement.
- → If water is scarce, when building, it's best to use water not fit for human consumption to preserve drinking water.
- → If possible, build during the period when water is widely available.
- → Minimize the use of water in areas where it is scarce by choosing construction techniques such as those used by the country's nomadic populations based on lightweight materials of plant origin.
- → Informal quarries (earth or stone) help to provide the water required for building during the dry season.

Construction

- → Water containing salt should never be used to mix concrete or cement mortar, nor to produce adobes or plasters, as salt reduces the strength of concrete and adobes and corrodes steel reinforcement in concrete.
- → Be careful with introducing drinking water and sewage pipes to the dwellings in which wells and water pipes organized water access and drainage for centuries. It can generate a permanent risk for humidity in the ground and cause leaning walls, cracks, and the eventual destruction of buildings[30].

[30] (Varanda, 2012)

2 RAW EARTH

Sun dried earth bricks in Aden © CRAterre

Transitional shelter: Wattle and daub, Harad, Coastal Region © CCCM

Earth brick building, Shabwa Gov., Almarkha Alsofla Dist.,2022 © YFCA

Cob walls, Al-Jawf Gov, Almtoon district, 2021 © YFCA

Transitional shelter: earth Blocks, Sa'ada and Harad © CCCM

Shibam, maintenance of an earthen tower house © Tom Leiermann

Cob wall mortar preparation and earth plaster © YFCA

IMPACTS AND DISADVANTAGES

Environmental degradation

- The extraction of materials from informal quarries remains an environmental problem, as they are often operated without authorization, without a management plan, with little control over extraction sites, or with uncovered quarries.

Management issues

- There is a possible lack of availability nearby if many constructions are under building process simultaneously.
- When earth brick houses are reconstructed, cement plaster is applied to the bases to protect the basement. Unfortunately, the incompatibility of the 2 materials (cement tends to trap moisture) accelerates the structure's deterioration and collapse.

Socio-economic disadvantages

- Agricultural land use is a concern (the land to be built on has to be taken from the non-arable layer).
- Extraction can leave large pits with health risks (falls, mosquito proliferation with stagnant water, etc.).
- Earth construction is getting synonymous with poverty. Around urban areas, people no longer maintain their houses and leave them abandoned.

ADVANTAGES

Environmental advantages

- Earth is a material that can be recycled for life (as long as it is not stabilized with cement or lime).

- → Earth is available in abundance in almost all parts of the country, and it is manually processed to build with wattle and daub, adobe, cob, or as a mortar for stone masonry or plaster. It can help build sustainable housing both quantitatively and qualitatively.
- → Earth promotes independence from heavy, polluting industries. Earth creates no pollution or waste. The carbon footprint of raw-earth buildings is virtually zero, as the processing of the materials uses little or no fossil energy.
- → Extraction and processing of local raw materials do not require expensive tools.
- → Raw earth does not require transportation.
- → Soil extraction can be carried out in such a way as to favor the development of channels, retention basins, dikes, and embankments (access to water).
- → Water is scarce in some areas during the dry season, and the ponds in the quarries provide water for domestic animals.

Health and comfort benefits

- → Earth (soil) is a healthy material with no toxic elements (unless contaminated by waste).
- → A wide variety of solutions enable a high comfort level when the site's bioclimatic conditions are taken into account.
- → Raw earth provides an effective moisture regulator in interior spaces, increasing comfort.

Socio-economic advantages

- → Row earth is one of the primary building materials used for millennia in Yemen (wattle and daub, adobe, cob, mortar, floors, and plasters). These building cultures result from knowledge, know-how, and collective intelligence improved over centuries through trials, failures, and successes.
- → Earth-building practices are alive mainly in rural areas. However, in some regions, earth buildings also exist in urban areas. Skilled laborers are available in many places, and inhabitants know how to maintain and repair their houses.
- → Local raw earth-building cultures prevent family impoverishment by benefiting the local economy and residents' independence from costly industrial materials they cannot produce or buy. And they promote the sharing and equitable distribution of wealth, avoiding the enrichment of a minority to the detriment of the majority.
- → Soil is an abundant material, often free or at lower cost, and available close to most construction sites, saving on transportation. The maintenance can be done with these local resources by the family and is affordable.
- → The cost of an earth house is lower than a concrete construction, which generally runs up to 30 % higher due to steel reinforcing[31].
- → Earth building stimulates local production, processing, and trade. The production of certain materials is labor-intensive. Quarries (formal or informal) employ many households and are a source of low-cost materials.

GOOD PRACTICES

Extraction and management

- → When projects have a large scale, it is necessary to properly manage quarries for extracting earth, sand, or stone to avoid damaging the environment.
- → The earth for earth buildings - whether in wattle and daub, cob walls, or earth brick walls - is usually produced at the construction site, but there are a few places where earth bricks are manufactured and sold to other construction sites.
- → Extract soil where it cannot cause any danger or impact on the environment, and manage the useful life of quarries and their end-of-life.
- → Extracted soil can be used to create canals, retention basins, embankments, etc.
- → Quality of earth: regional knowledge is helpful to know the best earth. In some places, the topsoil is considered poor quality because it contains salts from agricultural fertilizers. In Hadramawt, two types of earth are considered: "hot" and "cool". While the "hot" earth is full of salts, the "cool" earth does not contain salts. Masons collect suitable earth from around the date palms in some other regions after the floods.
- → Socio-economic good practices
- → Support local livelihoods/industries through the use of low-processed local materials.

Design and construction

[31] (Mehta, 2007)

- → Avoid building earth walls in flood-prone areas. Areas prone to flash floods are commonly known, and construction is avoided.
- → Design, build and maintain correctly to ensure long-term sustainability.
- → Use local knowledge and building cultures (for wattle and daub, this has to be considered very linked to timber resource availability to avoid deforestation).
- → Doorsteps to prevent water from entering houses are a common practice.
- → Drainage is an important strategy to keep wall bases free of moisture and direct contact with water.

Lifespan extension

- → If well-designed, built with know-how, and maintained by the inhabitants, the lifespan can be very long: when talking about the age of the oldest house, local master masons' answers varied from 80 to 500 years[32].
- → Water must be kept away from the base of the walls to improve earth-constructions lifespan. This can be done in two main ways: by building a foundation of non-water-sensitive materials, if possible, with a moisture barrier against rising water or by building houses on earthen platforms with slopes that help drain rainwater away from the base of the walls. The sides of buildings exposed to driving rain should be protected with plasters compatible with the walls (avoid cement as much as possible).
- → Improve the resistance of walls with bases made of inert materials (stone, cement blocks, and anti-dump plastic membranes or similar between base and wall).
- → In many cases, earth walls have no inert base, and sometimes inhabitants add rough stone or earth masses, creating a sort of masonry bench or at least a slope to protect the base of walls exposed to rainwater. This sacrificial mass must be maintained to prevent the base of the wall from eroding.
- → Earth plaster is the first line of defense for protecting earth brick walls, which is the load-bearing structure. Earth plaster acts as a sacrificial coating[33].
- → Improve the strength of the surface by applying an earth plaster every year with stabilizers commonly used by communities. Maintenance of earth brick buildings consists of replastering the exterior walls, but only once the earth bricks begin to show. Depending on the rains, decades can pass before the need to replaster. In some places, lime plaster or limewash appears to be the best protection for roofs and parapets. Cracks are treated with whitewash. When earth plaster is the only protection, replastering may be performed after 10 years or after each rainy season to prevent tracking earth from the roofs (terraces) into the houses.
- → The increased use of cement to protect vulnerable parts of earthen buildings is a physical risk of long-term damage. Some of these interventions are a severe risk for earthen structures.

