MASTER THESIS BOOKLET

EARTH ARCHI-TECTURE

TOWARDS A SUSTAINABLE FUTURE

BY CAROLINE HALJE & HANNA WERNERSSON

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Earth Architecture: Towards a Sustainable Future?
Jordarkitektur: Mot en Hållbar Framtid?

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Earth Architecture

Towards a sustainable future

Master Thesis Booklet

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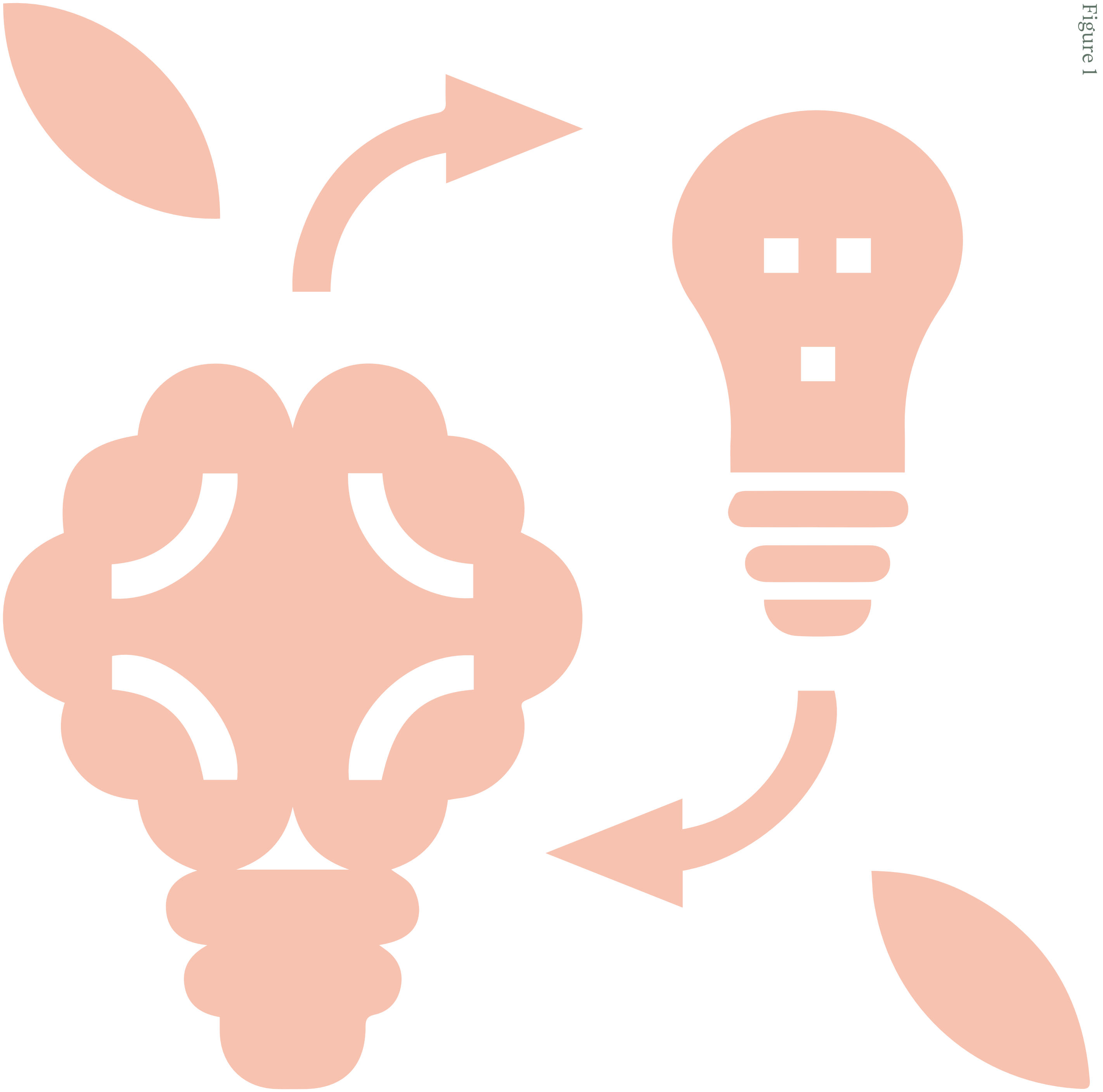

Figure 1

Architecture As A Catalyst

Looking Good is just Not Good Enough

A heartfelt fear of change has become more and more prominent. There is a growing fear of climate change and the consequences of more frequent natural disasters. There is a fear of rapid urbanisation, overcrowding and inequality, threatening the quality of life for many people.

The challenges of providing livable space increases.

Architecture is not only about a physical structure. It can also be a catalyst for a healthier planet and better societies. This kind of positive and generative nature of architecture - or of any kind of activity performed by human beings - seem to be of interest all around the world. People are more aware of and eager to know the environmental and social impact of our actions on earth. Ongoing trends regarding groceries and fashion contain an almost manic obsession in getting every piece of information possible on the impact of products on a larger scale. The man in the grocery store twists and turns the package in his hand until he has investigated every millimetre of it. The same goes for the woman holding a pair of jeans. She wants to be able to mirror herself not only in the new piece of clothing, but also in the whole chain of actions before it.

The process is just as important as the product.

The building process has enormous potential to influence various sustainability aspects. Just as it can be a catalyst for a sustainable future, it could also be the opposite. So why does the architectural field still seem to accentuate the ideas behind a project and the finished results more than the impact of it? If architecture looks good but doesn't do good - is it good then? It seems to be time for a more holistic architectural approach, where a new ethical dimension is added to Vitruvius' well-known three principles of good architecture: *Strength*, *Utility* and *Beauty*. Let us make room for a fourth principle: *Impact*, as in modern times, good architecture should also generate a more socially fair and environmentally sustainable future.

Abstract

It is widely recognised that the two major challenges of the 21st century are climate change and poverty. The building sector is responsible for over a third of all global carbon dioxide emissions. At the same time, we see vastly overcrowded and rapidly growing informal settlements in developing countries, where people lack the basic right to decent shelter. This is simply not sustainable and forces us to rethink the way we produce architecture today. Since the middle of the 20th century, the awareness of human impact has led to a strong desire to promote solutions that are based on more sustainable principles. An increased interest in earthen building materials is seen all around the world, mainly due to their low climate impact, availability, low cost and ability to support thermal comfort. Earth is one of the world's oldest building materials and many people still use it for building construction today.

This thesis looks into the potential for earthen building materials for modern architecture. The purpose is to increase the understanding of unburnt earth and investigate how a greater use of it in building structures can impact social, environmental and economic sustainability. The work highlights the latest research, presents contemporary earthen architecture, discusses architectural qualities and reviews challenges, potentials and required future steps. It also brings forward a construction project in Tanzania where we have carried out practical field work together with the NGO TAWAH, where local earth was used as the main building material.

An increased use of earthen materials has the potential to save natural resources, drastically decrease emissions, create healthy indoor climates, strengthen local economies and support cultural heritage. Despite the many advantages from a sustainability point of view, earthen materials face many challenges to be considered a contemporary building material. Until more standards and codes are established, we believe their future use in modern architecture is most likely to be seen in various types of hybrid buildings where conventional materials are used where they are most needed. Earth has the potential to be used as infills in such structures. It comes down to the matter of integrating earth and using the right material in the right place where the philosophy should not be to completely substitute conventional materials with earthen materials, but rather to minimise the use of highly processed building materials. Although earthen materials have their limitations, their unique advantages might eventually become predominant in the light of the challenges we face today. Using the best of the old and the best of the new could be one way to achieve sustainable architecture.

Figure 2

It Takes a Village

A Thank You to All of You Making This Thesis Possible

We would like to thank a number of people for their help and support during the production of this master thesis.

First of all, we want to express our deepest gratitude to Dr. Victoria Marwa Heilman, whose heart, driving forces and power of action really took us by awe. We are very greatful.

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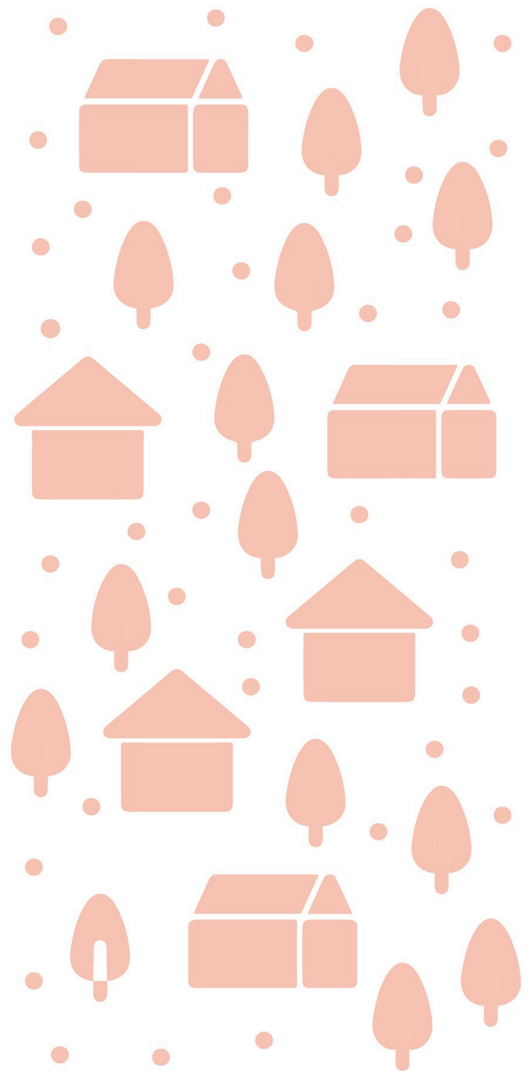
Caroline Halje & Hanna Wernersson



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Introduction

What

This thesis looks into the potential of the use of earthen materials for contemporary architecture. The purpose of the work is to increase the understanding of earth as a building material and to investigate how a greater use of it can impact social, environmental and economic sustainability. The work highlights the latest research on earthen building materials, presents modern examples of earth architecture around the world, discusses the material's architectural qualities and reviews challenges and required future steps. The work also highlights a construction project in Tanzania where local earth has been used as the main building material.

Why

This thesis is based on a will to - with architecture as a tool - make a positive impact on the planet and the life of people. We have during our architecture studies come to understand that building with earth has potential to contribute to such an impact. For this reason, we believe that it is valuable to look into the subject of earthen building materials in more depth. We are convinced that material knowledge might be one of the most significant skills for architects in the future as it lies in their power to design structures with a greater social and environmental impact, something that is becoming increasingly important. Taking advantage of locally available resources can be the key to overcoming the challenges we are in the middle of today. Materials are highly intertwined with the early stages of designing as they make up the fabric of any structure. It is therefore important that the architect knows the possibilities and limitations of different materials, to be able to make good design decisions that nurture sustainability.

How

To study the potential for earthen materials mainly from a social and economic point of view, we have chosen to carry out practical field work on a construction site in Tanzania, on which earth is used as the main construction material. By being physically in Tanzania, a country that struggles with major social and economic problems, we will be able to study the matter of social sustainability on our own, and through that gain valuable insights and knowledge that can be hard to find in literature. To complement the collected data from the field study, we have done literature studies to investigate the properties of earthen materials and their environmental impact.

Figure 4

Chapter 1

1.1 The Use of Unsustainable Building Materials

'Even a rich country cannot afford to keep wasting resources in its attempt to construct glossy and shiny buildings, a dinosaur from the past.' - Diébédo Francis Kéré (Designboom, 2021a)

From time immemorial, humankind has created habitats and shelters by using locally available materials such as grass, wood, stone and earth. The built environment we created for ourselves was in harmony with our planet as we optimised the use of locally available resources. With the arrival of the industrial revolution, production of building materials changed and the traditional ones were replaced. Industrialised materials resulted in an increase of speed of construction, minimization of human labour as well as an enabling of standardisations. However, these industrialised methods often require high-temperature and toxic processing combined with long transportation chains, causing carbon dioxide emissions and large consumption of non-renewable resources (Ben-Alon, 2019).

Carbon dioxide emissions are as commonly known the primary source of climate change. According to the UN environment programme, the building construction industry is today responsible for almost 40 percent of the carbon dioxide emissions (UNEP, 2020). Since the industrial revolution, the majority of modern buildings are constructed with highly processed materials such as reinforced concrete, chemically treated wood and synthetic insulation. According to the Global Alliance for Building and Construction, the extraction, production, and transportation of raw materials used in the construction of buildings now accounts for around 11 percent of global emissions, and that number continues to rise (Ritchie, 2021). To reach the goal of the 2015 Paris Agreement and the UN Sustainable Developments Goals it is crucial to urgently decarbonise the building- and construction sector (UNEP, 2019). Relying on conventional building materials at a global level is mostly unsustainable as they leave behind a great environmental footprint, consequently neglecting larger risks to our ecosystem (UNEP, 2019).

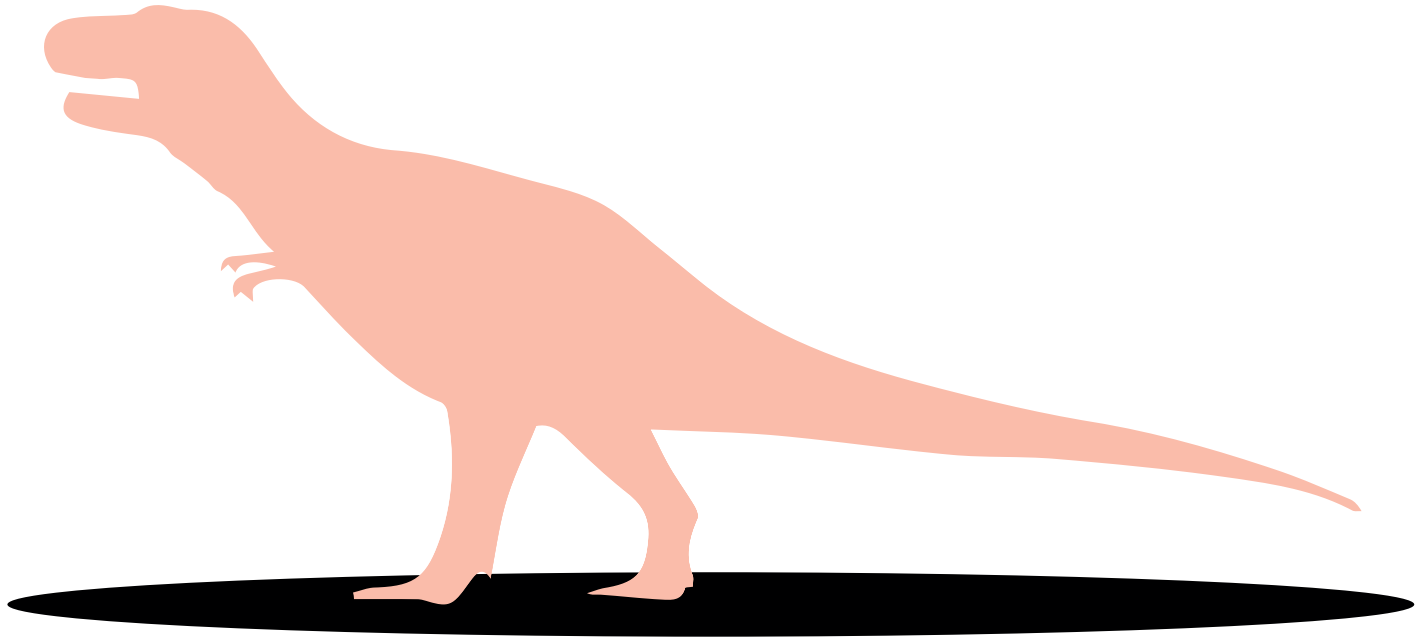


Figure 5

1.2 Dysfunctional Urbanisation Trends

'In the end, our society will be defined not only by what we create, but by what we refuse to destroy.' - John Sawhill (Peach, 2017)

Historically, cities have been key factors in economic uprisings and development. Throughout the past 200 years along with the industrial revolution, there has been an increase in living standards which wouldn't have been possible without cities. Urban areas have the potential to provide more job opportunities, affordable and accessible public services such as infrastructure, clean water, electricity, drainage and sewage systems, healthcare and education (Gardham, 2021). The forces behind urbanisation are therefore strong and rightfully filled with hopes for a better life.

Currently, half of the world's population live in urban areas and the number is estimated to grow substantially for years to come. Even though urbanised areas in for example most African countries fare better in nearly all measures of human development compared to their rural counterparts (Gardham, 2021), rapid urban growth raises a lot of challenges when the population exceeds the capacity of the city, which currently can be seen in many developing countries. It results in a competition of limited resources such as employment, decent shelter, food and water, causing more and more people to sink beneath the poverty line (Conserve energy future, n.d).