Reuse and recycling

- → A common practice has been to pull down a whole building that has been damaged beyond repair and rebuild it in the same position and on the same principle of design. It is demolished, and the earth, stone, and timber are re-used in the new building. Houses are reconstructed to the same layout and height[34]. The positions of windows and ventilation openings are noted beforehand so they can be distributed in an identical pattern in the new building. Sometimes old doors and windows are refitted in their old positions in reconstructed buildings.
- → Earth is a lifelong recyclable material without losing its cohesive characteristics (provided it's not stabilized with cement or lime).

[32] (Jerome, Chiari, & Borelli, 1999) and (Damluji, 1992)
[33] (Jerome, 2010)
[34] Ibid

3 FIRED BRICKS

Fired brick building in Sana'a CC Rod Waddington

AlHudaidah Gov., AlKhokha Dist. YFCA

IMPACTS AND DISADVANTAGES

Environmental degradation

→ Fired brick production requires firing. The firing process (especially on a small scale) leads to air pollution and deforestation phenomena.

→ The extraction of materials from informal quarries remains an environmental problem, as they are often operated without authorization, without a management plan, with little control over extraction sites, with uncovered quarries, etc.

Management issues

- → Possible lack of availability nearby due to small-scale production.
- → The quality of fired bricks is uneven due to a lack of fuel and poor firing.

Socio-economic disadvantages

- → Due to only a few remaining fired brick plants, transport is a big issue.
- → Use of agricultural land is a concern (the land to be built on has to be taken from the non-arable layer).
- → Nowadays, there is a limited amount of fired brick available for construction. The small quantities of the traditional fired brick which remain around Sana'a City may be sufficient for restoration work but not for large-scale construction[35].
- → Extraction can leave large pits that can present health risks (falls, mosquito proliferation with stagnant water...).
- → Due to fired brick shortage, they are more expensive than cement blocks.

ADVANTAGES

Socio-economic advantages

- → It can be used in mixed techniques building; with raw earth bricks or with stone masonry
- → The structures are safe, secure and resistant to climate risks, floods, heavy rains, strong winds, fires, termites, and erosion.
- → Know-how still exists in some urban and rural areas.
- → The structure allows expansion, such as upgrading to multi-floors.
- → Walls of stone or fair-faced fired brickwork do not need an external finish and do not require maintenance.

GOOD PRACTICES

Extraction and management

- → Use only in areas where fired bricks are produced in good condition for the labors and with low-environmental impacts such as deforestation. Minimize the use of fired brick produced by small-scale ovens.

Design and construction

- → Use local knowledge and building cultures in mixing this material with raw earth blocks or cement blocks.
- → Use good storage and loading practices when transporting.
- → Design, build and maintain correctly to ensure long-term durability.
- → Use local earth mortars or lime mortars wherever possible when earth is unsuitable.

Lifespan extension

- → Existing practices and technical details facilitate the maintenance. For example, in Sana'a, wood ring beams allow sections of earth bricks wall below to be renewed with less danger of the wall above cracking[36].

Potential alternatives to cement

- → When the production of fired brick is well-managed (proper quarries management, fuel sources management, and quality, kiln quality and size), its overall environmental impact is lower than cement. Moreover, fired brick production can be improved by using specific kilns. However, increasing the use of local fired bricks impact local wood resources directly, which are already depleted. It must be accompanied by specific programs for managing fired bricks production and forest preservation.

[35] (Varanda, 2012)
[36] (Matthews, 1985)

4 STONES AND OTHER MINERAL MATERIALS

Stone masonry, Aldhalea Gov., Damt District, 2022 © - YFCA

Rubble masonry, Ibb – ©Alezz/ Shelter cluster

Lime production CC Motohakone

Transitional shelter, stone masonry, Sa'ada, and Amran © CCCM

IMPACTS AND DISADVANTAGES

Environmental degradation

→ Unplanned rock extraction can cause landslides and hydrogeological impacts.

→ Extraction of materials from informal quarries remains an environmental problem, as they are often operated without authorization, without a management plan, with little control over extraction sites, with unplugged quarries, etc.

→ Lime and gypsum production requires firing. The firing process (especially on a small scale) leads to air pollution and deforestation phenomena.

Socio-economic disadvantages

→ The high cost of stone masonry can be a barrier. This technique requires hiring skilled laborers.

→ Rock extraction from quarries sometimes involves blasting. Without planning or protection, blasting leads to occupational hazards.

→ Quarries cause noise, dust, pollution, habitat destruction, and vibration if not properly managed.

→ Transporting material can affect rural roads.

→ Due to the shortage of skilled masons and generally low productivity, most major projects have eliminated stone as a load-bearing material. However, it remains popular as a facing to reinforced concrete frame structures. The exterior walls of high-income housing are often constructed in stone masonry, and local masons execute this work with great skill. The architectural appearance of houses is most appealing, but the labour and material cost is high, and only wealthy clients can afford mass stone masonry[37].

→ Extraction can leave pits that can present health risks (falls, presence of mosquitoes with stagnant water, etc.).

ADVANTAGES

Environmental advantages

→ The country's geology offers a great variety of stones for construction: basalt, volcanic stone, black or grey lava, sandstone, tuffite, and limestone.

→ Stone (where it exists) is an abundant material, often free or at lower cost, and available close to most building sites, saving on transport.

→ Stone is endlessly recyclable and can be sourced from many parts of the country in sufficient quantity and quality to build sustainable housing.

→ Local stones require no transport and create no pollution or waste.

→ The carbon footprint of buildings constructed with local materials is virtually zero, as the processing of the materials uses little or no fossil energy in the country. Stones are available in different areas of the country, their processing is manual, and they are reusable mineral resources.

→ Water is scarce in some areas during the dry season, and the ponds in quarries provide water for domestic animals.

Health and comfort benefits

→ The structures are safe, secure and resistant to climate risks, floods, heavy rains, strong winds, fires, termites, and erosion.

→ A wide variety of solutions enable a high comfort level when the site's bioclimatic conditions are taken into account.

→ Lime and gypsum plasters were commonly used in the Tihama region and in the mountains to render interiors and exteriors of walls. Know-how exists regionally.

→ Stone masonry provides an effective temperature regulator (thermal inertia) in interior spaces, increasing comfort.

Building advantages

→ Strong masonry know-how exists; skilled masons are available in urban and rural areas. Moreover, the technique is proven, and people have confidence in its capacities.

→ The load structure in stone masonry allows expansion, such as upgrading to multi-floors.

→ Walls of stone do not need an external finish and do not require maintenance.

Socio-economic advantages

→ The production of certain mineral materials is labor-intensive. Quarries (formal or informal) employ many households (providing income) and are a source of low-cost materials.

→ Local stone-building cultures prevent family impoverishment by benefiting the local economy and residents' independence from costly industrial materials they cannot produce or buy. And they promote the sharing and equitable distribution of wealth, avoiding the enrichment of a minority to the detriment of the majority.

→ This building material can encourage local self-sufficiency by reducing economic dependence on the materials market, thus avoiding indebtedness and promoting local production, processing, and trade.

→ Local materials promote independence from heavy, polluting industries.

GOOD PRACTICES

Extraction and management

→ The material is available locally. Take advantage of it rather than carrying it from far.

→ When projects are on a large scale, it is necessary to properly manage quarries for extracting earth, sand, or stone to avoid damaging the environment.

[37] (Derek & Evin, 1984)

- → Use only in areas where the stone can be extracted without causing danger or environmental impact.
- → Minimize the use of lime from small-scale producers using wood-fired kilns in deforested areas.