One of the main challenges is the growing of informal settlements. They are usually highly dense and vastly overcrowded. In 2018, 55 percent of the urban African population lived in such areas, compared with 30 percent in Asia and 20 percent in Latin America (Buchholz, 2021). The houses in these settlements are normally poorly constructed, lack clean water and proper sanitation and are sometimes erected close to dumpsites or heavily polluted areas. The building materials required are often both costly and insufficient. A proper set up and management of sewage systems is difficult for the government due to the fast increase in population. This results in pollution of water, making the already scarce clean water contaminated with the waste water. People living in these highly dense urban areas are exposed to a lot of environmental risks, and they usually don't have proper access to health care services (Conserve energy future, n.d).

These growing informal settlements are in urgent need of structural improvements and upgragrading in order to provide people living there with decent living standards. The immense requirements for shelter in these areas are proven to be impossible to fulfil with industrial building materials and techniques due to insufficient financial resources and a lack of productive capacity. One way to tackle this problem is to use local building materials and rely on do-it-yourself construction techniques (Minke, 2006).

Figure 6

1.3 Affordable Housing, A Flashing Red Light

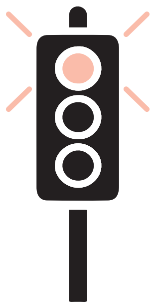


Figure 7

Affordable housing is a global issue. Housing can be considered affordable if the cost (mortgage or rent) of it is below 30 percent of the disposable income. If the cost is more than 30 percent, it can be considered a cost burden. Affordable housing covers more than just the economic viewpoint, it also includes physically adequate shelter fit for human habitation. It means that a house is not considered as affordable if it is overcrowded and unhealthy. Housing is a basic human need seen in the objective of UN SDG number 11 (Habitat, 2020). Despite that, many people struggle to find decent shelter. Actions are urgently needed to reduce pressures in the housing market. The rapid pace of housing price growth shown during the last decades is affecting affordability as well as posing a financial stability risk. The higher prices can be connected to decades of housing deficiencies, along with a rapidly growing population. At the same time as the demand for shelter increases, new construction still occurs at a rate far too slow to catch up with the lacking supply (Farr and Keith, 2022). The ongoing affordability crunch is pointing to the direction of a serious need for a global change. Housing affordability is determined by the following three aspects for people with mortgages (Farr and Keith, 2022):

- Household incomes
- Mortgage rates (the cost and availability of financing)
- Housing prices

Although the general world-wide trend has been an increased growth in all three areas, the different acceleration rates between the first aspect and the latter two are disproportionate. Households on the lower end of the income scale, as well as young people, are therefore particularly suffering from this imbalance (Lerner, 2016). In developing countries however mortgages are not a case scenario since most people can't afford to take loans.

With investments and a reconstruction of city centres, follows rising house prices. The consequences become particularly prominent in developing countries with ongoing rapid urbanisation trends. Generally, the urban poor are forced to move to the outskirts of the city, segregating them from public amenities, work and transport, highly decreasing their quality of life. However, the formation of informal settlements is a contradiction to this phenomena. The driving force behind the formation of informal settlement, along with all previously explained aspects, is severe poverty. In many African countries, the urban households have 55 percent higher costs relative to their per capita GDP than households in South America and China (Lall et. al. 2017). The guideline of housing costs around 30 percent is way too expensive for this group of people. The remaining income cannot cover their basic need for food, water, sanitation and medicines nonetheless transportation costs (Habitat, 2020). Regulated housing is therefore simply not an option. To be able to reach their work within a reasonable amount of time the severely urban poor have to be located close to work opportunities. The only choice available is then to settle down in a hazardous informal settlement (Lall et. al. 2017). The right to adequate and affordable housing is a basic human right according to UN's article 25. However, the pandemic worsened the plight of slum dwellers, constituting over 1 billion people in 2021 (UN, 2021).

Figure 8

At the same time, contrary to peoples' expectations, the pandemic did not stop the ongoing trend of increasing house prices. They kept increasing even more. From Munich to Shanghai, Auckland to Miami, home prices are still soaring. Among the 37 wealthy countries constituting the Organization of Economic Cooperation and Development, the fastest year-on-year growth in the past two decades occurred. A rise of almost 7 percent was seen between 2019 and 2020 (Ziady, 2021). Of the over 60 countries analysed and displayed in the Global House Price Index by Insights and Analysis on Economics and Finance (IMF), three-quarters showed an increase of house prices during 2020, a trend that largely has continued afterwards (IMFBlog, 2021). This development shows that we have a long way to go before we are able to provide affordable housing that meets the global demand.

1.4 The Power of Architecture

Figure 9

Implementing sustainability is today a matter of course in all sectors, none the least the building sector. Sustainability is often defined as "meeting the needs of the present without compromising the ability of future generations to meet theirs". To do this, we must balance three factors in harmony: environmental, social and economic. These are usually called the "three pillars" of sustainability (Beattie, 2021). Architecture can to a very high degree make a positive impact on all three of them.

Planet: Environmental Sustainabilty

Sustainability covers many issues. Perhaps the most important one in relation to climate change mitigation considers energy usage and carbon emissions. Architects and builders have both the opportunity and responsibility to lead humankind to a sustainable future since building impacts the environment more than any other human activity. There are many strategies on how to make the building sector more responsive to the climate and they are reflected in the design, choice of building materials, construction methods and resource use throughout the life of the building. Modern science and technology need to be used in combination with ideas from traditional building practices that respond well to human needs, regionalism and climate. A large part of the emissions from the building industry comes from operating buildings, i.e heating, cooling, lighting etc. Architects therefore have a key role to play as their design determines the capability of the building to heat, cool and light itself, with or without needing support from energy using equipment. To reduce the consumption of energy through energy efficient design is one step forward in addressing the carbon emissions from buildings. Apart from that is the matter of embodied carbon emissions, i.e. carbon emissions generated during the manufacturing of building materials, transportation and the construction process. This accounts for about one quarter of a building's total carbon emissions throughout its lifetime (Budds, 2019). In order to reach environmentally sustainable architecture, new ways of producing and using building materials with less environmental impact than the ones we frequently use today is one way to go. As we see it, there are three options:

1. **Go back in time and study traditional building materials and methods** that were used before the industrial revolution – and that still are used in many developing countries – and combine them with modern science and technology

2. **Improve the materials** we most frequently use today and turn them into sustainable alternatives

3. **Develop completely new materials and techniques** that meet the requirements for a sustainable future

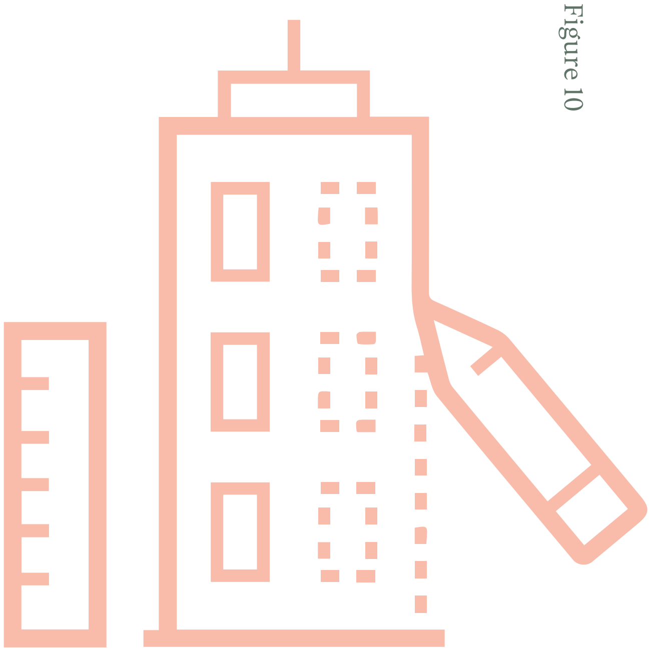


Figure 10

People: Social sustainability

Achieving environmental sustainability is not enough. Architecture can contribute to more inclusive, healthy and equal societies, by providing physical environments that support communities in meeting their social- and cultural needs. While most people understand the environmental aspects of buildings' construction and operational costs, the effects of architecture from a socially sustainable point of view are more difficult to grasp. While carbon emissions are objective and quantifiable, social impacts are often less immediately obvious and harder to measure. Social value is not found in hard data and excel-files. It is found in the outcomes of a project, where the soft value is shown in the positive effect it has on collective quality life and livability (Wilson, 2018). In the same way as architects and engineers routinely make design decisions based on embodied carbon and energy usage, they can also take social values into consideration. Social values can be implemented on different levels, generally divided into buildings, communities and society (Energy Efficiency & Renewable Energy. n.d). The extent of created social values is driven by the designing of decision-making strategies. Different methods to integrate and achieve social sustainability in the built environment are by using co-design strategies, support social cohesion and cultural integration.

Aspects that can promote social sustainability through the choice of construction material (Supply Chain Sustainability School, 2012):

- **Health and wellbeing:** the material affects both people during the construction phase as well as its users throughout the building's lifespan.

- **Circular economy:** considerations about how much of the project budget is spent on local supply chains and reinvested in the community through local labour compared to the material itself.

- **The degree of ethical risk:** the choice of materials affects what kind of labour standards associated with the extraction and processing of a finished product within the supply chains that are supported.

Profit: Economic sustainability

In today's society, one of the main issues concerns affordability. Economic sustainability is not only about making profit for developers -although its an important factor that is also to be discussed-, but also about constructing buildings that are affordable to accommodate. Architecture plays an important role in this issue, since accommodations have become much more unavailable in recent years, causing young and poor to fail to achieve their basic right to decent shelter. As rents are getting higher and the market supply lower, it is crucial to discuss how to build more affordably. A solution lies in the choice of construction material. By choosing to construct out of local materials using local labour, not only can the cost for the material itself and the supply-chains around it be cut, but also spur the local economic development of communities. By lowering the cost of accommodation, a larger economical margin is provided, enabling families to spend money on other things thus spurring the circular economy. Affordable rents attract companies and stores to settle down in the area. Not only does this promote walkable cities, but it also provides job opportunities for the local workforce (Forward Housing, 2021). It results in a larger economic contribution to the communities, which is beneficial for the contractors and developers point of view as the whole community becomes more vibrant.

Oftentimes, the developer's interest lies in how buildings can provide maximum economic profits. The outcome is usually based on short-term strategies, which causes poor decision making where cheap - and unethical - materials are chosen above qualitative ones (Supply Chain Sustainability School, 2012). However, growing evidence points to the direction that choosing to base construction on more sustainable strategies can provide financial rewards for both building owners, operators and occupants. It can be accomplished by considering the following aspects (Energy Efficiency & Renewable Energy. n.d):

- **Long-term perspective:** promotes a longer life-span for the building, lesser repair ⟶ saves money

- **Sustainable and passive design methods:** promotes lower operational costs ⟶ saves money

- **Architectural qualities, materials and designs:** promotes health and well-being, as well as the liveability which improve the ability to attract new employees/users, reduced expenses for dealing with complaints/repairs and increased asset values and the chance to increase the income ⟶ earn money.

- **Circular economy:** spur the economic outlooks on a community level, encourage entrepreneurship and self-employment as well as providing conditions to develop circular economies making people more eager to spend within the community ⟶ earn money

Figure 11

1.5 The Pressure is on New Buildings

‘By 2060, the number of buildings on Earth is expected to double; this is equivalent to building a New York City each 30 days for the next 40 years.’ - Yet-Ming Chiang (Chiang et.al. 2019)

Along with the need to properly take care of the existing building stock through appropriate renovation, is the demand for new buildings that are efficient, resilient and have zero emission impact on the environment (Architecture 2030, n.d.). Sustainable new buildings are crucial for the direction of the future, especially in developing countries where the need for new construction is particularly high. Instead of having developing countries following the footsteps of developed ones in terms of using highly processed, industrialised building materials, they can choose to base their development on more sustainable principles. Any other way of approaching future architecture is unfavourable for life on earth. Since the construction industry accounts for over one third of the global emissions, a great responsibility lies with it. The UN Environment Programme stresses that the use of environmentally friendly, local and affordable building materials for new buildings is one of the ways to tackle environmental, social and economic issues around the world (UNEP, 2020).

1.5.1 Let’s Talk About Cement and The Villain Limestone

‘Annual world production of cement is enough to make 4 tons of concrete per year for every person on the planet. Concrete is the most abundant of all manufactured products.’ - Hendrik G. van Oss (US Geological Survey, 2018)

Carbon Emission Issues

Cement is the most widely produced man-made material in the world (U.S. Government Publishing Office, 2018). The cement and concrete industry is one of the main producers of carbon dioxide (Harvey, 2021). Furthermore, they are the second most consumed materials on the planet after water (Walker, 2021). How to reduce the material’s carbon emissions is one of the most difficult challenges the cement industry faces today.

Carbon emissions in cement products are released in two different ways, direct and indirect. The direct emissions account for around 50 percent of the total concrete industry emissions. It occurs through calcination, i.e. when limestone is heated and broken down to calcium oxide and carbon dioxide. The indirect emissions

Figure 12

(accounts for 40 percent) occur when fossil fuels are used for the heating process of lime in the kiln, as the most efficient way to reach the required temperatures is to burn a lot of coal (Stone, 2019). However, other fossil fuels such as natural gas and oil are used too. The remaining 5-10 percent originates from other indirect emissions connected to electricity used to power plant machinery together with the transportation of the finished product (Rubenstein, 2012).
Although the cement industry is fully committed to reducing the embodied carbon within the materials and has shown signs of progress, they are too slow and insufficient. Therefore, the environmental impact of cement production still remains substantial. As our time window for preventing consequences from climate change grows smaller, major investments in new technologies are needed. But it takes time to change the way a whole industry operates.

Air Quality and Health

Apart from carbon emissions, another aspect to be raised concerns the use of non-renewable resources. One of these is lime, an essential component in cement production. The mining process destroys landscapes while releasing dust and other pollutants from the explosion process to break down limestone and clay, affecting the air quality for the surrounding environment. Mined components are mechanically crushed and sent through a series of chutes. It is during this stage that the main pollution source is produced, namely the cement by-pass dust.

Despite pricey implementation of mitigation measures to safely dispose of the component, it continues to destroy natural environments and harm human health. This is seen in Egypt where annually around 2.4 million tons of cement by-pass dust is diffused into the atmosphere (El Hagger, 2005). Another example of the issue is found in Chilage, Zambia, where residents near the cement plant suffer from respiratory tract infection (RTIs), throat problems, excessive tearing and eye itchiness as a direct consequence of the exposure of dust connected to the cement production. Furthermore, the dust pollution affects the growth and productivity of crops and plants in the distal cement plant (Mungwa, 2017). Additionally, research from Indian Institute of Technology Kanpur shows that cement dust from the process of mixing concrete is estimated to make up for 10 percent of the coarse particulate matter that chokes Delhi. In 2015, a study showcased that 19 of 19 large scale construction sites exceeded the safety levels by at least three times (Safi, 2017).

1.6 A Growing Interest in Earthen Architecture

'Earthen architecture is one of the most original and powerful expressions of our ability to create a built environment with readily available resources.' - UNESCO World Heritage Convention (n.d.)

Figure 13

The changing of attitudes towards earthen architecture can be seen across the globe as there is a rising awareness of environmental, social and economic issues associated with building. For this reason, an increased interest in earthen building materials is seen. This is mainly because they have lower environmental impact in comparison to conventional materials such as concrete or bricks as they do not require heavy industrial transformation processes before use. Furthermore, it appears that earthen materials have potential to make use of excavated soils. In Europe, 50 percent of all waste production comes from the construction sector and among these, 75 percent consists of soils and stones that could be reused for earth buildings. This is of particular interest since it is increasingly hard to find suitable landfill areas for this waste. In terms of social and economic issues, building with earthen materials can have a positive impact in developing countries where there is a strong demand for affordable houses. Conventional materials such as concrete usually require importation and transportation which push the prices up, whereas earth is usually locally available, affordable and fairly easy to learn to work with for unprofessional builders. Consequently, local economies can profit from earth constructions which generate a positive social impact (Fabbri et.al. 2022).

Figure 14

The stabilised rammed earth structure from 2019, the Bayalpata Hospital in Nepal, transforms an aged and overrun clinic into a model of sustainable rural health using local labour and materials.

During the last twenty years, the number of scientific studies of raw earth construction materials have increased substantially. This has resulted in the development of standards for earthen materials in at least 18 different countries such as Australia, New Zealand, France, Germany, Switzerland, USA, Colombia and India. However, the technical information of the different standards varies and there are neither uniform laboratory test methods nor universally accepted standards for earthen building materials, making them an unattractive and unsuitable choice for modern constructions that require reliable standards (Vyncke et.al., 2018).

Earthen materials are still commonly used in large parts of the world, especially in developing areas in Africa, India, Central- and South America. When directing the attention to this ancient material, one can gain knowledge about climate control, economic construction techniques and from there find ways to put this same material into contemporary use in a combination with conventional materials.

Why Don't We Build More with Earth Today?

Contemporary mainstream architecture is rarely built with earthen materials as they are not considered to fit modern building practice. This is mostly due to their high variability, reliance on local specificities, lack of codes and standards and insufficient structural abilities such as compressive strength and durability (sensitivity to water). Furthermore, building with certain earthen techniques is very time consuming, which is a problem in highly industrialised countries. Apart from being considered an out-dated construction material, another important reason for the abandonment of earth is the loss of knowledge about its use as a building material. Today it is difficult to find globally recognised and established educational opportunities in earthen architecture, which leads to its neglect in common building practice.

Amount of relevant articles about earthen materials and buildings in the world

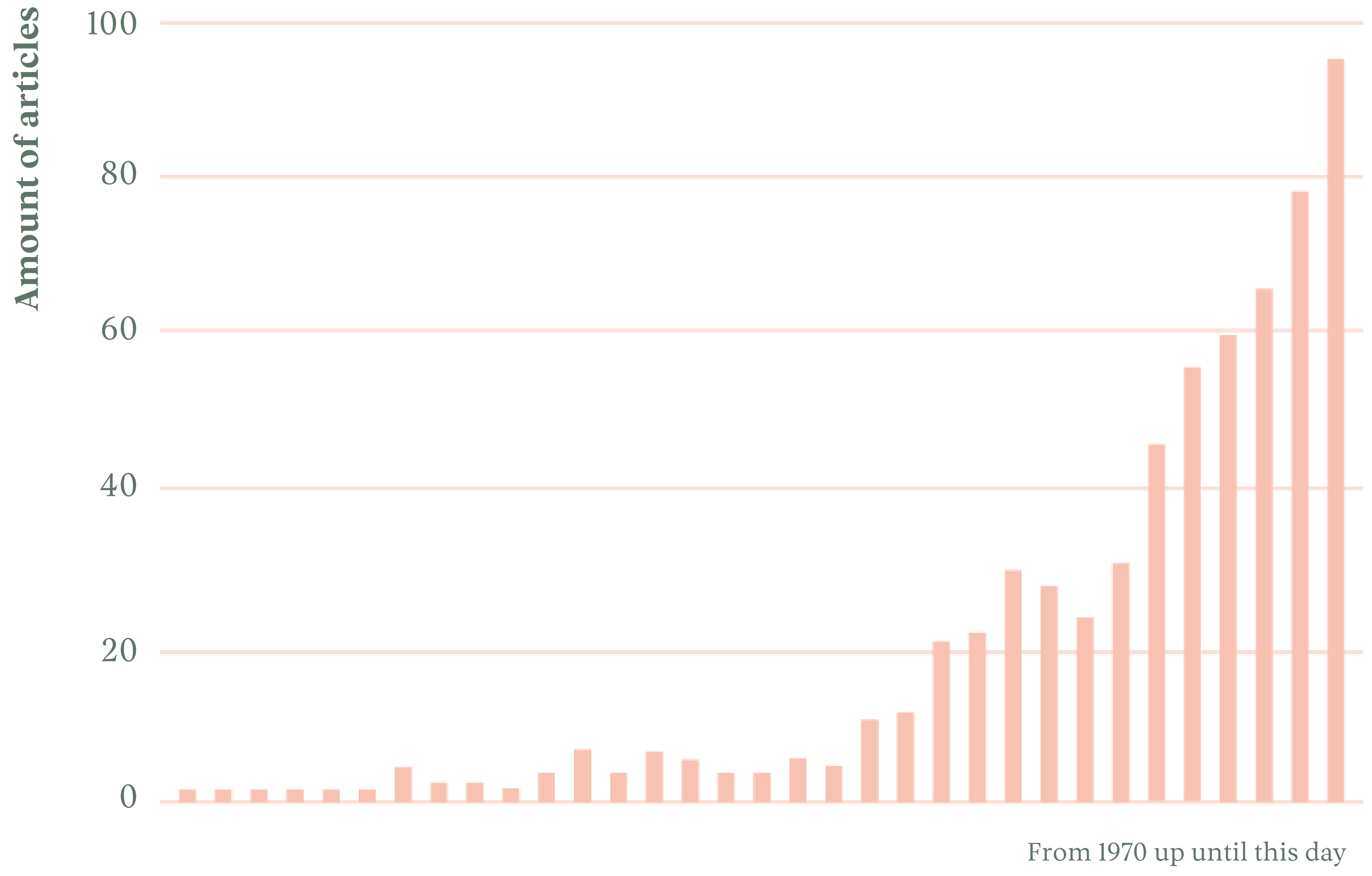


Figure 15

Map illustrating the worldwide use of earth construction

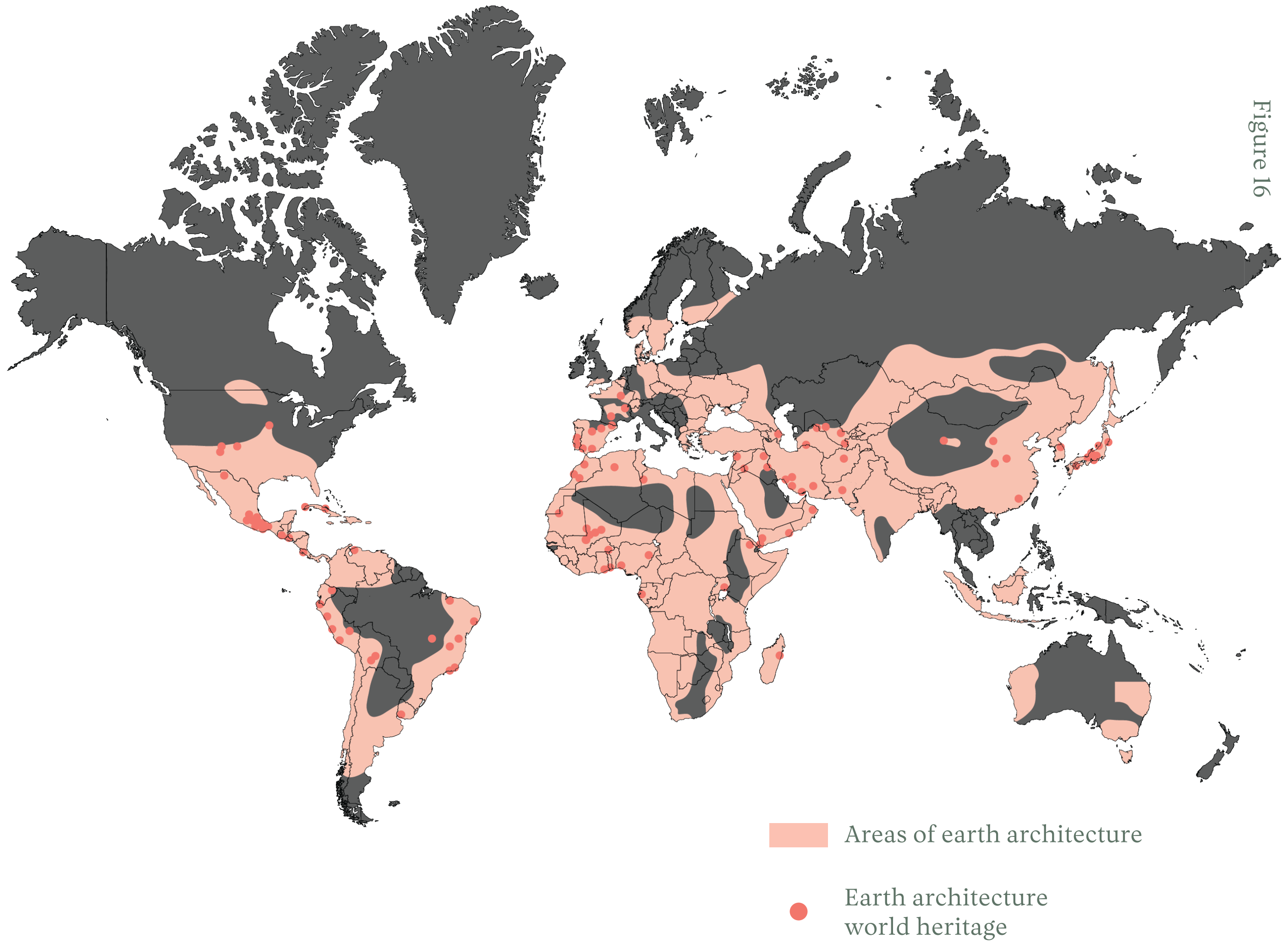


Figure 16

1.7 Objectives and Aims of Study

Figure 17

Our interest in earth as a building material was evoked during the course Urban Shelter at Lund University, School of Architecture, where we were introduced to urban planning in developing countries. The design project for the course was located in Dar es Salaam, Tanzania, where we were to develop a neighbourhood design followed by a building design with focus on sustainability in general, but affordable housing in particular. Along with careful considerations about the design, was the matter of choosing sustainable building materials. We then realised that this was a complete world of its own. The awareness of our lack of sufficient knowledge gave rise to a curiosity about a somewhat unexplored academic field of study; earthen building materials. As earth architecture seems to undergo a revival, we believe that a more profound study of the material is valuable for our future as architects. To be able to promote sustainable building materials - and in the long run sustainable architecture - we need to know more about them. Our aim is to highlight the knowledge and scan the latest research on earthen building materials and earth architecture as it has not really been part of the academic curriculum at the Architecture School at Lund University. Our hope is to increase our knowledge and gain a better understanding of this material and its environmental-, social- and economic impact and furthermore its potential to be incorporated in contemporary architecture.

Figure 18

Kawe, the area which we were to develop during the course Urban Shelter, where both of us were introduced to urban planning in developing countries and laid the foundation for this thesis.

Figure 19

CSEB (Compressed Stabilised Earth Blocks) used for construction of built environments. The photo is taken at the Building Research Institute in Dar es Salaam, where we learnt the basics behind the production.

1.8 Delimitations

Figure 20

This thesis will treat earth as a building material for building construction. By earth, we mean raw earth and not burnt earth. Information about earth as building material is widespread but inconsistent, making it a slightly difficult subject to investigate. Given the time frame that we have for this thesis, our aim is not to create guidelines on how to build with earth, nor to present detailed information of its technical properties, but rather accentuate some of the existing knowledge about the material.

Furthermore, we will not go into detail about the potential for earthen building materials in a specific climate or country, but will rather investigate the overall potential earthen materials have for the future built environment around the world.

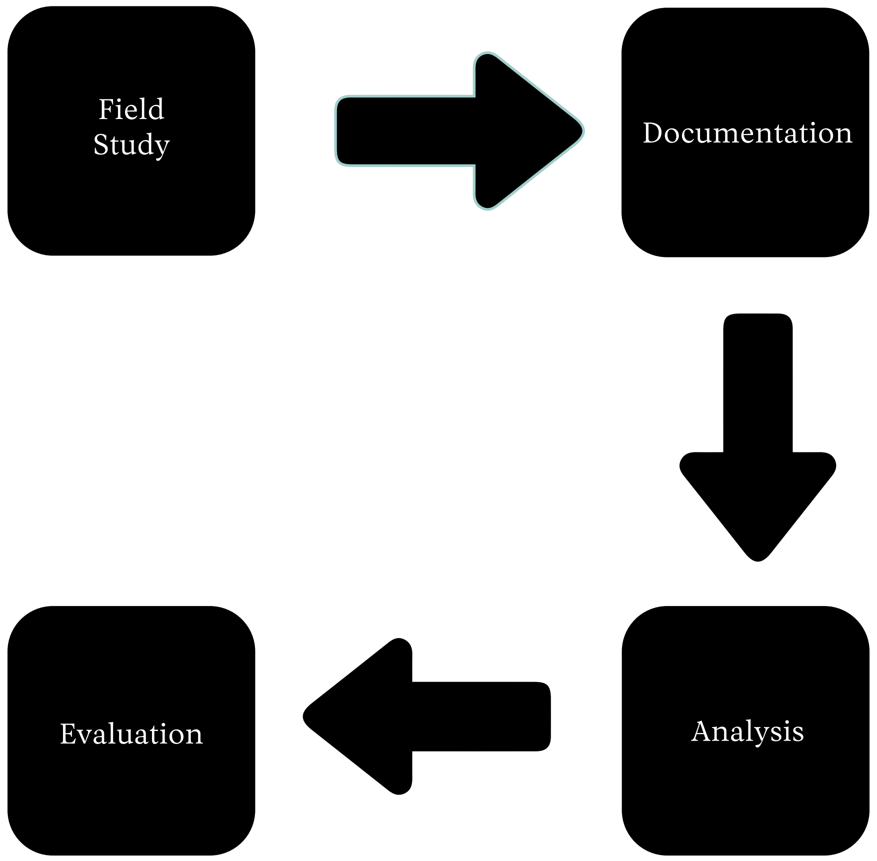
1.9 Method

Figure 21

To study the potential for earthen materials, we chose to carry out a field study between January and Mars, 2022. Together with the NGO TAWAH, Tanzanian Women Architects for Humanity, we participated in parts of the construction of TAWAH Vocational and Resource Centre in Mhaga Village. We first encountered the organisation through a lecture in the course Urban Shelter at Lund University, which was held by one of its founders; Victoria Marwa Heilman. The work and enthusiasm of TAWAH made a lasting impression so we contacted her afterwards to learn more. Parallel to the conversation, we had a growing idea about a master thesis treating the topic of earthen materials. To our delight, a project was to start during the fall of 2021, where earth is used as the main construction material. Our collaboration evolved gradually over a period of a year where we had an on-going conversation to plan everything accordingly and get updates before the arrival.

While on site we conducted several interviews with the female participants of the project, where volunteers at TAWAH translated the questions and answers. The participants in the interviews that we conducted were chosen based on who was working that specific day as well as dependent on who wanted to participate. TAWAH furthermore let us take part of their previous studies, interviews, drawings, contacts and experience which have given us invaluable insights throughout our stay. To complement the collected data from the field study we conducted literature studies and participate in webinars in order to investigate earthen materials and their environmental potential. Our findings will be put together and result in a compromised handbook of earthen materials.

Our reasoning behind choosing Tanzania, lies in the struggles that the country faces in terms of major social and economic problems. By conducting a field study on site we were able to study the matter of social sustainability on our own, and hopefully gained valuable insights and knowledge that can be hard to find in literature. Getting to know a culture, a society and people living there is important in order to get a better understanding of how we as future architects can contribute to a positive development. The first hand experiences of the country inevitably provided a more holistic understanding of it, that can simply not be achieved in any other way.



Field study in Tanzania: participate in the construction of TAWAH Resource and Vocational Centre in Mhaga Village

Documentation: literature studies, webinars, study visits, meetings with experts and participate in workshops. Conduct different testing methods for soil to identify its properties and characteristics.

Analysis: Discuss earth in terms of a contemporary building material. Analyse the potential in integrating earthen materials with other contemporary building materials in so-called hybrid-constructions.

Evaluation: Evaluate the potential of earthen materials as well as TAWAH Resource and Vocational Centre in Mhaga Village

Chapter 2

2.1 African Urbanisation

Figure 22

Africa is one of the continents with the highest urbanisation rates. It takes place in countries such as Tanzania, Nigeria, Mozambique and Angola (Buchholz, 2021). Much of Africa's urbanisation has been what the development economist Paul Collier would call ''dysfunctional", characterised by insufficient infrastructure, shortage in formal jobs and all the issues followed by the vastly overcrowded informal settlements (Collier, 2017). There is a shortage of active and far-sighted governmental policies followed by a lack of economical and influential power, consequently putting authorities in a weak position. Above that, many of these countries struggle with corruption and distrust from its citizens (Gardham, 2021).

Figure 23

The City Centre of Dar es Salaam .

2.2 Tanzania

Almost one-third out of Tanzanians nearly 60 million people live in urban areas. Among these, approximately 40 percent of those lived in informal settlements in 2018 (The World Bank, 2022). Dar es Salaam alone hosts a population of over 7 400 000 people. It makes it the fifth largest city on the continent (World Population Review, 2022a and b). It is projected to be crossing the ”megacity” threshold of ten million people before 2030 (UN, 2016). As Tanzania is one of the countries experiencing an explosive urbanisation, the demand for new construction is high. The country therefore holds a great potential to improve construction trends.

However, the country faces big challenges regarding lack of governmental influence, unemployment and economy. Although the GDP has increased over the past decades, Covid-19 resulted in an economic shock followed by the first GDP decrease in 25 years. As a consequence, the poverty line has been estimated to have risen from 49,3 percent in 2019 to 50,4 percent in 2020. In 2020, 53,1 percent were unemployed according to official records (The World Bank, 2021a). Fortunately, the trend is not only negative. The country progressed and went from a low income country to a middle-low income country in 2020 (The World Bank, 2021b).