Design and construction

- → Use local knowledge and building cultures. Stone is particularly relevant in foundations and plinths in areas where it is available. This material used in the right place helps to protect earthen wall elevations.
- → Use good storage and loading practices when transporting.
- → Design, build and maintain correctly to ensure long-term durability.
- → Use local lime mortars wherever possible when earth is not suitable.
- → The fine and square tailoring or cutting off only the exterior face of the stones, and the complete lack of tie-beam constructions, caused a general lack of bonding. The 20th century introduced the square cut-face stone technique with conically cutting away the rear side, which caused severe problems due to wind and water erosion, and foremost with earthquakes[38].

Lifespan extension

- → Existing practices and technical details facilitate the maintenance. For example, in Sana'a, wood ring beams allow sections of the stone wall below to be renewed with less danger of the wall above cracking[39].

Potential alternatives to cement

- → As for lime, its overall environmental impact is much lower than that of cement. Moreover, lime production can be improved by using specific kilns and controlling the amount of water used after burning. However, increasing the use of local directly impact local wood resources, which are already depleted. It must be accompanied by specific programs for managing lime production and forest preservation.

[38] (Nienhuys, 1983)
[39] (Matthews, 1985)

5 SAND AND GRAVEL

IMPACTS AND DISADVANTAGES

Environmental degradation

→ Infrastructural development and construction built out of concrete result in heavy dependence on natural resources, including the basic components of building materials like concrete coarse aggregate (gravel and stones) and sand[40].

→ Extraction of materials from informal quarries remains an environmental problem, as they are often operated without authorization, without a management plan, with little control over extraction sites, with unplugged quarries, etc.

→ Gravel and sand are often extracted from rivers or quarries, contributing to bank erosion and displacement, increasing bank slopes, and leading to changes in river morphology. They can cause riverbank collapse, loss of land and/or adjacent structures, downstream changes in deposition patterns, and destruction of riparian habitats.

→ As with stone, extracting gravel from quarries can involve blasting. Without planning or protection, blasting leads to occupational hazards. Quarries cause noise, dust, pollution, habitat destruction and vibration if not properly managed.

Socio-economic disadvantages

→ Although sand and gravel production (extraction, transport, and crushing) is a source of income for many families, it is often associated with fairly arduous working conditions.

→ Influential residents often control river sand and gravel extraction.

ADVANTAGES

Lifespan

→ Cement-based materials have good constructive characteristics when used in the right places in constructions (foundations, underpinnings) and are appreciated by most users.

Socio-economic aspects

→ The production of certain materials (gravel) is labor-intensive.

GOOD PRACTICES

Alternatives

→ Use alternatives to concrete and cement-based products, if possible local, non-polluting solutions.

Design and construction

→ Mix concrete in small quantities to minimize waste. Do not mix more than is used in two hours.

→ Use standardized block sizes to minimize the use of setting mortar (sand) and plaster (sand).

Recycling

→ Use crushed debris as an alternative to gravel. If 30% recycled coarse aggregate is used, the modulus of elasticity is 17% lower, making the concrete still usable for the desired strength requirements[41].

[40] Barwell (2016)
[41] Hettiarachchi, M., & al (2021)

6 CEMENT AND CONCRETE

Cement block house Al Hudaidah – ©YFCA

Cement block house Al Hudaidah – ©YFCA

IMPACTS ET LIMITATIONS

Environmental degradation

→ Infrastructural development and construction using cement-based materials result in heavy dependence on natural resources, including cement and sand for blocks and mortar[42].

→ The cement industry is one of the most polluting. The use of these construction solutions (cement and reinforced concrete) contributes to climate change. Cement production is energy-intensive, polluting and a source of greenhouse gases that have an impact on climate change. It accounts for 8% of the world's annual production of CO_2.

→ Concrete constructions in flood-prone areas act as barricades, so the floodwater and its rebounding effect push the flood toward more vulnerable buildings[43].

[42] Barwell (2016)
[43] (Jerome, 2010)

→ The manufacturing process for concrete reinforcing bars requires large quantities of metal, which can contribute to the negative impacts of mining, CO2 production, impacts on climate change.

Building sector disadvantages

→ There are no unified construction technologies, methods or regulations that control the construction process in the country. This has created a tendency in the project's owners to minimize their construction costs by eliminating or minimizing the technical and engineering assistance in design and supervision. This tendency has led to over-designs, excessive use, and site waste of construction materials. Quality concrete of the specified strength is not frequently produced due to the operation being improperly supervised[44].

→ Construction with cement-based materials is not always of the highest quality due to a lack of know-how and compliance with standards. For example, the quality of hand-produced blocks varies from very good to poor, depending on the skills of the craftsmen involved, compliance with aggregate/cement mix dosages, the quality of aggregates and cement, and compliance with wet cures.

→ This type of architectural solution is extremely costly in areas where transport networks are not in good condition. Because of the difficulties involved in inspecting projects (isolation, cost of inspection), it is challenging to guarantee the work's quality.

→ Building expansion and upgrading are possible but need skilled know-how, which is not easily available.

→ The increased use of cement to protect vulnerable parts of earthen buildings is a physical risk of long-term damage. Some of these interventions are a severe risk for earthen structures.

Health risks

→ In Aden city (and in other cities in Yemen), many houses were built between 1880 and 1990 and therefore corrugated asbestos cement roofs as one type of asbestos boards, were used widely in coverage of the buildings and garages. The risk of developing asbestos-related diseases, like lung cancer, is associated with the level and duration of exposure[45].

Comfort disadvantages

→ The modern structures don't provide thermal time lag (as for earth and stone buildings). The internal climate is hot in summer and cold in winter because of the thin and void walls and roofs.

→ One of the problems with concrete houses is still designing for the climate. Concrete buildings have cooling and heating requirements that were non-existent in traditional construction. This has proved problematic since the little available electricity comes from the overburdened public utilities or private generators, none of which is continuously operated[46].

Socio-economic disadvantages

→ According to economic studies, with imported materials, a large proportion of the cost goes into the pockets of a few contractors, with only about 25% remaining in the district[47].

→ Few people benefit from the biggest share of cement or concrete reinforcing steel production revenues. Influential residents often control the materials needed to make concrete, such as sand.

→ Material and know-how are mainly available in urban areas. Industrial materials are expensive and difficult to obtain in rural areas and for less affluent urban populations. The high cost of the material and skilled labor is a barrier.

→ Cement and reinforced steel are mostly imported, and the execution of reinforced concrete is often of poor quality for reasons such as lack of training, poor shuttering timber, aggregates of inferior quality, polluted water, inadequate compaction, and poorly maintained concrete mixers. Except on large projects, a qualified technician or engineer rarely inspects concrete quality, and facilities for concrete testing are not available[48].

→ Transporting the materials needed to build with reinforced concrete can damage rural roads.

→ The cost of an earth house is lower than a concrete construction, which generally runs up to 30 % higher due to steel reinforcing.

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[44] (Sultan, 2008)

[45] https://www.researchgate.net/publication/342572225_Assessment_of_the_Elements_and_Oxides_Concentration_in_the_Dust_of_Asbestos_Used_in_Roofs_of_Houses_in_Al-Qalluah_Town_Yemen

[46] (Varanda, 1994), (Jerome, Chiari, & Borelli, 1999)

[47] https://al-bab.com/commentary-yemeni-traditional-architecture

[48] (Derek & Evin, 1984)

ADVANTAGES

Lifespan

- → Cement-based materials and concrete have constructive characteristics that are relevant when used in the right places in construction (foundations, plinths, etc.).
- → If well-built, properly designed, and implemented, it is able to resist extreme conditions, especially flooding.
- → If well-designed and built with know-how, a concrete structure may last long.
- → Building, expansion, and upgrading are possible but need skilled know-how, which is not easily available.