Figure 24

Figures 25

2.3 TAWAH

Decent Shelter for All

Who: TAWAH (Tanzanian Women Architects for Humanity), NGO
Origin: Dar es Salaam, Tanzania
Established: 2011
Profession: Architects, Construction engineers, environmental engineers, economist and quantity surveyors

TAWAH, is a NGO established in 2011 by female Tanzanian architects and engineers. The name itself stands for Tanzania Women Architects for Humanity, where the reason behind a team solemnly existing of women is rooted in the will to strengthen the position of female professionals in the field of construction. Today's Tanzania is still influnced by the traditional belief that construction is a man's field, and on which basis, women face discrimination due to their gender. The TAWAH members have extensive experience in all phases of construction, including financing, pre-design -identifications of project beneficiaries-, design, material production, construction, improvement of buildings, project management and turnover of the finished structure (Julius Bär Foundation, 2019). The organisation focuses on helping marginalised communities such as women, children, people with disabilities and people in poverty. By implementing a participatory approach by using locally available materials such as earth, they can achieve affordable and adequate shelters and educational facilities. These projects are usually so much more than just built structures. They also work as catalysts for economic and social development for these often small communities as they strengthen the practical building knowledge among the local people and therefore also the capacity for self-help (TAWAH, 2021a).

2.4 The Project

A Centre for Self-Resilience

Figure 26

Access to decent shelter is a major challenge in Tanzania, especially in the rural areas. It is particularly challenging for elderly, people with disabilities and single female-headed families, since they usually lack stable incomes and influence. The need for a support system tied to social relationships and relatives therefore plays an important part in their everyday lives. After a previous construction of a boarding school for girls in Mhaga Village, the villagers got so grateful that they decided to donate land to TAWAH. This gesture later led to the project and construction of TAWAH Resource and Vocational Center in Mhaga village. The finished centre is intended to be a women-led knowledge and training centre, focusing on teaching and producing Compressed Stabilised Earth Blocks (CSEB), mainly made out of locally available soil. The interior spaces will accommodate theoretical learning while the exterior spaces in front of the building will host the practical teaching as well as the brick making production. Women from all over Tanzania are expected to arrive and participate in the learning.

The aim of the project is to strengthen community relationships and problem solving, as well as empowering females' self esteem and self-capacity. By using a participatory approach, the construction will be built mainly by women from the village who will be trained by professionals in the construction field. The centre will focus on CSEB making and will teach the participants knowledge of construction techniques using locally available materials. The intention is to equip women with technical and managerial skills to spearhead the construction of decent shelter and affordable construction. This provides tools so that they later on can create enterprises and continue working in the construction field on their own, and have a reliable income even after the centre is finished. All in all, it is expected that 120 women from Mhaga will participate in the construction along with 24 volunteers and around 16 skilled builders.

Enhancing social interactions, inclusiveness and sustainability are key design goals. The centre is mainly constructed of interlocking earthen bricks, which will have an overall polished finish, with plastered corners for aesthetics. The design language is rooted in Swahili architecture and promotes culture preservation, climate suitable choices and nurturing of the Mhaga community. The spaces are made in rectangular shaped complexes with large roof overhangs for screening off sun and rain. They are arranged around a private courtyard, with a big tree in the centre for shade and outdoor activities. Usually the shaded space underneath a big tree is where social gatherings take place in Tanzania.

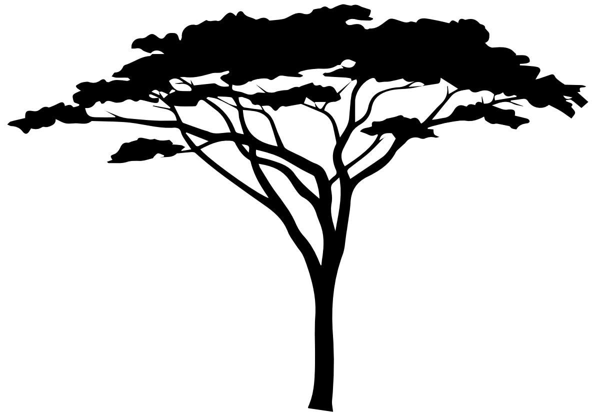


Figure 27

Life Happens Under the Tree

We actually got the honour to name this tree and came up with the word "Fika", chosen due to its two meanings. In Sweden, it is a concept associated with a break from an activity, where people gather to drink coffee or tea and eat something light such as a small sandwich, a cake or some fruit while chatting with each other. In Swahili the word refers to the verb "Fika '' which means to arrive. We believed it to be suitable due to the aim of attracting women from all over the country to reach the learning centre.

Figure 28

Figure 29

2.5 The Village

The Rural Area of Mhaga

Mhaga Village is located 77 km east of Dar es Salaam, in the coastal Kisarawe district. The village consists of approximately 2000 inhabitants who live under very simple conditions and lack access to electricity and running water. Houses are scattered in the landscape, connected by small trails. Most of the houses are built with earth, constructed with the cob technique wattle-and-daub. It is a wet soil, often containing cut straw, that is thrown on an interwoven mesh constructed out of branches and twigs with a diameter of around 30-60 mm. The roof is either covered by thatch or corrugated iron sheets. Some of the villagers have managed to save enough money to be able to construct houses out of sand-cement blocks. Others have piles outside their clay house, hoping to earn enough money to someday be able to buy the remaining blocks and start construction. The main occupation is agriculture intended for private use. The few who can afford it, travel to Kisarawe town, 39 km from the village, to sell their crops and buy necessities. An earthen road is splitting the village in half, to later be subdivided into a few minor roads that lead to the public buildings of the village. It is not common to reach residential houses by car since most people walk, bike or travel with motorcycles. The houses can be quite far from a road, around 30-40 minutes by foot.

TAWAH Resource and Vocational Center is located in the northern part of the village, bounded by two distributing roads, with the main village road to the north and a smaller road that provides access to the site in the east. The area of the site is about 20 639 m^2 (5 acres) with a relatively flat topography, originally covered in grass and vegetation. Due to the overall situation of the village, the site lacks access to utility infrastructure. The microclimate of the site is hot-humid with high UV-index with an average of 6.3 making it essential to build north-south oriented buildings.

2.6 The Women of Tanzania

A Marginalised Group

Figure 30

Among the most marginalised and underutilised groups in Tanzania are women (USAID, 2021). Even though the majority of the citizens support equal rights and opportunities for women, the reality is somewhat different. Apart from payment gaps, women face challenges concerning credit and skill development, productive resources and domestic violence (The United Republic of Tanzania, 2018). Tanzanian society largely consists of patriarchal communities where women are under the control of men and therefore also addressed with a lower social status (Minde, 2015). The division of labour and resources within the household is stereotyped and split into masculine and feminine roles. As many as 40 percent of all women have experienced physical violance, 20 percent of the women have suffered from sexual violence (from the age of 15), while 44 percent of married women have experienced both physical and sexual spousal abuse. There is also growing evidence of increasing sextortion, where sexual favors are extorted in return for rendering public services in workplaces, health centres, public service offices and even in primary and secondary schools (The United Republic of Tanzania, 2018).

Although the issue of inequality is addressed by national authorities, most of the progress is driven by grassroot oriented organisations and NGO:s. Initiatives are directed to women in both urban and rural contexts, aimed at getting them more educated and involved in activities from which they can earn their own money. One initiative intending to contribute to the progress for Tanzanian women was implemented by the government in 2016. It states that among other rights, women are entitled to “acquire, own, use or develop land under the same conditions as men” (Reuters, 2014). However, only about 15 percent of privately owned land in Tanzania is under sole female ownership. That is to be compared with 47 percent male owned land respectively 38 percent joint male-female ownership (The World Bank, 2013). On top of that, the custom practice for women to get access to land is still through their fathers, brothers, husbands or other men (Duncan and Haule, 2014). In Tanzania, access to land is crucial for food production and income generation. It is also a source of power that increases social status (SIDA, 2015). In fact, women account for 70 percent of the food production (The United Republic of Tanzania, 2018). In order to reduce extreme poverty, build healthy communities and promote inclusive growth, gender equality needs to be achieved. Therefore, females must have greater access to and over resources, opportunities and decision-making power (USAID, 2021).

Figure 31

Figure 32

2.7 The Local Voices of Mhaga

About the Women in the Village

Figure 33

By focusing on the real stories and desires of the individual women in Mhaga Village, a foundation for a kind of "identity architecture" can be developed. A kind of architecture that like a fingerprint fits the needs for the target demographic group: the rural and poor female villagers. After conducting several interviews and conversations with the female workers on site, both before and during the construction, one thing is particularly clear: there is a strong will to learn and change course in life.

The women of Mhaga Village express a strong will and desire to become something greater than just a mother and a wife. There is an eagerness to learn new skills and be independent. They want to be able to support themselves and their families and obtain a personal income, to recover financially and gain a life-long self resilience. Some women want to use their new gained knowledge to build and/or improve their own homes while others express a desire to possess a leading position or become teachers in the construction field.

The situation of the women today is harsh. Their living conditions are tough with little chance to change their situation on their own. A vast majority of 81 percent of the women in the village earns their living through agriculture, 13 percent operate a

Figure 34

small business involving amongst other charcoal making and woven mats, while the remaining 6 percent have no kind of occupation at all. For the women working in the agricultural field, the work is made by hand and on a small scale, around 1-3 acres.

Concerning marital status, 60 percent of the women are married, while 27 percent are singles and 13 percent widows. 71 percent of the women have children and among them 20 percent are single mothers and 7 percent widowed with children. The most common number of children to have is three, but the number ranges from one to seven. Above that, 29 percent have responsibilities towards relatives. Only 2 percent of the women have only themselves to take care of. The situation described is one where these women, in 98 percent of the cases, have someone else that is dependent on them (TAWAH, 2021b). Women are also more likely to spend their income and time on family, relatives and community rather than personal interests compared to their male counterparts (Marwa Heilman, 2022). Providing a platform for personal development would therefore not only affect the women themselves, but the whole village profoundly.

The age span of the participants ranges between 20 to 70 years, with an average- and median age of 40 years. Most of the women, 82 percent, have finished the seven years long primary school education, whereas 7 percent have completed four years of primary school and the remaining 11 percent haven't studied at all. None of the women have completed or started any higher education (TAWAH, 2021b). Due to the educational fees the women cannot afford to continue or advance their studies. The centre will therefore provide an invaluable asset in the prospective personal development and enable new potential ways forward.

“We are here, we are motivated and we want this project to continue to expand.”

Name: Mwanzani Mape
Age: 50 years

“I am satisfied to participate in the construction of the centre. I can see a light in my life. I now have skills to either be self-employed or get employment. I see a bright future!”

Name: Salma Betala
Age: 47 years

“We are very grateful to have this project here in the village that will realise the dreams of mothers. It will bring us a lot of income. We are used to living with the thinking that we were unable to do anything as women, but this project has shown that women can work together”

Name: Debora Maskati
Age: 61 years

“We are all happy to be given the project to our village. Not only for the sake of us mothers ourselves, but for our children too. We have children who will soon finish grade seven. After that nothing lies ahead of them, except work on our fields. We therefore hope that there will be a chance for them to participate and learn from this project too.”

Name: Maua Samweli
Age: 47 years

“Since the start of this project I have seen great benefits from it in Mhaga Village. So many young people here, including myself, were desperate because of the hardships of life. Now a change in mindset has occurred in these people and hope has started to grow.”

Name: Salma Mdago
Age: 25 years

“I am happy to be working together as a community. We have already started to create one with the women working here on site, to continue helping each other out and build homes for everyone in the village. And I want to construct even more groups.”

Name: Salma Ndovu
Age: 36 years

Figure 35

2.8 The Phases: From Centre to Community

About the Organisation

Figure 36

The project is divided into four phases, each expected to be finished within a year. Along with the construction of the centre, 44 elderly homes in Mhaga village will be reconstructed to also improve private shelters in the village. The housing condition is very poor, where most of the people live in wattle-and-daub houses while others live in houses solemnly made out of thatch. Many of them suffer from severe cracks, big holes covered with unfastened iron sheets and insufficient roofing making rain reach the interior.

Some houses completely lack toilets, while others have holes in the ground covered by thatch. The reconstruction of the houses is part of the training program for the women participants to learn and receive more knowledge in affordable housing and brick production. Simultaneously, it is a way to bring community groups together for training in how to create strong, supportive communities that help the needy and marginalised people. At the time of writing we are in phase two.

Figure 37

Phase 1

The first phase includes the construction of the centre, starting with the main entrance, a reception, two training rooms, a meeting room, an office, toilets, a nursery and a bricks production plant.

Figure 38

Phase 2

The second phase includes the completion of the canteen, kitchen, parking space, a guard house reception and the construction of the first 6 elderly homes. The remaining 38 elderly homes will continue to be built during the following years and are expected to be completed in the final phase.

Figure 39

Phase 3

In phase three, an addition of two more training rooms will be added along with a toilet complex accessible from the exterior.

Figure 40

Phase 4

In the final phase the construction of volunteer accommodation facilities will be completed as well as the remaining elderly houses.

Figure 41

The housing conditions of Mhaga Village is more or less the same as this ealdely house in the village.

Figure 42

The TAWAH team gathered in front of one of the elderly homes ready to start the construction of a new house.

Figure 43

Beginning of the construction of one of the eldely homes in Mhaga.

2.9 The Construction

Form Follows Materiality

Figure 44

Tanzania has a widespread and far-reaching tradition of using local earth as building material. Although many houses are still built with earth, especially in rural areas, the most commonly used building material is sand-cement blocks (sandcrete). Usually the cement content in these products are down to 4 percent, which can be compared to ordinary concrete which contains between 10-20 percent. Cement is the main driving cost in building constructions in Tanzania which explains the widespread use of sand-cement blocks instead of concrete (Isaksson and Mrema, 2016).

The choice of building material for the TAWAH Vocational centre in Mhaga Village was determined before the sketching process started. The whole project centred around using as local building materials as possible, in order to allow for the people in the village to continue to build even after the project has finished. The material chosen was for that reason compressed stabilised earth blocks (CSEB) made out of local soil from the site mixed with a portion of cement in order to achieve a steady load-bearing structure. There are some design solutions to take into consideration when designing with CSEB. Use of a column system combined with a ring beam are common ways to improve the structural strength.

Because of the assumption of high clay content in the soil, the amount of added cement had to be higher (8 percent) than the amount used in the sand-cement blocks (4 percent) in order to compensate for the lack of aggregates in it. The reason for constructing out of earth was not primarily based on lowering the cement amount, but rather the cost, combined with the opportunity to teach how to construct with local earth. Although the amount of cement can be equated with concrete, the cost of the cement is still lower than the cost of buying and transporting sand that would otherwise be the case if sand-cement blocks were used. By using soil extracted from the building site itself, purchase- and transportation costs could be reduced, thereby increasing the affordability of the project.

Figure 45

Figure 46

For the construction of the centre, two different kinds of earthen blocks are produced, one solid kind and one hollow. The solid ones are used for the construction during phase 1, while the hollow ones will be introduced in the beginning of phase 2 and will be used to construct the remaining part of the centre as well as the individual houses for elderly. The hollow earth bricks aren't load bearing and a system of columns is needed for sufficient support. The bricks are stapled on top of each other without any plaster in between. Instead they are interlocking with each other and kept in place through the use of a ring beam on top. A ring beam is a reinforced concrete strip placed at the top of the wall in order to tie the bricks together so that the wall will be able to carry the load of the roof.

In the final drawings, before construction, a 9 metre long perforated wall was to be built. However, due to the heavy load of the ring beam, it would cause structural issues. The wall had therefore to be divided into two perforated wall pieces with one solid wall piece in the middle to carry the load. By using the interlocking technique, the earth blocks are able to move more freely and therefore become more ductile. It allows the walls to cope with horizontal forces better, making it more earthquake resistant which is necessary in this area. Hollow bricks improve it even further. The plaster saved by using an interlocking system composes a large proportion of money. It's one of the main reasons why it is economically possible to construct the centre. Plaster is only used on the exterior facade to seal the gap between the joints, making it more resistant to water and vermin. As a finish, a glaze coat epoxy sealer is used to make the facade water resistant and give it a glossy expression. The corners, ring beam and part of the interior walls will be covered with a sand-cement plaster for aesthetic reasons.

Epoxy requires careful handling as all epoxy resins and hardeners are liquid chemicals. As a consequence, the epoxy users need to protect themselves. It is essential to wear respiratory, nitrile gloves (or a suitable barrier cream) and it is recommended to use safety goggles, long-sleeves and pants (resin8, 2022).

The openings have to be made in a specific size for the walls to be able to carry the loads. General guidelines is to have openings that run from the foundation all the way up to the ring beam. The openings shouldn't be wider than 2 metre, with at least 1 metre spacing between them. These large openings are very suitable for the hot-humid climate as they improve natural ventilation and therefore thermal comfort, decreasing the necessity of air conditioning.