Possible reduction in the use of wood

- → No need for lumber in load-bearing structures (but need of timber for formworks and need of lumber props for slabs).

Social aspects

- → The construction of cement block houses is not limited to a specific season, so masons can work anytime.
- → The local population often appreciates this material as it represents modernity.
- → Although more expensive, a concrete structure can be built in one season, providing wider interior square footage on the same parcel of land.

GOOD PRACTICES

Alternatives

- → Use alternatives to concrete and cement-based products, if possible local, non-polluting solutions.
- → Use optimal design calculations to minimize waste.

Design and construction

- → Use standardized block sizes to minimize the use of setting mortar and plaster.
- → Store cement in a dry, waterproof space with as little humidity as possible.
- → Optimize mixing: do not overdose (waste) or underdose (lack of strength) cement.
- → Mix in small, sufficient quantities to minimize waste. Do not mix more fresh concrete or cement mortar that will be used in two hours.
- → When earth brick houses are reconstructed, cement plaster is applied to the bases to protect the basement. Unfortunately, the incompatibility of the 2 materials (cement tends to trap moisture) accelerates the structure's deterioration and collapse.
- → Cement mortar, now commonly used in foundations or even concrete foundations, promotes the migration of soluble salts from the cement into the earth brick superstructure with disastrous results. Think about it when selecting and mixing several materials.

Reuse

- → Never dispose of cement-based products in the environment. These can be reused on-site / off-site for construction purposes (e.g., filling) or transported to a building materials recycling area or controlled landfill.
- → Never reuse rebar to build again in reinforced concrete, as this is structurally unsafe.
- → Never reuse asbestos cement boards or asbestos cement roofs, due to the risk of developing asbestos-related diseases.

Asbestos measures and safety

- → Manage adequate transfer of construction asbestos waste to specific and approved disposal site.
- → As airborne asbestos fibers may remain suspended in the air for some time and can be carried long distances by wind before settling down, asbestos boards should be encapsulated by a safe material to prevent or reduce their risks[49].

[49] Idem note 45

7 LOCAL AND IMPORTED LUMBER

Local lumber for floor – © YFCA

Floor on cob construction – © YFCA

Floor on cob construction – © YFCA

Ceiling with earth plaster – ©Fernado Varanda

IMPACTS AND DISADVANTAGES

Environmental degradation

→ Timber extraction can lead to forest destruction, landslides, soil degradation and habitat destruction, flood risks, droughts, and a growing spiral of hardship.

→ Roughly 1% of Yemen's total land area is classified as forest[50]. The demand for fuel and fodder exceeds the regeneration capacities of Yemen's remaining forests. Yemen relies on imports of wood for its construction needs[51].

→ Today, cutting trees for timber production is proving an unviable alternative in the quest for local materials as building materials.

Management problems

→ Yemen does not have a national forest policy or legislation governing forest land. Under the customary law of Yemeni tribes, people living in or near forests have the right to use the forest for wood, grazing, hunting, and fruit gathering.

→ In times of internal crises, famine or financial hardship, households harvest wood to sell as fuel or charcoal. It has a major impact on the forest in Yemen. Many people have no alternative option as a source of livelihood.

Socio-economic disadvantages

→ The population uses wood as firewood, most often in three-stone fireplaces, which are very inefficient in terms of firewood consumption.

[50] USAID: Country profile property rights and resource governance.
[51] FAO 2010

- → The use of toxic chemicals for treatment purposes entails environmental and health risks.

Industrial lumber issue

- → The manufacture of plywood panels uses chemical binders and takes place in large plants using energy-intensive processes. Processing leads to air pollution.
- → If poorly managed, manufacturing local or imported lumber in factories can cause air and water pollution.
- → CO_2 is produced during manufacturing, with subsequent impacts on climate change. Similarly, cutting down trees reduces their absorption of CO_2.
- → Transporting sawn lumber from abroad generates significant CO_2 emissions.
- → The use of toxic chemicals for processing leads to environmental and health risks.
- → Income is concentrated on a few people.
- → Imported sawn wood or plywood is frequently attacked due to its low quality and treatment.
- → Timber transport can further damage forests and rural roads.

ADVANTAGES

Environmental advantages

- → It's a renewable resource if properly managed. Wood from forestry has minimal impact on natural forests. In this sense, forestry can become a commercial and environmental priority.
- → Community forestry projects can reduce environmental problems and provide sustainable livelihoods for communities.
- → Mitigating the impacts of climate change through tree plantation is particularly important in areas where heavy rains cause flooding and topsoil erosion, which deforestation can only exacerbate.

Community self-sufficiency

- → Plant-based materials are traditionally used and provide good comfort in homes.
- → This material can encourage community autonomy as it makes self-building possible. Wood can reduce economic dependence on the building materials market, thus avoiding indebtedness. This can contribute to the local economy and the livelihoods of local communities.
- → Community forestry projects can provide sustainable livelihoods to neighboring communities.

GOOD PRACTICES

Extraction and management

- → When wood is used in construction, sustainable management must be checked: it is necessary to use wood from reliable and legal sources and consider reforestation as a contribution to habitat solutions that will use wood responsibly.
- → Avoid timber extraction in areas where deforestation worsens the effects of flooding and promotes topsoil erosion, and thus mitigate the effects of climate change.

Design and construction

- → Avoid oversizing timber structures. Carry out appropriate structural design and calculate wood requirements accordingly. Minimize cut-offs.
- → Store wood in a covered, dry place, high up but taking care to lift it well to avoid sagging.
- → Minimize the use of timber for formwork, prefer reusable modular formwork instead.
- → Schedule timber delivery according to the phase of the project during which it will be needed to avoid unnecessary exposure to the elements.
- → Local knowledge of the para seismic full wood strips (*basut*) embedded in the walls and running along the courses as a form of bracing for the masonry should be enhanced. This technique appears mainly in the country's southern half, from Sana'a through Dhamar and the Ibb province.

Extending lifespan

- → Wood structures (joists or beams) are often covered with earth plasters, ensuring good fire resistance.
- → Termites are widespread in rural and urban areas. Wood needs termite treatment to ensure its long-term durability. In this sense, local people have developed a range of relevant strategies over time, which vary locally.
- → Wood needs termite treatment. Treat wood correctly to ensure its long-term durability. There are several local recipes for termite control. In reed houses, spent oil is applied to the wood before inserting it into the wall[52]. Be carefull with such a solution, which can be toxic for the inhabitants and pollute the environment.
- → Some local woods are termite-proof and durable, even though these trees may be endangered today because of deforestation problems.
- → Active strategies: The presence of poultry in concessions helps control termite presence.
- → Wooden posts can have rotting problems when in contact with the ground. To prevent this from happening, or to avoid having to replace the whole post when it does, it is possible to:
- → Build poles in two joined parts, of which the one in contact with the ground would be "sacrificial", the short part in the ground -fusible- once damaged, can be easily replaced without affecting the main structure;
- → Build posts insulated from the natural ground with water-resistant bases (stones, fired bricks or cement blocks, small concrete elements);
- → Build wooden posts embedded in concrete (in this case, they cannot be easily substituted).

Reuse

- → Chemically untreated wood can be reused for many purposes, depending on the condition of the wood: survey stakes, formworks for concreting, floorboards, beams, door and window frames, and structural elements.
- → Chemically treated timber cut-offs should be considered hazardous and never be used as firewood.

Recycling

- → Non-chemically treated wood can be recycled for uses such as landscaping, animal bedding or use as fuel.