The addition of a large outdoor veranda provides sheltered space for social interactions and dining in the shade. Shaded pergolas and perforated walls are added to create comfortable interiors with natural ventilation. The design pays attention to local culture, economy, and the overall situation of the village. Waste management, recycling, easy building maintenance and inclusiveness for women and staff with all types of disabilities have shaped the design of the centre. The main challenges on the site is the supply of water and electricity. By using an Anaerobic Baffled Reactor for grey- and black water treatment, both gas and water will be upcycled and used for irrigation and gas for cooking. Municipal supply will be complemented with rain water harvesting to access clean water. The centre will be powered with solar energy panels together with electricity from Rural Electrification Agency (REA).

Figure 47

Noteworthy is that this project is a pilot project where both the members and the participants will be part of a learning process. The result is therefore yet to be seen.

2.10 The Building Components

The Materials and its Manufacturing

The Soil:

The soil on site has not been properly evaluated. The CSEB recipes were based on the assumption that the soil was sandy clay loam, the same as the general classification of Mhaga Village.

Figure 48

The Foundation:

Components: Concrete and sand-cement blocks

The rubble foundation consists of these following layers named from bottom to top:

- Compacted soil (by machine)
- Big rocks
- Sand
- Termite spray
- Plastic film
- Concrete

Recipe Sand-Cement Blocks:
(35 solid pices)

- Sand: 1070 kg
- Cement: 50 kg
- Water: 70 kg

Ratio:

- 90 percent sand
- 4 percent cement
- 6 percent water

Walls:

Components: CSEB

Earthen bricks for the wall construction and sand-cement plaster for the corners and some of the interior walls. A glaze coat epoxy sealer will be used to make the exterior facade waterproof. On the top of the wall a ring beam is to be constructed.

Recipe Earth Blocks:
(36 solid, 70 hollow pices)

- Loam: 550 kg
- Cement: 50 kg
- Water: 70 kg

Ratio:

- 82 percent soil
- 8 percent cement
- 10 percent water

Roof:

Components: Mono pitched iron sheets, a wooden structure and a ring beam.

The mono pitched iron sheets are designed with a large overhang to reduce the usage of wood, and cut the costs. The iron sheets are fastened on top of a wooden structure attached to the ring beam.

Floor:

Components: Sand-cement screed

A floor made out of a mixture between sand and cement to create a semi-dry floor with a coating to prevent dusting

Figure 49

Openings:

Components: wood, glass, mosquito-net

A variety of local treated timber panels, this also applies for the verandah columns that will render the building with a natural wooden colour.

Outdoor:

Components: earth, gravel, vegetation

Earthed pathways will be accompanied with gravelled parking areas and softscapes of newly planted vegetation among some fruit bearing trees and existing native vegetation

Figure 50, 51, 52

2.11 The Design

Architectural Qualities

Figure 53

The original shape of the ground has been redistributed and reshaped by the hands nourished by it as large parts of the building's materials have always been on the site. Maybe that's why it's perceived as so interconnected with its surroundings? Through its colour, scale and tactility, the building becomes a form of resonance with the surrounding context. Despite its 478 square metres, it feels subtle and humble. Its horizontal spread creates an embracing gesture towards the outdoor working area. The building's two wings cast shadows over "the typical Swahili courtyard". Together with planted trees, they protect the users from the strong rays of the sun. The window openings are mainly located in the north and south direction, while the east and west facades are mainly adorned with perforated walls that create a play of light and air flow into the rooms. They additionally create a variety and ornamentation experienced both from the exterior and interior. The pent roof in combination with the generous ceiling creates a dynamic spatial play, despite its regular shape.

In terms of functionality, attention has been paid to the user's needs. It is seen in the nursery room where the participants can leave their children during the learning events, to be able to focus better on their work. Most of the rooms have been compromised to fulfill the essential needs, but still allowing space for various kinds of activities. It is seen in the training rooms (classrooms) where the dimensions vary between 8.7×7 and 9×7 metre.

The training rooms are placed to the right from the main entrance, accessible from both a roof covered pathway and from the courtyard. To the left, the head offices are to be found with an entrance towards the showroom and reception area. In the right wing, supportive functions are placed, such as the nursery and the canteen. In the left wing two more training rooms are located. All are accessible from the courtyard. The flow can therefore be described as logical and fluent, where the movement integrates outdoor and indoor.

The canteen is placed so that it's connected to the outdoor brick making area, creating contact with the activities of the centre with sightlines to training rooms, nursery, brick making area, main entrance and of course the courtyard.

To ease the movement for elderly and people with disabilities the otherwise seldomly seen ramps are used along with staircases. All in all, 3 ramps are placed around the centre.

Figure 54

Figure 55

Figure 56

1. Reception, 2. Training Room, 3. Meeting Room, 4. Office, 5. Volunteer Residents, 6. Bathroom, 7. Nursery Room, 8. Kitchen, 9. Canteen

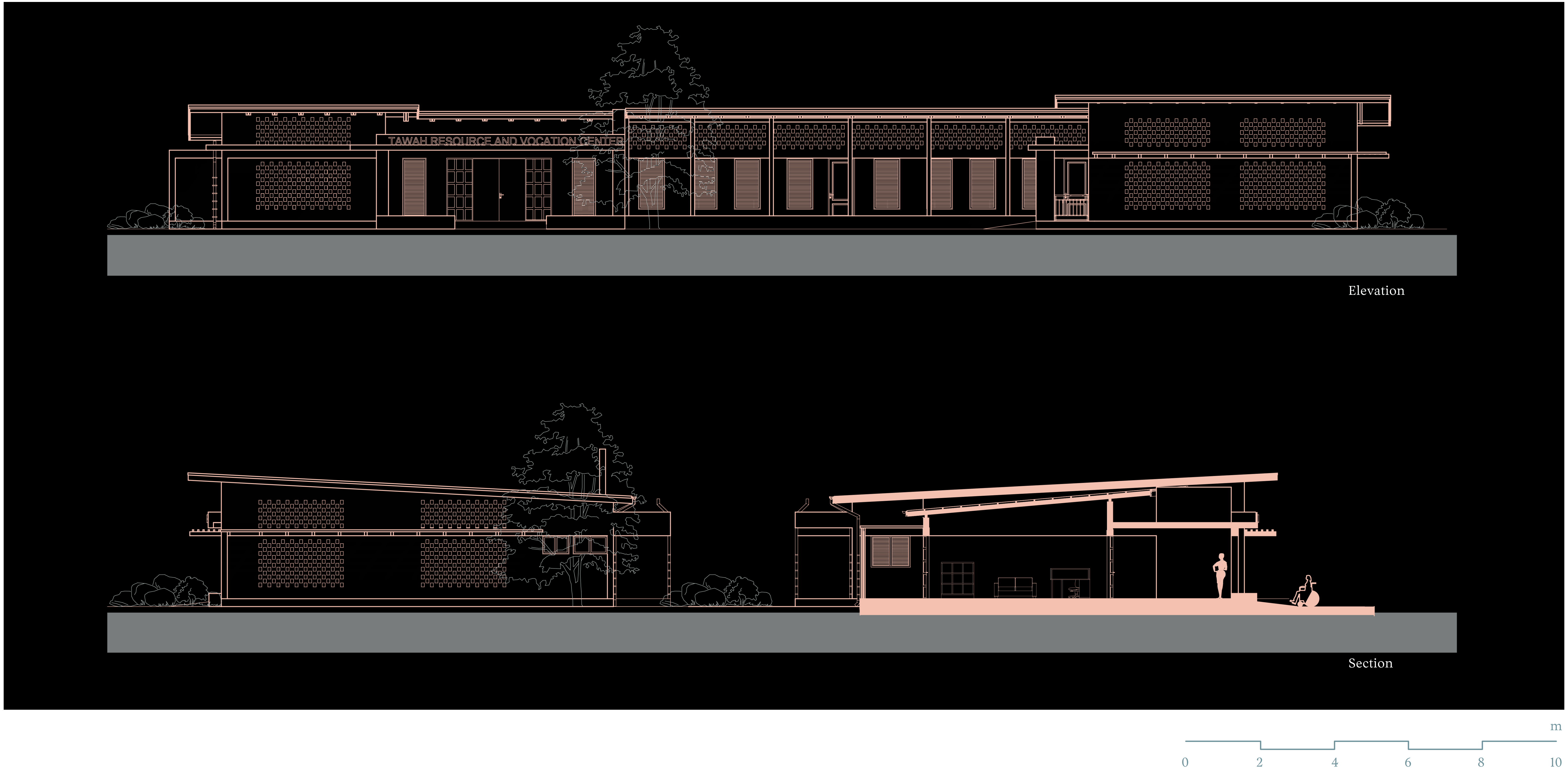

TAWAH RESOURCE AND VOCATION CENTER
Elevation
Section
m
0
2
4
6
8
10

Figure 57

Figure 58

2.12 The Building Process

Contradictions and Challenges

Our own experience from being on the site has brought us invaluable insights. During our field study, we have participated in the construction of the centre as well as conducted interviews with the women on site. Quick problem solving skills have been essential at several occasions as things more often than not tend to go differently than planned. One major issue arose when the first batch of cement was to be delivered prior to our arrival in Tanzania. The weather the day before had made the ground soaking wet and muddy. The lorry got stuck and the terrain was only to worsen further down the road. Instead of driving the whole way to the construction site, it simply had to reverse. The 200 bags of cement were stapled on the ground outside where the lorry got stuck, 500 metres away from the building site. The youth that were hired to help carry the bags saw the changing plans as an opportunity to negotiate. Instead of 500 TSh per bag, which equals 0.22 USD, they required double. A cost too high for the project budget. But the situation was pressured by bad weather, which would destroy all the cement, causing a much higher cost. The fundi of the site (fundi=skilled person and the one in charge of the construction) stood irresolute. His first plan was to cover the cement in a tarpaulin, but that was a risky move. What if it was to blow away? At the end, he, together with 4 other skilled builders, decided to carry all the bags of cement themselves, and ended up working all night.

Another issue occurred in mid-February, and by that time we had arrived in Dar es Salaam. We had gone to the site and were prepared to complete the foundation work so that we the day after would be able to pour the concrete. As we travelled along the main road of the village we stopped to pick up one of the female trainees. She had visited a friend and was on her way home because there was no material on the site. When we reached the site, her story was confirmed. No one was working and the materials arranged to be delivered that day were nowhere to be found. Four lorries were to deliver materials; one sand, one gravel and the last two big rocks. The rocks were particularly important as they were to be stapled first. The day was spent counting each lorry to make sure that all of the materials expected for that day actually got delivered. When the time reached 19.00 we had to go back to the city, even though less than half of the expected deliveries had shown up. The previous week, there was an issue in getting hold of three more brick-making machines. After a lot of phone calls

Figure 59

made by TAWAH, the machines were finally tracked down. However, when TAWAH was about to pick them up two days later only one was to be found. Somehow the other machines had gotten stolen. We therefore had to postpone our trip to the building site for additional two days - five days in total - until we luckily found two other brick making machines available. Unfortunately, they had to be paid for again.

Social challenges circled around attitudes among village leaders and spouses. They were not happy about the fact that the women were now earning a (small) income and gaining knowledge. Some village leaders and elderly spouses with young wifes were particularly against it and were actively trying to keep women away from the construction site. These men had very conservative viewpoints of what women were supposed to do. Since the start of the construction, the village leaders did furthermore favour some women over others. It caused some women to never participate. The village leader kept information from them and never invited them to work. When these women showed up anyhow, someone else was doing their work. To prevent this from happening again, TAWAH had to make a time schedule where every woman was given a certain task, time and date, in order for everyone to benefit from the project. In the beginning of the construction phase, few women showed up to work. Not everyone had been convinced and had enough trust in neither themselves nor in TAWAH to take the chance to participate in the construction. From their point of view, it was rather a risk. As the work on-site proceeded and the women who had decided to join started generating an income and gaining knowledge from the project, more and more women from the village wanted to engage themselves and learn. They had seen with their own eyes that women were capable of doing construction work and also what advantages the participation could bring. Eventually, TAWAH had engaged a majority of the women of the community in the construction work of the centre.

During one of our first visits on the site, we had to witness a minor conflict between TAWAH and the skilled workers that were hired to teach the women. For financial reasons, the women were left to do repetitive and unskilled labour, whereas the skilled builders constructed more advanced parts. It was seen during the digging of the foundation. As the skilled builders started to staple sand-cement blocks on top of each other, women were given the task to fill in the holes with earth. The reason behind was the set payment agreement that was based on a fixed sum

paid for each completed task, rather than a payment method based on the amount of hours it took to accomplish it. The workers' interest was therefore to complete each task as quickly as possible to move onto the next one in order to earn more money. Teaching and guiding the female trainees in the construction was therefore more time-consuming. The fact that the trainees also were slower than the skilled workers contributed to this frustration even more. TAWAH had to have a serious talk on site and remind everyone of the fundamental principles on which the project was based in the first place, namely to train women in all parts of the construction. Since then, this unwanted division of work between skilled workers and trainees hasn't been as prominent, although it is not non-existing. There is a constant balance between financial interests and skill development, which sheds light on an important issue that can arise on a project like this where there is a learning- and participatory approach. Some participants are more interested in the short term financial gains, which can jeopardise the catalyst nature of the project. It becomes particularly prominent

Figure 60

when the work on site already is delayed by other factors such as weather, deliveries and so on, which highlights these different interests.

Some other issues that became prominent during our field study was the overall challenge in making the women maintain their skills. In order for them to remember in a long term perspective it is important for them to write down their knowledge. Providing paper and pen along with a questionnaire is therefore another important aspect of the work achieved on site. Hopefully that will inspire them to contain their knowledge and make them continue to learn more by themselves later on.

For the TAWAH-team as well as us personally, perhaps the biggest obstacle was the time consuming travels back and forth to the building site. Although the distance is less than 80 km, the time to reach the site varied between 2 ½ - 4 hours. We spent between 5-8 hours in a car per trip. The road is rough which resulted in one trip with a flat tire. Another time the car got stuck in mud, forcing us to exit the vehicle and dig it out on several occasions for it to be able to move forward. However, the most time consuming part were the traffic jams in Dar es Salaam, where moving one kilometre can take up to one hour. To be able to go to the site we had to rent a minibus with a driver, which was also fairly expensive. Due to the expenses both in terms of financial means and time, we only visited the site once or twice a week. Some weeks we weren't able to go at all.

2.13 Our Evaluation

Reflections of the Project in Mhaga Village

Figure 61

During our field work, we discovered that there is potential for improvement, as in most projects. It came to our understanding that proper soil testing hadn't been done, making it slightly difficult to determine the soil character and quality. After we had done some experiments for classifying the soil quality ourselves (see Chapter 7.2), by following the field test methods found in literature, we found that the quality of the soil sample differed from the one we had been told was used. Judging from our tests, the soil should have been categorised as "plain loam", while the TAWAH team had used the general qualification of the soil found in Mhaga Village, namely "sandy clay loam". However, repeated field tests or laboratory tests would be required to confirm the result from our own field tests. Nevertheless, as the local soil on the site had not undergone proper characterization tests prior to construction, the amount of cement needed might not have been accurately calculated. Due to this, chances are that the amount of cement could have been reduced, which could have cut both costs and environmental impact without compromising the load-bearing capacity. Furthermore, there might have been a more efficient way of using the earth

blocks. Perhaps it was not necessary to use high cement content in all earth blocks. By strategically placing the high cement content blocks into a load bearing column system, blocks with less or no cement (CEB, Compressed Earth Blocks without stabilisation) could have been used within such a system, since they would not need to be load-bearing. By implementing this method it would also have been possible to fold these earthen blocks back into the ground when demolished, supporting a circular economy. This solution would however need further investigation by a structural engineer.

In terms of social aspects, we have been able to see change in terms of both anticipation and sense of togetherness. During the short period of time that the project had operated, the women have expressed a growing sense of community where they are starting to mobilise themselves into groups in their spare time in order to get things moving and help each other out. This is something quite remarkable and wasn't present prior to the start of the project. Furthermore, they have shown a growing self-confidence. In just a few months they have gone from being very hesitant, withdrawn and insecure to taking more initiatives, getting more optimistic about their future and most importantly, regaining their belief in themselves. The change is seen in their whole being, from the upright way that they move to the tone and energy behind each word that they speak. That is strengthened by their answers when talking with them about their state of mind. A uniform answer of a more optimistic future with a bigger self-esteem was prominent. Before they didn't trust themselves in working outside of the house or the agricultural fields. Through most of their life, they have felt inferior and have undervalued their capacity due to the lack of means for fulfilling desired achievements. With this project, they have seen what they are able to accomplish. It is something completely different from their former perception of reality. It causes them to reformulate the image of their lives and their own potential to shape their futures. The income earned on the site has slowly started to reshape their livelihood. The money has been spent on their families and children. New shoes for one's daughter have been bought while others have spent it on better and more food or medicine for their elderly parents. The economic benefits are therefore already noticeable for many people in the community.

Figure 62

Another insight we had in terms of earth as a building material was that earth buildings do not necessarily have to be more environmentally sustainable than other more conventional materials such as concrete. This is due to the fact that cement is often used in the soil mixture. Careful calculations are required to ensure that no more cement is used than necessary. In Tanzania, the incentives for using earth as a building material are often not primarily based on a desire to build sustainable from an environmental perspective, but rather economic ones. That was also the case at the Building Research Institute at Ardhi University, where they are currently working on developing and promoting earth as a building material for Tanzania. When we asked about sustainability, we quickly became aware of the fact that they were more concerned with creating a low-cost building material than a building material with a low carbon footprint. This is however understandable given that the country faces other major challenges such as widespread poverty and rapidly growing slum areas.

Figure 63

In Terms of Sustainability

To conclude, in our field study we will reflect on the three sustainability principles that we have mentioned earlier, namely the environmental-, social- and economic aspects as a final part of our evaluation.

Planet: Environmental Sustainabilty

Talking about environmental sustainability in a context where people lack their basic rights can be considered as controversial. Understandably, the focus point on projects in developing countries lies in fulfilling the basic needs of people instead of cutting down carbon-emissions. Social- and economic sustainability is therefore of bigger interest when dealing with these kinds of projects. Environmental issues come last and are mostly a side-effect from using cost-effective choices. This is the case for choosing to construct out of excavation soil, instead of other conventional building materials.
Excavation soil is from an environmental perspective advantageous from several different points of view. Perhaps the most obvious reason is giving a material that otherwise is handled as waste a new purpose. Through the use of natural building materials as well as labour performed by hand, the building project should reasonably have a low carbon footprint. Unfortunately, the use of cement, consisting of 8 percent of the CSEB mixture, contributes to a considerable carbon footprint. It can therefore be speculated whether the carbon savings from not having to transport building materials to the site are greater than the emissions connected to the cement usage. Perhaps sand-cement blocks would have been a better option? By stabilising the soil, one of the materials most beneficial aspects is lost, its recyclability. The usage of epoxy sealers contribute to toxins in what could otherwise have been a non-toxic construction project. At the same time do the epoxy sealers provide a more durable and easily maintained complex.

Moreover, the design is adapted to suit the climatic context to make the most out of the given conditions. This in turn minimises the operational costs by using passive design techniques. Natural ventilation, orientation of buildings as well as sun-screens help to contribute to a comfortable indoor climate without the use of air conditioners or fans.

People: Social sustainability

The major focus point for TAWAH Resource and Vocational Centre in Mhaga Village has been the empowerment of women. From day one research, interviews and collaborations with the community has been made to promote women in the construction field and target the specific group. The design is made to celebrate the cultural heritage, while at the same time updating the expression to make it contemporary. A lot of effort has been made to create a sense of trust and spread their message. The work is holistic, meaning that the implementations made are to provide tools for the participants so that the self-

Figure 65: The rubble foundation. Each stone block is placed by hand.

help capacity will increase and continue to grow even after the centre is constructed.

Instead of importing expensive building materials, the soil of the site was used to form CSEB. The released capital from this choice was reinvested in the community, improving the conditions of the whole area. For the construction a program was developed to fit and teach unskilled builders in the construction technique of the centre where the participants were to learn everything from how to make CSEB to construct a roof. A process that employed over 120 women living in the village. Letting people from the community participate in a building project, has led to a major change. For the short amount of time we were there we could already see a shift in mind in the participants. From being timid, shy and insecure, they eventually attended the construction site with energy and confidence. The money earned on the site has started to improve the life of all the villagers, from new shoes for their children to a mosquito net for an old father. As the level of prefabrication is low in developing countries, labour intensive constructions are wide-spread providing the potential for a prospective income. The chance of earning a living from the field is not only prominent for the women themselves, but for the future generations of the village. As the knowledge now exists it can be handed over to the youngsters, so that they in turn can earn enough money to lay the foundation for a life that they dream of. By small means such a large impact can be made which has made us rethink the whole concept of architecture and the power of change we architects actually possess.

Figure 64

Profit: Economic sustainability

The economical reasons for choosing excavation soil for the project is simply because it's free. The economical aspect is further strengthened by the reduced need for transport. Other materials would have needed to be bought in Dar es Salaam which would increase the price of the construction by having to buy both the material itself as well as pay for the transportation to and from the site. Fuel is expensive and the risks of transporting to and from Mhaga Village are not unnoticed. The roads are in varying conditions and the probability of getting stuck or not arriving at the unloading site contributes to risk factors for both the time schedule and its budget. By using passive design techniques the operational costs are reduced to a bare minimum. The aim is to be self-supported where solar panels are to cover the electricity supply, while the water harvesting and treatment secures free water for the centre. If for some reason the supplements aren't enough, electricity from the Rural Electrification Agency will be used along with a municipal supply for water. When managing a good-will project, raising money is always an issue and the budget is tight. Cutting costs is therefore essential for the realisation of any project and a source of conflict when interest varies. Being aware of and spending money cleverly, a project can contribute to so much more than just a building itself. It can be the catalyst for progress.

The diagram to the right displays a compact summary of significant aspects in terms of sustainability and building properties.

Evaluation of TAWAH Resource and Vocational Center in Mhaga Village

Properties	Low ←				→ High
Carbon Footprint	○	○	●	○	○
Use of Excavation Soil	○	○	○	○	●
Material Reuse	○	○	○	○	●
Material Recyclability	●	○	○	○	○
Embodied Energy	○	○	●	○	○
Operational Energy	●	○	○	○	○
Durability	○	○	○	●	○
Local Material	○	○	●	○	○
Ability for Easy Maintenance	○	○	○	○	●
Local Economic Development	○	○	○	○	●
Local Labour	○	○	○	○	●
Suitability for Untrained Builders	○	○	○	○	●
Labour Intensity	○	○	○	○	●
Level of Prefabrication	○	●	○	○	○
Affordability	○	○	○	●	○
Thermal Comfort	○	○	○	●	○
Level of Toxins	○	○	●	○	○
Support of Cultural Heritage	○	○	○	●	○
Fire resistance	○	○	○	●	○
Water resistance	○	○	○	●	○
Acoustic Properties	○	○	●	○	○
Earthquake Resistant	○	○	○	●	○

The data displayed in this table is based on our personal experience during the field study.

Chapter 3

Earthen Materials

3.1 Earthen Constructions Through Time

Then & Now

Figure 66

Earthen materials have been employed by mankind since the Neolithic time. They have been used in constructions through various building techniques such as monolithic walls, infills, bricks, insulation, load bearing walls as well as in floors, roof structures, plasters and mortars (Hamard et.al, 2021). It has been the most prevalent building material world-wide. Today, one third of the human population live in houses constructed out of earth. The number is even higher in developing countries (Minke, 2006). Newly developed earth construction techniques demonstrate the value of earth also for industrialised construction. According to the 2019 Global Status Report for Buildings and Construction by the UN Environment Programme, a key action to increase sustainability into the construction industry is to introduce information on low-carbon materials, such as earth constructions (UNEP, 2019).

Who Builds with Earth Today?

There are mainly three categories of earth house builders that can be distinguished in the world today.

The most numerous category includes those who can not afford to build houses with conventional building materials. Unfortunately, it is not uncommon to find these earthen constructions being built in a quite careless manner, as those houses are normally intended to be a temporary solution until there are more funds to build a "real" house.

These houses often have quite small dimensions and small windows that don't allow for much light to enter the interior. This is the case for many earthen constructions that can be seen for example on the countryside in Tanzania. The image of earthen buildings mainly derives from these kinds of constructions that are generally viewed as "outdated poor quality constructions" and not suitable for modern lifestyles.

The second category consists of those whose building traditions and culture cherish earthen buildings. They want to keep their vernacular heritage alive. As their ancestors taught them, one should do the best with the smallest amount of resources and make small changes for every building project. This can be seen for example in small towns in Uzbekistan where well-built modern houses are constructed with earthen materials in a more contemporary manner with larger dimensions and window openings, offering interior spaces more light.

The least numerous category is the third one, consisting of people who choose earth for contemporary constructions despite having the means to choose any material on the market. The reasons for this choice vary, but is mainly due to the ecological and aesthetic character of the material. This group is increasing quite fast, indicating a change of attitude towards earth, from being a material for the poor to a contemporary building material that suits modern lifestyles.

However, these constructions in today's building practice are usually quite expensive as earthen building materials in many countries lack building codes and standards as well as professional earth builders (Moriset et.al., 2021).

1

Figure 67: A little shop in wattle and daub, Tanzania.

2

Figure 68: Contemporary earthen houses in Uzbekistan.

3

Figure 69: IHA Residence from 2018, India.

Ancient Days

Historically, raw earth has been used for residential, religious, commercial and monumental structures. Architectural excavations have revealed earth buildings in Russian Turkestan dating back to 8000 to 6000 BC (Minke, 2006). The famous Great Wall of China 770 BC is by many looked upon as a stone structure, but it's actually a solely rammed earth construction, that only later got covered with stones and bricks. During ancient times, Mesopotamia and Egypt widely used raw earth. Temple of Ramses II at Gourna, Egypt, was constructed out of mud bricks 3200 years ago, poses as an example. The 2 million ton heavy rammed earth Sun Pyramid Temple in Teotihuacan in Mexico was built between 300 - 900 AD. Furthermore, adobe buildings are found in nearly all pre-Columbian cultures in Mexico, Central- and South America such as the Indus, Toltecs, Aztecs and in the Andes by Mochica (Mwakyusa, 2006). The traditional cave dwellings in Shaanxi province in China, locally referred to as yaodong, are man-made caves where soil is excavated and constructed to align with the natural terrain. These traditional dwellings have roots in the northern part of the country and date all the way back to 2000 BC (Panse, 2019). In 2012 almost 30 million people lived in these caves, and prefer to continue to do so (Murray, 2012).

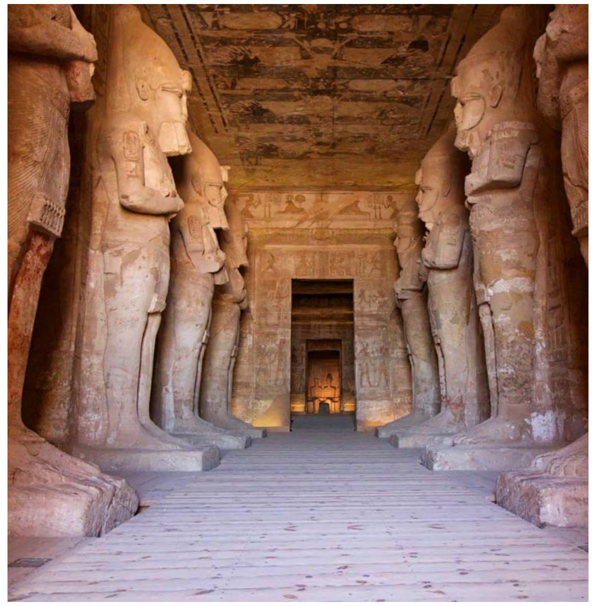


Figure 70: Temple of Ramses II.

15th Century and Earthen Constructions in Cold-wet Europe

In 15th century's France, the rammed earth technique "terre pisé" started to spread across the continent until the 19th century. Several of these buildings outside of Lyon are still occupied. It is estimated that over 15 percent of the rural buildings in France are made out of raw earth. Additionally, thousands of earthen buildings can be found in cold-wet countries such as England, Germany, Denmark and Sweden. In fact, the tallest solid earth building in Europe, the seven-storey high building, is located in Weilburg, Germany (Jaquin, n.d.). It was completed in 1828 and stands till this day (Minke, 2006). A potential reason for the widespread use of earthen materials in Germany, was the shortage of timber and stone in the country as a consequence of the wars and social reconstructions in 1700s Europe. In 1764, a solution that made the material more desirable was put forward by Fredrick the Great, who introduced earth building through an ordinance. The earthen heritage driven by him remains prominent til this day (Heringer et.al. 2019).

Figure 71: Half-timbered house, Sweden.

The 20th Century and its Pioneers

In the 1900s the renowned architects Rudolph Schindler from 1912 and Frank Lloyd Wright in 1940 contributed to spreading the research on earthen buildings in the US, although their results were never physically realised. Another gigant in the architectural field, Le Corbusier, did the same in France. Between 1919 and 1945, in the aftermath of the two World Wars, Germany adopted a national strategy to rebuild destroyed structures with earth, which resulted in over 80 000 erected earth constructions (Dethier, 2020a).

One of the great pioneers in promoting a modernisation of earth constructions, is the early 20th century egyptian architect Hassan Fathy (Dethier, 2020a). As one of the prefigures promoting affordable housing he devoted himself to rural improvement in developing countries. He worked to intertwine nature, traditions and spirituality with modern aesthetics into his project. The outcome was a more locally-centred form of modernity that often got constructed out of earth (Zaineldine, 2021). His project New Gourna from 1945 revived in the 1970s, when it was widely appreciated. Its popularity still poses a significant position and continues to inspire architects all over the world.

Figure 72: New Baris Village, Egypt, is designed by Hassan Fathy.

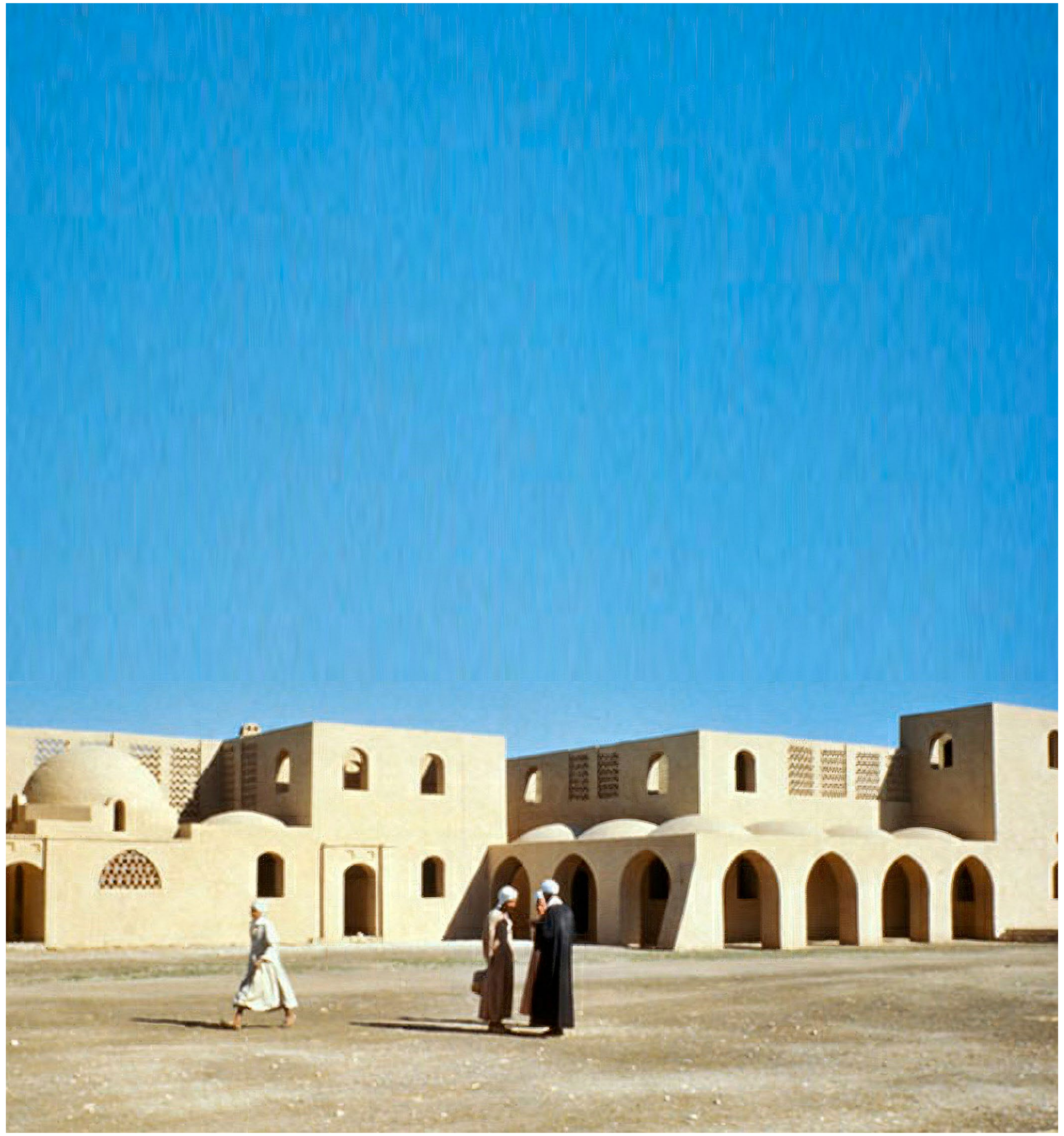


Figure 73: New Gourna Village by Hassan Fathy

1970s and the Introduction of CRAterre and RILEM

In 1979, the French based research laboratory CRAterre was established, after a student initiative in Grenoble School of Architecture. CRAterre have focused on design, management and essential theoretical and practical teaching on how to master earthen architecture. They also lead the UNESCO Chair "Earthen architecture, construction cultures and sustainable development". The chair aims to accelerate the spreading of scientific and technical knowledge on earthen architecture (CRAterre, n.d.). CRAterre, together with the other French originated organisation RILEM founded in 1947, are two of the leaders in the research and development of earthen architecture.