[52] (Jerome, Chiari, & Borelli, 1999)

8 OTHER PLANT-BASED MATERIALS

Zabid, traditional roofing CC Tom Leiermann

Coastal area, plant-based shelter CC H.Grobe

IMPACTS AND DISADVANTAGES

Environmental degradation

→ Straw is becoming scarcer due to the climate crisis, with increasingly frequent floods washing away soil, and prolonged periods of drought. Deforestation is also due to local populations who cut for cooking fuel.

→ Pressure on the use of these resources increases the risk of erosion, deforestation, landslides and flooding. This can deprive communities of resources essential to their livelihoods and expose people, infrastructure and ecosystems to an increased risk of future disasters.

Socio-economic disadvantages

→ Thatched roofs have a limited lifespan due to their susceptibility to rot and insect infestation. If the roof is smoked indoors by fire, this lifespan can be increased. However, exposure to smoke inside the house when cooking with wood (or charcoal) harms health.

ADVANTAGES

Environmental advantages

→ It's a renewable resource if properly managed and biodegradable.

→ Many types of thatch are a by-product of agriculture, which would be wasted if not used for roofing or animal feed.

Community self-sufficiency

→ Material available to households or at a small industrial scale. It can support local people's livelihoods and enhance their knowledge.

→ Extracting and processing local raw materials does not require expensive tools.

Building sector advantages

→ It avoids metal or concrete materials in roof construction.

→ If well-designed and built, a thatched roof is more lightweight than a flat roof and therefore requires less wood to support it.

GOOD PRACTICES

Management

→ Appropriate management of natural or cultivated vegetation (reeds, grasses, branches...) is necessary to avoid negative impacts on ecosystems.

→ Use local knowledge for the appropriate management of these resources.

→ Support local people's livelihoods and local factories.

Design and construction

→ It is a way of showing local roofing options without using plastic or metal in humanitarian projects. It is more appropriate to test thatched roofs in places where straw is available.

Extending lifespan

→ Thatch needs to be protected against insects for greater durability. It can, however, be solved by regular inspections. Hen breeding may also be useful for insect control.

→ Consider fire risk when planning and designing, as the material is combustible.

→ If well-designed and built, a thatched roof is very durable.

Reuse

→ Thatch can be composted, spread on the ground or buried in the soil and left to decompose naturally as long as it has not been chemically treated. Avoid disposing of large quantities in watercourses.

9 LOCAL MATERIALS OF ANIMAL ORIGIN

IMPACTS AND DISADVANTAGES

→ Cow dung is not usually available in sufficient quantities for large-scale projects, needing to forecast the availability of these materials with sufficient anticipation.

ADVANTAGES

→ Locally available, existant know-how.

PRACTICES

→ These materials are resources valued by communities and used in construction (mainly earth plaster and mortar).

10 METAL SHEETS AND METALLIC MATERIALS

NRC, transitional shelter in Amran , from Yemen shelter typologies, 2020 © NRC

IMPACTS AND DISADVANTAGES

Environmental degradation

→ The manufacturing process requires large quantities of metal (depending on the material: iron, steel, zinc and other metals), which can contribute to the negative impacts of mining.

→ Manufacturing takes place in large, energy-intensive factories. Plants can cause severe air and water pollution if poorly managed. Manufacturing processes can release toxic heavy metals.

→ Production generates CO_2 emissions and impacts on climate change.

→ Importing raw materials (iron, zinc, aluminum, and others) to production plants (often located in different places than where the minerals are extracted) also generates greenhouse gas emissions.

→ The transport of manufactured products (often from coastal countries in the sub-region) impacts greenhouse gas emissions.

Socio-economic disadvantages

→ Transport can damage rural roads.

→ Income is concentrated on a few people.

→ Industrial materials are expensive and difficult to obtain in rural areas and for less affluent urban populations.

- → Changing a corrugated galvanized iron sheet (CGI) when damaged is not easily affordable (compared with thatched roofs).

Disadvantages for health and comfort

- → Dangerous in high winds. The main problem is the possible uplift of sheet metal due to high winds and inappropriate fastenings that can cause injury and loss of life.
- → CGI roofs and walls cause discomfort and can lead to health problems. The sheets reflect some of the sun's rays due to their shiny surface, but they also heat up and diffuse heat throughout the house. During the day, the house's interior and the roof become very hot. As the sheets rust, they become darker in color and reflect less and less. As a result, building interiors get hotter.
- → In addition to their thermal disadvantage, metal sheet roofs are noisy during rainy periods.
- → Sheet edges can be very sharp, so transporting and handling sheet metal can be dangerous, and hands need to be protected.

ADVANTAGES

Socio-economic advantages

- → Sheets are easy to transport and lightweight. The load-bearing structure can also be quite simple and light.
- → Sheets are valuable and can be sold if households need to raise funds.
- → Corrugated sheeting can eventually be assembled and disassembled elsewhere and is appreciated by the local population.
- → Metal tubes for shelter structures are unaffected by termite attack, prolonging their useful life.

GOOD PRACTICES

Management

- → Use certified products.

Design and construction

- → Use optimal design calculations to minimize waste.
- → Don’t use too thin CGI sheets that are more exposed to distortion and may not last long.
- → Avoid contact with the ground or high humidity levels if used in walls.
- → To improve comfort under CGI roofing, ventilation systems and false ceilings are recommended to limit discomfort due to sunlight radiation through the iron sheet. False ceilings can compensate for certain defects, reducing noise and creating thermal insulation.
- → Avoid using CGI sheets in corrosive environments (e.g., by the sea).
- → Avoid using CGI sheets on walls and search for options with local materials.

Extended service life

- → Proper installation and fastening of the cover are important to ensure water tightness and good mechanical strength.
- → Corrosion resistance makes aluminum sheeting more environmentally friendly than steel sheeting in corrosive environments. Aluminum is a light but strong metal that's not prone to corrosion, is non-toxic, durable, and can be shaped at will. It is more durable than galvanized sheet steel but more expensive.

Reuse

- → Encourage the reuse of uncorroded sheet metal from old buildings unless it may be stolen during a conflict.
- → Never dispose of metal sheets in the environment; they can be sold as scrap metal.

11 PLASTIC MATERIALS

Enhabced shelter kits, NRC, Lahj, from Yemen shelter typologies, 2020 © NRC

IMPACTS AND DISADVANTAGES

Environmental degradation

→ These petroleum-derived materials contribute to environmental degradation during their manufacture, which consumes large amounts of energy and pollutes the air during the combustion required for their production. The oil industry is at the root of major environmental problems.

→ Production generates CO_2 emissions and impacts climate change.

→ Importing raw materials (petroleum) to production plants (often located in different places close to oil extraction) also generates greenhouse gas emissions.

→ Manufactured products transport also generates an impact on greenhouse gas emissions.

→ The material's end of life, becoming waste, generate pollution.

Socio-economic disadvantages

→ Plastic tarpaulins and sheets (for walls and roofs) present several problems related to their lack of durability and thermal discomfort in buildings.

→ No toxicity in use but it can emit dangerous fumes when burning.

→ These materials are systematically imported and offer no local benefits.

ADVANTAGES

→ Can provide an emergency solution to shelter recently displaced or disaster-affected populations.

GOOD PRACTICES

Reducing transport emissions

→ Give preference to materials from the sub-region rather than imports from distant areas.

Design and construction

→ Use optimal design calculations to minimize waste.

→ Be careful with the local practice, which suggests to put a plastic sheet on the beams under the 15 to 20 cm layer of earth plaster. This way of preventing water infiltration can have severe consequences on the rafter and the roof's stability because it prevents moisture from escaping.