RILEM is French for "The International Union of Laboratories and Experts in Construction Materials, Systems and Structures" and works towards advanced scientific knowledge related to the construction field. Their aim is to promote sustainable, safe and innovative development and cover activities and networks in over 90 countries (RILEM, 2022). In 2016, they set up a Technical Committee called TC TCE (Testing and characterisation of earth-based building materials and elements) consisting of international experts on earthen materials with the aim to define testing procedures for earth as a building construction material (Vyncke, et. al. 2018). In 2022, they made a State-of-the-Art Report in an effort to provide a basis for international standards of earthen materials (Fabbri et.al. 2022).

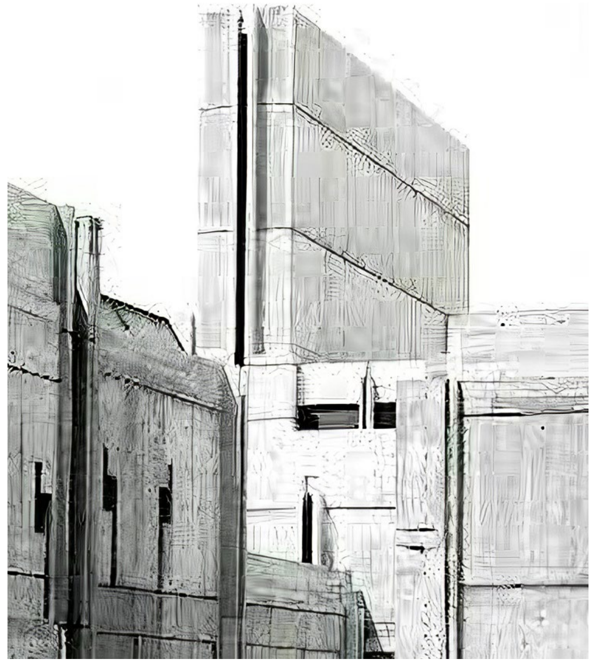


Figure 74: Grenoble School of Architecture.

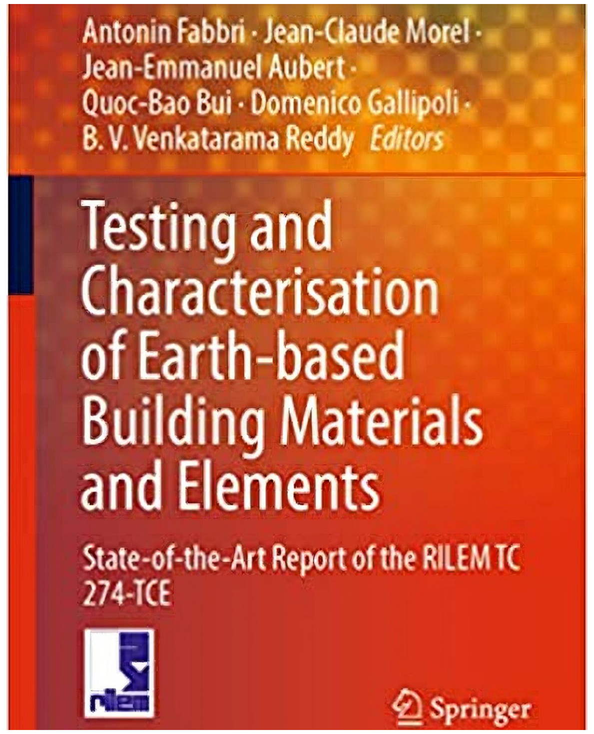


Figure 75: One of the books made by RILEM TC TCE.

Figure 76: The Great Mosque of Djenné, Mali.

The Turn of the Millennium and Onwards

There are several internationally renowned contemporary architects that have supported the revival of earthen materials and have through their work demonstrated a possibility to use it for modern constructions. During the 1990s to 2000s, the use of rammed earth received a revival, especially in America, where architects such as Rick Joy constructed luxury villas. Francis Kéré has been another key player since the 2000s with his innovative rural schools and medicine centres. He can also titulate himself as the winner of the Pritzker Prize 2022 (The Pritzker Architecture Prize, 2022). Noteworthy is the frequent use of cement stabilised earthen methods for the construction of their projects. That is not the case for all architects during this era. Mariam Kamara has constructed several projects out of raw earth and the same goes for Wang Shu whose most recent project is the ambitious multi-purpose urban estate at the gates of Paris by Quartus together with CRAterre and the German architect Anna Heringer. The project promotes integration of circular economy into the urban areas, where excavated earth from the digging of the metropolis new rail network will be used in the construction. The new neighbourhood will be constructed with a rammed earth technique. Anna Heringer has also worked with multiple other projects favouring earth and other materials collected on building sites, such as the METI school in Bangladesh that she designed together with architect Eike Roswag. She has been recognised with prestigious awards such as the Aga Khan Award for Architecture Award in 2007 due to her efforts to through architecture strengthen local building skills and cultures, support local economies and foster the ecological balance (Heringer, n.d.)

Furthermore, the maintenance of earthen structures has in many areas turned into a festive activity, bringing communities together, that is the case in Djenné in Mali. The UNESCO World Heritage building "the Great Mosque" has over centuries become the epicentre for the cultural and religious life in the region. Every year they hold the festival "Crepissage de la Grand Mosquée" -the plastering of the Great Mosque-, where the surface gets replastered (Dainese, n.d.). Earthen constructions have therefore demonstrated the potential and ability for earthen structures to withstand time, weather and even earthquakes -especially if well maintained- (Heringer et.al. 2019).

Figure 77, 78 and 79

The Majara Village by Zav Architects features 200 pointed and rounded domes constructed out of plastered sandbags. Since 2020 it offers a creative and joyful environment for both locals and visitors of Hormuz, Iran.

Figure 80

Casa Munita Gonzales designed by Arias Arquitectos + Surtierra Arquitectura in Chile, 2010. Rammed earth.

3.2 The Architectural Qualities of Earth

Figure 81

Earthen materials have the potential to meet a wide variety of architectural expressions, styles and scales. From large scale, prefabricated modules down to a piece of furniture shaped only by the touch of a hand. The varying design expressions of earthen material can integrate the best of concrete's minimalist and monolithic aesthetics, at the same time make use of the playfulness and contrasts of the brick while carrying the warmth of the wood. It can have the texture of a silky polished surface or a rough, textured finish. The colours can change from almost black to occra, peach and taupe. They can also be coloured by pigments to provide a wide range of choices ranging from blue to pink, yellow and green. The material displays colours and textures that belong and blend into the surrounding context in a balanced, calm and harmonious manner, and through that offer the users a chance to reconnect with nature.

Its Inviting Texture

The material can be obvious just as much as it can be subtle. The wall can be left raw, displaying an authentic finish or plastered with different nuances and textures making the materiality of the compound less prominent. Maybe it is the sense of subtle life created by the small shifts in the material that draws the attention of the eye and makes it want to rest there. The expression is harmonic yet living and provides the urge to touch the surface. Perhaps because it brings old memories and associations back to life. Earth is after all the most familiar material to children, out of which imagination is given a physical form. We are indeed used to play with it, shape it and touch it. A desire that will continue to exist within each human being. Earth is smooth and soft, with small variations that evoke a tactile sensation. Although wood is quite similar to earth, it can give the hand splinters, while bricks can tear, just as concrete.

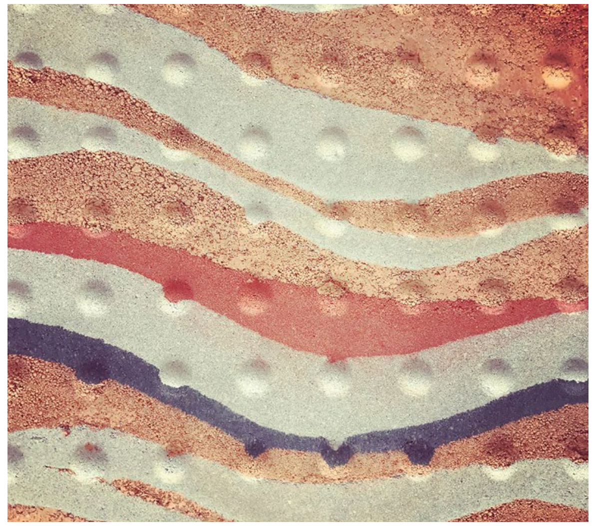


Figure 82

Aucoustic rammed earth wall, Hive Earth Studio.

The Tectonics of Earth

One of the most significant architectural benefits of designing and building with earthen materials is its versatility in form - it provides the designer with the ability to choose a broad spectrum of architectural styles. Since the generic term "earthen construction" hides many different techniques, the possibilities in terms of shapes and forms are almost endless. Cob for example, is malleable and flexible and can be shaped by hand directly on site without using any forms. Its free-forming properties enable organic and dynamic shapes that can appear almost plastic. Scale 1:1 can sometimes be challenging to fully imagine. Since cob is moulded in-situ, it holds the advantage of changing scale, form and texture on site. In contrast to concrete that requires formwork and offers a small room for alterations when casted, earth can be changed little by little as you go. The shape can be built up gradually, letting the form grow in different ways and happen inside the process. The time between thought, hand and result is very short when working with earth, it is almost intertwined. Just as when building a sand castle, the shape appears to be made simultaneously as the thought. It is a big advantage when dealing with complex shapes and forms.

At the same time, earth can also have the same tectonics as bricks. When constructing with adobe or CEB, the potential to create something out of the set dimensions of each block provides a framework in which the architectural expression gets its starting point. Here, the game of creativity can happen. Depending on the choice of

Figure 83

Experimentation of CEB-shapes by Omar Rabie.

bond, pattern and inserting or protruding elements, a rhythm can arise along with a play of contrasts in the form of colour and light.

Rammed earth on the other hand, can manifest itself as a monolithic large-scale object while, through its layerings, still displaying a human scale. This technique can accentuate razor-sharp lines or form enclosing circular compounds, highlighting its versatility for various architectural concepts and applications. In terms of colour, texture and decorative features the technique can be composed in a way to form artistic- and sculptural aesthetics that can create eye-catching results.

Between Human and Material

It can not be forsaken that earth architecture continues to sting the eyes of many people. Perhaps it is the connection between small-scale complexes and organic forms that brings to mind vernacular structures and triggers the feeling of something backward-looking? In today's society, we basically strive to erase the human hand and instead emphasise the precision, symmetry and finish of a machine. Simultaneously, there are ongoing trends and great interests in living in older houses where words such as patina, richness of details and spirit are used to describe it. What is intended is the human factor, which in this context, gives a charm and layers to the building. The modesty of earthen materials brings out a feeling of holiness, peace and authenticity. Beauty is allowed to be seen in its simplicity. The feeling of human care, combined with the human energy imprinted into the material, can in turn create a sense of belonging, safety and recognition of the space. The human hand carries something warm, something breathable and something living. Earth has the potential to bring forth the human presence through its formability and vitality, a quality too important to lose.

Figure 84

Construction of the cob-sculpture "Pepita" for Mud WORKS! Architecture Biennale 2016, Venice

3.3 Earthen Building Techniques

A Contemporary Addressing

Figure 85

Many different earthen construction techniques have been developed throughout the years. We will go ahead and explain the most common ones that we see have the most potential to be of use for future building. They can be divided up in three categories; rammed earth, earth blocks and cob constructions. As the different techniques require their unique soil type as well as sometimes other ingredients, such as straw or reed, the finished product and its thermal, mechanical and physical properties will also differ from each other.

The choice of earthen technique depends on different factors such as for example available technology and machines, local soil type, aesthetic preferences, climate, costs of labour, regulations, scale and time frame for the project.

Figure 86

The Soil House by ADX is built out of an unconventional method, using excavation soil from the site. The soil is sprayed with expanded polystyrene foam to bond it and make it structurally sound. Japan, 2019.

Figure 87

The Earthship architecture concept is highly inspired by the green wave. It began to take shape in the 1970s with architect Michael Reynolds as one of the pioneers. The style can be described as a type of passive solar house that is made of both natural and upcycled materials such as earth-packed tires.

Rammed Earth

Rammed earth consists of a wet mixture of soil and water that is poured into a temporary formwork where it is compacted one layer at a time (approximately 15 cm thick) to form a monolithic wall. After having air dried, the finished wall is left with a horizontal pattern. Rammed earth can today be used as both non load-bearing and load-bearing elements (Heringer et.al. 2019).

Around the world, rammed earth has been a traditional building technique since as far back as 5000 BC. Architect François Cointeraux is commonly credited with having explored rammed earth in France, prior to the French Revolution. He referred to it as pisé de terre, and saw earth as a material with potential to be sustainable, not only in regards to the environment but also the society as it could benefit all social classes. By that time, rammed earth was only performed manually and along with the industrial revolution they faded into disuse as they did not fit the image of modernization, resulting in a lack of investments to promote its development (Heringer et.al. 2019).

There are still many rammed earth projects where the elements are produced manually and directly on site, especially in developing countries where there are insufficient resources for the purchase of machinery. Since the 20th century, electric techniques have been developed using sophisticated machinery such as aluminium or wooden forms and mixing

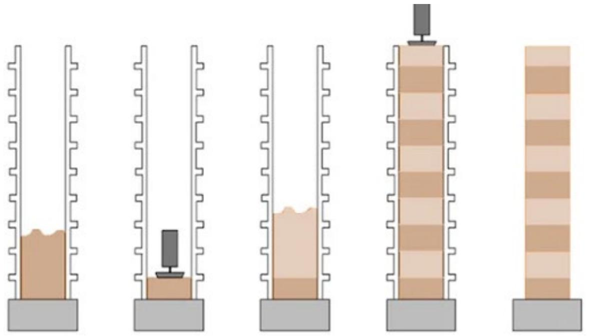


Figure 88

Rammed earth walls are made by compressing earth in between a wooden framework. It can be done either by hand or by machine. The soil is added little by little. When the desired height is reached, the formwork is removed to expose the finished result. The various layers from the compression work are then spotted adding an esthetic appeal.

machines, making rammed earth more relevant for industrialised countries (Vyncke et.al., 2018). This enabled rammed earth constructions to be prefabricated and delivered in components with high compressive strength and durability. The ability to prefabricate rammed earth does not only optimise the construction process, but also secures the consistency of the material quality, which facilitates the establishment of norms and standards. Having developed industrialised methods for rammed earth is of importance to the industrialised parts of the world where human labour is expensive, prefabricated building elements is common practice and the demand for standards is a fact (Heringer et.al. 2019).

In Germany, there are companies doing research on a type of multi-layered, prefabricated, load-bearing, cavity rammed

Figure 89

The PAMS Healthcare Hub Newman, Australia, is an aboriginal health clinic designed by Kaunitz Yeung Architecture. It is built out of rammed earth and the centre was completed in 2020.

earth wall with built-in insulation, on which the material's physics and life cycle are also being calculated (Heringer et.al. 2019). Germany is far from the only country where rammed earth technologies are being developed. For example, in the USA, Australia and New Zealand there are several companies exploring and building with rammed earth. However, it has become general practice to add cement as a stabiliser. Stabilised Rammed Earth (SRE) is believed to reduce certain risks and increase the performance, consequently compromising the environmental credentials of the material. This might, on the other hand, be balanced out if additional protection measures for non-stabilized rammed earth are put into the equation. This of course depends on the amount of cement used. The proportion of cement in SRE usually adds up to about 6-7% of the total soil mix (Greenspec, n.d).

In the USA, the firm Rammed Earth Works manufactures pre-made industrialised rammed earth panels. The soil used for their elements are waste products from mining and rock crushing that is later mixed with cement. The final product contains 50-60 percent less cement than traditional concrete panels (Rammed Earth Works, n.d).

One of the first well-known built examples of a prefabricated rammed earth building in Switzerland is the Ricola Kräuterzentrum. It was constructed in 2013 through a close collaboration with technical experts from Lehm Ton Erde and architects at the firm Herzog & de Meuron Architects. The building consists of excavated soil from the site itself, mixed with additional stone materials from within a radius of 8 km. The soil was then turned into 1240 m2 of non-load-bearing prefabricated rammed earth walls, in a nearby factory with a specially engineered ramming machine. Thanks to this, the walls could meet the high Swiss standards for structural capacity and material consistency. Many material samples were also tested in the lab, ensuring the compressive strength and stability. One of the main challenges with Ricola Kräuterzentrum was that there had never been a prefabricated rammed earth project in that scale anywhere in the world before, consequently resulting in a scepticism among both the client and the architects on the project. However, through studying other existing projects in Switzerland that were durable enough for the Swiss climate, such as the Etosha House at the Basel Zoological Gardens, enough trust was gained for the project to be realised (Heringer et.al. 2019).