→ Transportable solutions may be preferable for housing nomadic populations based on the same logic as their original homes. Improved thermal comfort, roofing materials' durability, and construction safety are key points for this type of habitat.

Extended service life

→ Tarpaulin roofs are sometimes present as a second protection for straw roofing. They are also widespread in humanitarian shelter projects. Tarpaulins from these projects are often reused in the houses that families subsequently inhabit, either to reinforce roof waterproofing, or to make curtains or interior or exterior finishes.

→ Plastic sheeting is usually reused up to a very end of lifecycle by households to improve their shelters.

→ Use certified products and avoid using them in corrosive environments.

→ Avoid exposure to direct sunlight wherever possible.

Reuse

→ Encourage the reuse of tarpaulins still in good condition from former shelters.

[4] Conclusions

↘ This document assumes that communities have developed contextualized responses to concrete problems, which must be taken into account and valorized within the framework of humanitarian assistance programs. In this sense, recommendations for sustainability in a broad sense are presented for each of these topics: environment, sociocultural aspects, economy, technology, and governance).

After a disaster or during humanitarian crises, shelter/housing response efforts increase the extraction of resources needed for construction. Minimizing this impact is a key criterion when selecting materials, as are their constructive qualities, cost, lifespan, maintenance requirements, availability on the market, aesthetics, economic impact on communities, and ecological footprint. By being aware of this impact, the humanitarian sector can play a crucial role in finding the best balance between different, sometimes contradictory, criteria in the shelter and settlement responses.

However, materials must always be considered with the intangible facet of knowledge and know-how, maintenance practices, and lifestyles because not everything is only technical. Consequently, it is essential to be careful with purely technical responses to situations requiring the assistance of the humanitarian shelter and settlement sector.

Chapter 1 presents good local practices for the management of building materials in Yemen at various levels: strategies for minimizing the effects of natural hazards and reducing the environmental impact of construction; sociocultural strategies that promote resilience; impacts on the local economy; technical aspects: site, design, construction and maintenance; and governance aspects.

Chapter 2 provides a table of questions that help to make an informed choice of building materials and techniques. The questions are organized into three blocks:

- Extraction/production/transport
- Construction/use
- End of life.

The choice of material (related to technique and construction process) depends on a contextual balance of a more global approach.

Chapter 3 analyses the building materials most commonly used in Yemen from environmental to social perspectives and proposes recommendations for better materials management in the various stages of their life cycle, from extraction to processing, construction, service life, and end-of-life. These aspects are divided by theme: environment, health benefits for residents, community self-reliance, good socio-economic practices, etc.

Solutions derived from local building practices without major innovations are more likely to be adopted and thus contribute to long-term development and increased local resilience. An excessive imbalance between what already exists and external and innovative proposals, however relevant, is likely to be unsuccessful, as it is necessary to work in stages before changing existing construction dynamics.

In conclusion, some contexts or situations will be more conducive to industrial materials and others more relevant to local solutions based on the use of local materials and resources. In many cases, a combination of these building materials used in the right places will be the best solution and are often already used by the local population (see, for example, houses built with cement blocks or stone as the base, and adobe walls, which are very common in the country). These choices depend on land tenure security, skills availability, the cost of intervention, the acceptability of the proposals, the issues at stake, and the project approach (emergency, transitional or permanent housing).

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Annex: material cards

MATERIAL CARD	WATER
Material	Water
Extraction	• **Surface water:** There are no permanent rivers in Yemen. The streams draining groundwater are seasonal. • **Rainwater harvesting, terrace:** Thousands of terraced fields have been constructed on steep, rugged mountain slopes using simple, highly effective rainwater harvesting methods, collected in the terraces, and soaks into the shallow soil. Low walls at the edge of the terraces prevent run-off from flowing down to the next terrace and allow the passage of run-off through sheet flow, which prevents damage to the terraces from water accumulating at certain points. • **Cisterns and sub-surface cisterns:** In many areas, cisterns are used to conserve rainwater. The cisterns of Tawaila (rain flood harvesting) and the Tawaila tanks are Aden's best historic sites. Traditional cistern and pond building (catchment and rooftop water harvesting) was neglected until the end of the twentieth century when the overexploitation of aquifers became evident. • **Dam**: during the last few decades, several small dams have been constructed to capture seasonal floods or springs from the small tributaries of the catchment areas. • **Spate irrigation:** Spate irrigation is an ancient water harvesting system in which floodwater is diverted from its riverbed and channeled into basins where it is used to irrigate crops and feed drinking-water ponds, serve forest and grazing land, and recharge local aquifers. Floodwater is one of the most important sources of irrigation in many areas, accounting for the irrigation of 70 percent of total agricultural lands in Yemen's southern and eastern governorates. • **Ma'aayeen irrigation**: the ma'aayeen system transfers water from different sources (wells, springs, howam, or karst pools) through open conduits or underground tunnels with openings for ventilation and lighting, called naqab, to agricultural lands or for use in rural and urban development. Water sources are naturally higher than the areas to which water is delivered[53]. • **Groundwater :** Farmers go to great depths to tap groundwater, including fossil water, in the Sanaa Basin. The average depth of wells in the basin reached 400 meters, depending on the location and aquifer type. However, it is reported that, due to Qat irrigation, some wells in the Sanaa Basin reached depths of up to 700 meters or more. Drawing water from such depths comes at a cost to farmers who use diesel pumps to draw the resource[54].

[53] (UNDP, 2022)
[54] "Being the Change in Yemen: Improving Integrated Water Resources Management for Food Security", Dr Hussein Gadain, FAO, https://reliefweb.int/report/yemen/being-change-yemen-improving-integrated-water-resources-management-food-security-enar

Application/techniques	• Production of earth mortar for wattle and daub walls and cob wall. • Production of masonry elements (sand-cement blocks, earth brick). • Production of mortar for masonry or for plastering these elements (earth, earth-cement or cement-based mortar); • Production of concrete and reinforced concrete; • Production of earthen flat roof terraces.
Transport	Sometimes water supplies are far away, and water has to be transported by humans, trucks, or carts.
Service life	N/A
Cost	N/A
Know-how	N/A
Informal/formal economy	Both
Urban/rural	Both
Large-scale potential	The country is rapidly approaching an era where only renewable water resources (rain, surface, and shallow groundwater) will be available[55] , which is insufficient for national consumption.
Seasonality	Easier to obtain in the rainy seasons or immediately afterward.

MATERIAL CARD	**RAW EARTH**
Material	**Raw earth** is present below the topsoil, and there are several types of soil in the country regarding granulometric composition: types of clay (more or less active in contact with water), proportion of clay, silt, sand, gravel, etc. **Raw earth** is a term that covers a wide variety of earth types with different compositions, techniques, and know-how. The different types of earth are presented together to avoid repeating similar analysis tables.
Extraction/production	• The choice of soil is empirical (texture, granulometry, water status, etc.) and based on in-depth knowledge of the environment and human settlement. • Regional knowledge is helpful to know the best earth. In some places, the topsoil is considered poor quality because it contains salts from agricultural fertilizers.

[55] (UNDP,2022)

	• Extraction sites are generally close to the construction site and are often tried and tested. • Another important criterion for selecting a soil extraction site is to avoid locations deemed unsuitable after consultation in the village or area. • The soil is extracted from the ground and cleared of organic matter and large stones. • The soil is mixed with water and, very often, additives such as grass, cow dung, or donkey dung. If the soil is very clayey, it is mixed with straw and sand. • **Earth bricks**: are molded in wooden molds that vary in size according to the use and regional variations and form walls of at least 50 cm thick: 30 to 45 cm by 19 to 32 cm, 8 to 9.5 cm deep. When preparing the mixture, the earth is wetted and mixed with chopped straw (*tibn or deyal*) to reduce the shrinkage and for reinforcement. In some places, dung is added. The straw is taken from the fields after the farmers harvest and crush wheat. The proportion of straw is determined by sight and feel, depending on the experience of the master[56]. The bricks are left to dry for a week and then stacked vertically. At this point, they are ready for use[57]. • **Cob wall**: The mixture is made of earth, water, and frequently chopped straw and chaff branches. The mixture is covered by a plastic sheet and left for 2-3 days before use. The mix is done by walking and moving on the mixture. A foundation is often about 50 cm deep and must reach good soil and be filled with earth mixed with hay. The earth-course mixture is formed into balls with a diameter of 12-15 cm, and the builder throws the balls -medium power- from head level with both hands. Each earth-course has a height of one arm equal to 45 cm[58].
Application/techniques	• Infill of reed houses made of wattle-and-daub walls • Molded sun-dried earth bricks (adobe) -> Load-bearing or non-load-bearing walls • Mortar for cob walls • Mortar in stone and adobe walls -> Load-bearing or non-load-bearing walls • Wall and floor finishing plasters -> Finishings • Earth flat roofs -> Roofing
Transport	Usually no transport
Service life	Long if well-designed, built, and maintained
Cost	Low cost
Know-how	Existing in areas where techniques are used (earth bricks, cob wall, wattle and daub)
Informal/formal economy	Both

[56] (Matthews, 1985)
[57] (Jerome, Chiari, & Borelli, 1999)
[58] YFCA, local and traditional building practices in Marib

Urban/rural	Both (in some regions, more common in rural areas)
Large-scale potential	Yes
Seasonality	Earth-bricks and cob wall construction is preferred during dry seasons

MATERIAL CARD	**FIRED BRICKS**
Material	**Clayey soil**
Extraction/production	The fired bricks are shaped by hand in a mold and are cooked under fire of branches and cow dung. They are square, about 16 x 16 x 4 cm or 16 x 8 x 4 cm for the half-size. Fired bricks make wall thicknesses of about 34 to 42 cm. They are also used for characteristic brick decoration. In the Tihama, bricks of a more conventional oblong shape are made. Fired bricks are almost unavailable in the whole of Yemen.
Application/techniques	**Fired brick walls** (*ajur*) are best represented in the Tihama region and in and around the major towns of the central highlands: Sana'a, Damar, and Rada. Nowadays, there is a limited amount of fired brick available for construction, and they are mainly used for architectural effects on a few new projects or for heritage restoration[59]. **Mixed techniques – earth brick and fired bricks:** Another use of earth bricks is in conjunction with fired bricks for an external skin. This is more resistant to rain. Three courses of earth bricks equal 5 fired bricks. In the mountains, the walls are often a mix of fired brick and stone masonry[60]**.**
Transport	By road
Service life	Long if well-designed, built, and maintained
Cost	High cost due to shortage
Know-how	Existing in areas where techniques are used
Informal/formal economy	Informal economy
Urban/rural	Mainly urban
Large-scale potential	No
Seasonality	N/A

[59](Derek & Evin 1984), (Varanda, 1994)
[60] (Matthews, 1985), (Varanda, 1994)

MATERIAL CARD	STONES AND OTHER MINERAL MATERIALS
Material	**Stones and minerals:** The country's geology offers a great variety of stones for construction: basalt, volcanic stone, black or grey lava, sandstone, tuffite, and limestone.
Extraction/production	**Stone:** stone quarries are available throughout the country. The stones are usually roughed out at the quarries, finishing is done by hand at or near the building site. But the escalation in the cost of labor is reducing the use of stone and causing the introduction of substitute materials. The type and precision of cut vary widely from one region to another according to inhabitants' wealth and available stone. The more precise and time-consuming work is limited to the main façade To reduce costs. **The size of stones** varies from one region to another, but often the depth of the stone is 20 cm or little more. The face varies from about 22 x 26 cm to 22 x 40 cm, 30 x 45 cm and 35x45 cm. • **Basalt**: a hard black stone used in foundation walls and footings; • **Volcanic Stone**: black or grey lava, famous for decorative use in facades around windows, arches, and corners; • **Sandstone and Tuffite**: available in the highlands in a wide range of colors (yellow, red, green, grey) and used for load-bearing walls; • **Limestone**: a hard, heavy stone used mainly for foundations and infrequently for walls. **Large quarries** produce 300m^3 or more aggregate daily and are equipped with trucks, bulldozers, and loaders. T**he small quarries** produce 50 m^3/day or less. The technology level depends upon the available equipment but is generally more labor-intensive[61]. **Stone floor tiles** are produced in small workshops. They are produced in sizes varying from 40 cm square to 60 cm square. They are generally rough cut and uneven, with a thickness of up to 25-30 cm at the center[62]. **Lime:** Limestone is abundant in Yemen. The burning of lime is a family tradition. Kilns (*furn*) are located outside the towns in remote areas. The kilns are keyhole-shaped in plan or a domed chamber open to the sky. Fuel oil is added in an elongated firing chamber or arched opening. Limestone is collected from the wadi after the floods or from the mountains, broken into pieces, and stacked[63]. **Gypsum:** Gypsum is also baked in kilns, and the powdered product is sold in bags direct to the builders or in the *suq*. Gypsum is the raw material for producing *goss*, and it is currently produced in small-scale workplaces that are mainly located around Sana'a and Ta'izz. Gypsum is also mined for use in the cement manufacturing plant at Bajil[64].

[61] (Derek & Evin, 1984)
[62] (Derek & Evin, 1984)
[63] (Jerome, Chiari, & Borelli, 1999)
[64] (Varanda, 1994)

Application/techniques	**Several uses:** Stone is used in manufacturing cement, walls, roofing materials, floors, and aggregates[65]. **Stonewall, foundations, and plinth:** Stone walls usually have stone foundations too. Some earth constructions have stone foundations and plinths. **Rubble walls:** There are many different types of random rubble walling in Yemen, depending on the character of the locally available stone. Internal finishes are the same as for hand-cut stones wall. Externally the stone may be exposed with cement mortar or gypsum pointing or with an external rendering of cement and sand or earth mortar[66]. **Lime plaster:** Lime is used as a mortar, particularly well-suited to plastering earthen walls. Stone houses are often whitewashed with lime and are covered with lime plasters[67] (or cement). **Gypsum plaster (*goss*):** *Goss* is a soft white plaster consisting of calcined gypsum, and it is traditionally used as mortar in stone and brickwork walls in mountain areas where rainfall is light to moderate. The material is also used as a plaster inside the houses, sometimes carved for decoration or molded to form a narrow shelf.
Transport	• Little transport when the material is locally available • By road when it comes from an area other than that of the construction site
Service life	Long-term if well-designed, built, and maintained
Cost	Medium - High
Know-how	Available depending on location
Informal/formal economy	Both
Urban / rural	Both
Large-scale potential	Depends on material availability and cost
Seasonality	Not applicable

MATERIAL CARD	**GRAVEL AND SAND**
Material	**Gravel and sand**
Extraction/production	**Gravel:** Available where wild rock exists. It is produced from crushed, often artisanal, wild rock or harvested from the surface. **Sand:** Beach sand mining is practiced, and artisanal sand mining.

[65] United Nations Environment Programme (2005)
[66] Matthews (1985)
[67] Scikei (2017)

Application/techniques	Concrete and reinforced concrete/Coatings /Sand-cement blocks
Transport	Little transport when the material is locally available. By road when it comes from an area other than the construction site.
Service life	Not applicable
Cost	Medium - High
Know-how	Available depending on location
Informal/formal economy	Rather formal
Urban/rural	Both
Large-scale potential	Not applicable
Seasonality	Not applicable

MATERIAL CARD	**CEMENT AND CONCRETE**
Material	**Cement:** Cement is available from local traders in most parts of the country. Some areas are difficult to supply because of the security situation. **Sand and gravel** have already been introduced in the previous sections. **Steel bars:** available in various standardized diameters.
Extraction/production	**Local cement factories:** There are currently 8 integrated cement plants in Yemen[68]. They are located with fairly adequate geographical distribution inland and along the coast. Nevertheless, a frequent shortage of cement has constrained the construction industry's output and increased the already high prices of cement[69]. However, numerous small yards are throughout the country, with 2 to 5 workers producing from 300 to 600 standard blocks per day. **Reinforced steel bars** are mostly imported.
Application/techniques	**Cement blocks** can be hollow or solid and are made from cast concrete, composed of Portland cement and aggregate (usually sand and fine gravel) for high-density blocks while including industrial wastes (such as fly ash or bottom ash) as an aggregate for lower-density blocks. The quality and bearing capacity of these blocks is very uneven. In many yards, the casting molds are badly worn, the vibrating and compaction equipment is inadequately maintained, the raw materials are of variable quality, the wet cure is not followed, and the cement content is often

[68] https://www.cemnet.com/global-cement-report/country/yemen
[69] (Sultan, 2008)

	reduced to save costs. Large, automated concrete block plants in Sana'a and Ta'izz produce blocks of adequate dimensions and strength[70]. **Reinforced concrete structure**: foundation, pillars, beams, slabs, lintels in structural concrete (with different diameters steel bars). **Concrete slab:** Concrete slabs became, in any case, a common way of building floors and roofs, justified mainly by the scarcity and high costs of timber **Cement roof sheet**: The vast majority of asbestos cement sheets were used to make asbestos roofing, but it's also found in siding and flooring materials. Never reuse asbestos cement boards or asbestos cement roofs, due to the risk of developing asbestos-related diseases. Manage adequate transfer of construction asbestos waste to specific and approved disposal site. **Mixed technics:** In the areas where cob walls are predominant, concrete blocks have been used not only to make new constructions but also for additional floors on existing buildings and to increase the number and width of openings. The blocks are laid on a reinforced concrete ring beam resting on the cob wall. Concrete also appears combined with stones and fired bricks. In Sana'a and Dhamar, hybrid techniques have been developed in which concrete blocks were used for the inner skin of walls faced with fired bricks or cut stones[71]. **Plaster**: cement is also used in plasters for finishings, with sand and water.
Transport	By road
Service life	Long if well-designed, built, and maintained
Cost	High
Know-how	Available depending on location
Informal/formal economy	Both
Urban/rural	Both
Large-scale potential	No
Seasonality	Year-round

MATERIAL CARD	**LOCAL AND IMPORTED LUMBER**
Material	**Local lumber:** Tamarisk, tenzania mangrove tree, and acacia wood are commonly used as a beam to make the roof. **Other:** to be completed

[70] (Miles & Ahmet, 1984)
[71] (Varanda, 1994)

	Imported lumber: Sawn timber comes in various sizes and is often imported. Sawn timber is often available from materials dealers.
Extraction/production	**Availability:** There is a shortage of indigenous building timbers, so imported timber of longer standard sizes is common. **Plywood panels:** Plywood panels are manufactured using sawmill by-products or cultivated softwood and chemical binders. Most often imported.
Application/techniques	In Yemen, traditionally, wood functions in the buildings are: • **A structure system:** wood was used to create frames that support the structures of the building roofs, intermediate floors, staircases, sanitary duct systems, and bridges between buildings. • **A reinforcing material:** wood branches, twigs, and straw were used to support the roof coverings and reinforce the walls of earth buildings and cities defensive walls[72]. **Reed houses[73]**: The wall is covered with layers of vegetable fibers - palm leaves, straw, or reeds - ranging from grass laid loosely over the frame to a woven fabric tied with ropes in careful geometric patterns. The exterior of the roofs is made of thatch only. **Imported timber** is mainly used for wall frames filled with CGI sheets or plywood.
Transport	No transport if resources available locally, by road if far away
Service life	Long if well-designed, constructed, processed (treatment is needed against termites), and maintained
Cost	Depends on quality, depends on extraction method
Know-how	Availability depends on locality
Informal/formal economy	Formal and informal
Urban/rural	Rather rural and suburb informal settlement
Large-scale potential	Yes for sawn timber from certified crops
Seasonality	Not applicable

MATERIAL CARD	**PLANT-BASED MATERIALS**
Material	**Reed / Grass / Palm leaves / Sisal fiber / Other plants**
Extraction/production	The many varieties of herbs, materials, and plant fibers are selected, prepared, and used at different levels of construction. The type and quality of material can vary.

[72] (Al-Sallal, 2022)
[73] (Varanda, 1982), (Varanda, 1994)

Application/techniques	**Reed**: it is used for building the so-called reed houses on the coast **Grass**: used for thatched roofs but also for the fabrication of the mats. **Palm leaves**: they are used for thatched roofs wherever they are available. **Other :** to be completed
Transport	No transport
Service life	Long if well-designed, built, treated and maintained
Cost	Low
Know-how	Available depending on locality
Informal/formal economy	Rather informal
Urban/rural	Rather rural
Large-scale potential	Yes
Seasonality	Usually linked to rainy seasons (e.g., grasses available after rainy seasons)

MATERIAL CARD	ANIMAL ORIGIN MATERIALS
Material	**Cow dung**
Extraction/production	Not applicable
Application/techniques	**Cow dung:** used in finishings of wattle-and-daub houses mixed with earth.
Transport	No transport
Service life	No data
Cost	Low
Know-how	Availability depends on location
Informal/formal economy	Informal
Urban/rural	Rather rural
Large-scale potential	Depends on location
Seasonality	Not applicable

MATERIAL CARD	**METAL SHEETS AND METALLIC MATERIALS**
Material	**Steel rebars / Metal sheets / Metal openings / Steel sections**
Extraction/production	Imported materials
Application/techniques	**Steel bars** are used in reinforced concrete structures and as steel reinforcement bars (rebar) used vertically and horizontally inside cement block walls to maximize the structural performance, and grouting cells with rebars are used to enable their bond to the wall. **Metal sheets:** they are available in different qualities and sizes, and in different materials such as CGI and aluminum. They are used in roofing and walls. **Metal openings:** frames and openings used for doors and windows and made of steel or aluminum. **Steel sections**: used as the main structure in some buildings
Transport	By road
Service life	Depends on quality and processing.
Cost	High
Know-how	Rather available
Informal/formal economy	Both
Urban/rural	Both
Large-scale potential	Yes
Seasonality	Not applicable

MATERIAL CARD	**PLASTIC MATERIAL**
Material	**Plastic tarpaulins (Polyethylene / PVC / Tarpaulin -polyester-) / Anti-damp plastic membranes**
Extraction/production	Imported materials
Application/techniques	**Plastic tarpaulins:** Different plastic materials are used in construction, from plastic sheets for emergency shelters,

	Anti-damp plastic membranes: Used as anti-dump membranes between the foundation or plinth and walls.
Transport	By road
Service life	**Plastic tarpaulins:** Short – very short **Anti-damp plastic membranes:** Good service life
Cost	Low
Know-how	Availability depends on location
Informal/formal economy	Both
Urban/rural	Both
Large-scale potential	Yes, but not relevant for durable / semi-durable shelters
Seasonality	Not applicable

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