Figure 90

Coloured rammed earth wall in Ghana.

Cob

Cob is a technique within a category that is in some literature referred to as "direct forming with wet soil". The soil consists of a mixture of clay, sand, straw and water. It is wet and dough-like, traditionally mixed through stomping it on the ground with the feet. It is then shaped by hand and stacked wet in order to form a wall or a structure. This technique differs from rammed earth and earth blocks in the way that no formworks are being used. As the mixture is wet during the construction, almost any shapes can be sculptured manually on site and therefore providing a creative challenge for builders and designers. Almost no tools other than hands are required, making this technique the simplest and most primitive one.

This technique is common to use in Africa, Asia and Saudi Arabia but also known in Europe and America (Minke, 2006). In England and France this technique is starting to regain some interest (Vyncke et.al., 2018). Another common technique - where the soil is prepared as cob - that has been used for thousands of years is the American, African and Asian "wattle and daub". The soil is here thrown on a woven mesh of branches of wood or bamboo. Similar techniques are to be found in the traditional European timber-framed houses, where soil is used as infills in a skeleton structure of timber. Also with the cob technique, lightweight soil can be used in order for the structure to provide sufficient thermal insulation for colder climates (Minke, 2006).

Figure 91

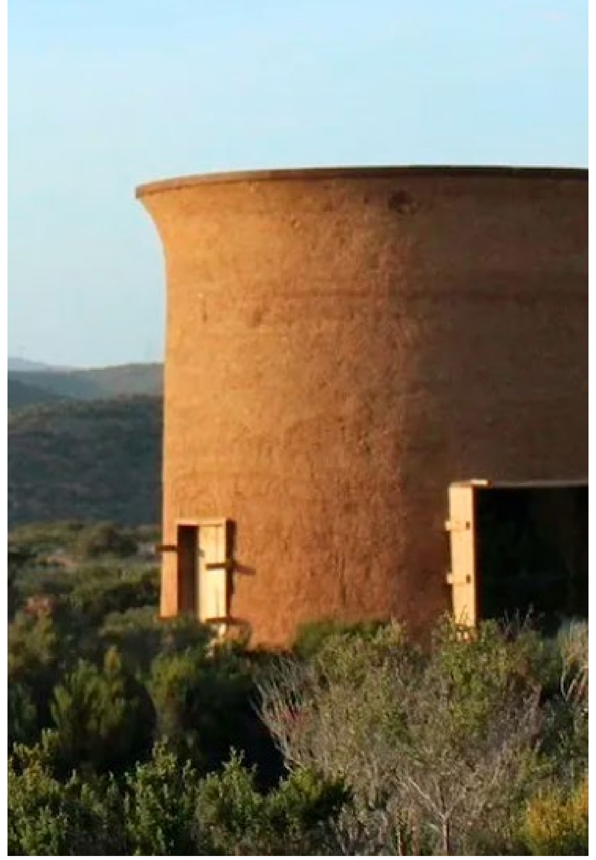


Figure 92

Galeria 2 Hijas, California by Cla Clá is entierly built out of cob. It was completed in 2021.

Earth blocks

Depending on the literature, earth blocks can also be referred to as unburnt clay bricks, sun dried bricks, earth masonry, cob blocks or mud bricks. Two of the most common earth blocks are adobe blocks and compressed earth blocks (Vyncke et.al., 2018). Building with earth blocks is an old tradition in many countries in the world, in hot and cold climates as well as hot and humid. For colder climates, the blocks are preferably made with lightweight soil to improve the thermal insulation capacity (Minke, 2006).

Structures of earth blocks as far back as from 8000 BC have been found, and even today in Egypt stands the 3200 year old earth block fortification wall of Medinet Habu. In the city Shibam in Yemen, the whole 20,000 m2 ancient core is built solely out of earth blocks. In Germany, earth blocks were used in the 6th century BC. For example, 140,000 earth blocks constructed the walls of the fort of Heuneburg. The use of earth blocks for construction was also common in Scandinavia and England in the 17th and 18th centuries, and the construction techniques were later brought to the USA by European immigrants (Minke, 2006).

Adobe blocks

Adobe blocks consist of a mixture of soil and water. The muddy mixture is then pressed by hand or thrown into a formwork, typically of wood. In developing countries it is common to use the throwing technique and the greater the force of the throw, the better the strength of the block. The formwork is later removed to allow the blocks to be left to air dry and harden. Cut straw or reed is usually added to prevent the blocks from shrinking and cracking. The dimensions of the blocks vary as a result of being produced by hand, but usually they are around the same size or a little bigger than regular bricks (Vyncke et.al., 2018).

Figure 93

Sandbox Beach Club, Ghana, uses sun-dried earth tiles developed by Hive Earth Studio in 2019. They are made of laterite, granite chippings, palm kernel, and a natural pigment.

Figure 94

La Casa Intermedia in Paraguay is a prime example when architecture is just between the industrial and craftsmanship. The residential house from 2021 is designed by Equipo De Arquitectura and constructed out of CEB.

Compressed earth blocks (CEB)

CEB is similar to adobe blocks but has a more controlled manufacturing process as the compression pressure is generated by a manual or industrial press. Due to this, the density of the block can be increased and it can therefore achieve better mechanical qualities. This technique developed in the 18th century and facilitated the production of earth blocks with less water content, consequently making it possible to stack the blocks on top of each other immediately after production without having them losing its shape.The type of press used decides the shape of the blocks. Rectangular blocks, rounded blocks, angled blocks, interlocking blocks and blocks with space for cables are some examples (Vyncke et al., 2018). There are both manual and industrial automatic presses that are more or less suitable for different contexts. Despite the fact that industrial presses can produce a larger amount of blocks per day, manual presses are still very popular as automatic block presses usually require large investments and might be difficult to maintain, especially for low-wage developing countries. It is nowadays common to stabilise CEB with 4-8 % cement (then called Compressed Stabilised Earth Blocks, or CSEB). The reason for this is because there is an absence of enough water to activate the binding forces of the clay minerals, and without cement they usually have less compressive strength than handmade adobe blocks (Minke, 2006).

3.4 Environmental Impact

LCA on Earthen Materials

Figure 95

To evaluate building products in terms of environmental impact, LCA (Life Cycle Assessment) has become a common and powerful tool to use. LCA is defined as the systematic analysis of the potential environmental impacts of products or services during their entire life cycle (Sphera, 2020). Due to the complicated production process of building materials, LCA progress is slower in the building sector than for other industries. LCAs on earthen materials for construction have not yet been thoroughly studied and there are many factors that can influence the results, however it is broadly argued that earthen materials have less environmental impact compared to conventional building materials do to their cradle-to-cradle life cycle, displayed in the diagram on page 117 (Ben-Alon et.al. 2019). In the 2022 State-of-the-Art Report by RILEM, the authors compare various LCAs applied to different earthen construction techniques, such as CEB, adobe, cob and rammed earth, in order to identify some key factors. They found that transport, stabilisers, local soil type, design, climate and geographical context are influential on the final result. In order to make a proper evaluation of the environmental impact for earthen materials, LCAs need to cover the production of the materials, the building process and also the energy usage throughout the use and end-of-life phase of a building. To combine LCA models with thermal and durability models is a key research issue (Fabbri et.al. 2022).

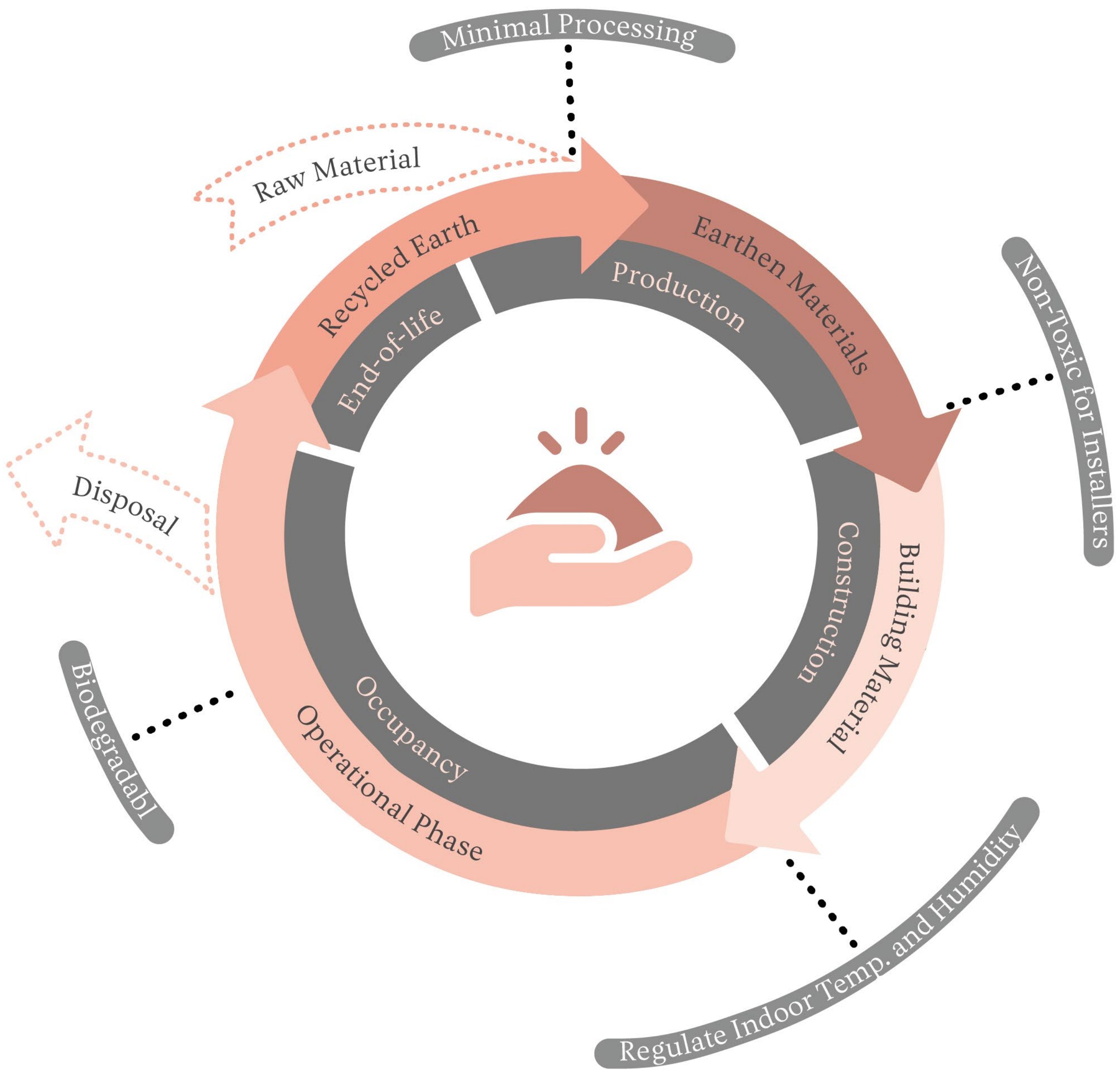


Figure 96

‘It shows that all walls that are made of earthen materials have significantly lower environmental impact than the conventional wall systems.’ (Ben-Alon et.al. 2019)

There are however several LCAs performed on earthen materials, but they cover different life cycle phases. Many only cover extraction and manufacturing steps and not the use or end-of-life phase. Even when the use phase is included, many LCAs do not take energy and thermal aspects into consideration, but only focus on maintenance aspects (Fabbri et.al. 2022).

An example of a LCA that compares different earthen construction techniques to conventional materials can be found in the paper Integrating Earthen Building Materials and Methods into Mainstream Construction Using Environmental Performance Assessment and Building Policy published in 2019 by IOP Conference Series: Earth and Environmental Science. The LCA does not take the use and end-of-life phase into consideration, but only the impact from cradle to construction site. It includes embodied energy demand, global climate change impacts, air acidification and human health (HH) air particulate pollution. In the study, 1 square metre of six different wall materials were investigated: cob, rammed earth, light straw clay, timber frame, insulated concrete block and uninsulated concrete block. The geographical context is a warm-hot climate in the US. The results that can be seen on the diagram on page 117, showing that all walls that are made of earthen materials have significantly lower environmental impact than the conventional wall systems. Transportation distance seems to have the strongest effect on the impact of the different earthen walls, as well as the emissions from pesticides and fertilisers during the production-stage of straw (Ben-Alon et.al. 2019).

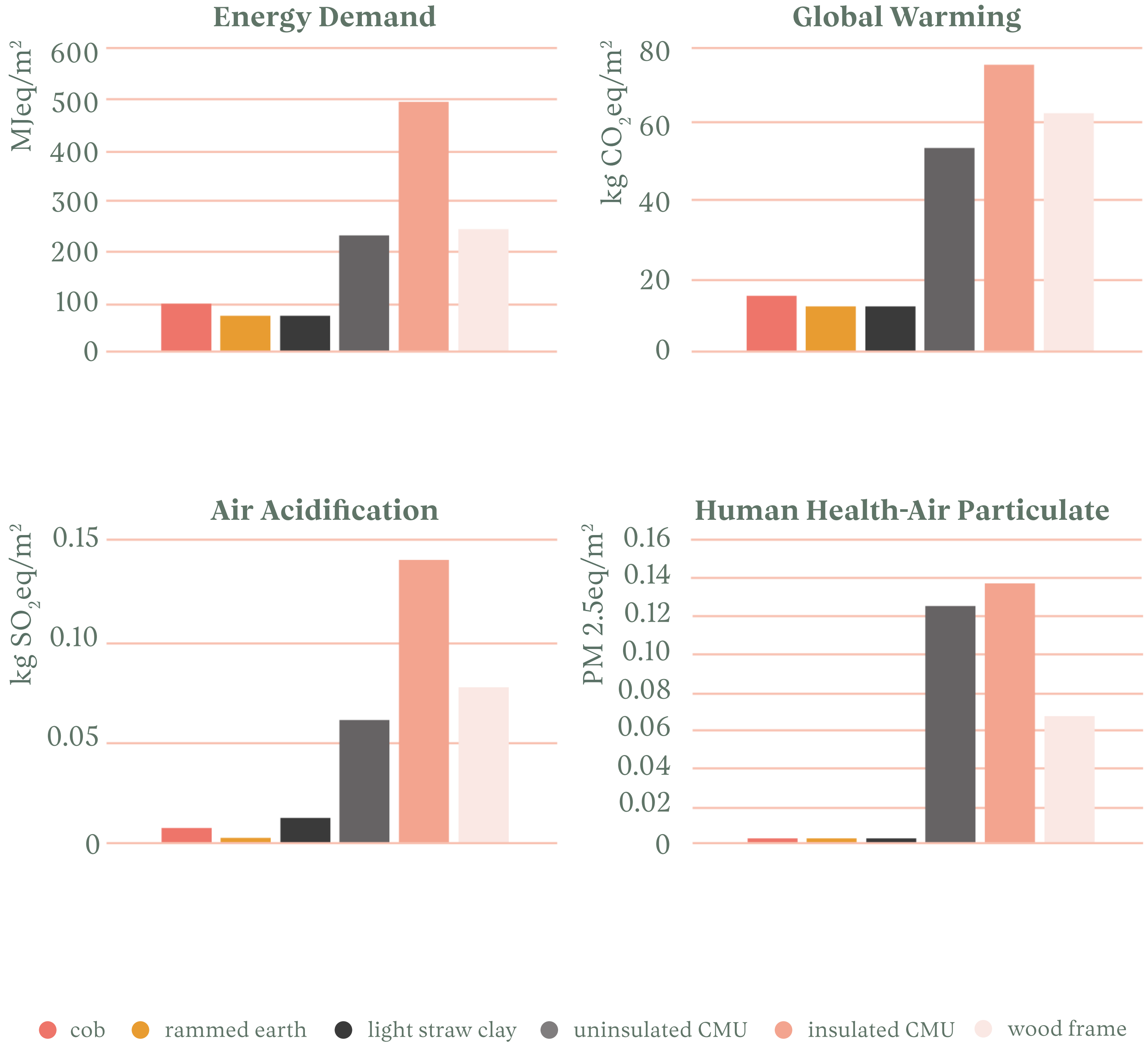


Figure 97

Environmental embodied impacts comparison among the wall systems: cob, rammed earth, light straw clay, uninsulated Concrete Masonry Unit (CMU) blocks, insulated CMU and wood frame (Ben-Alon et.al. 2019).

3.5 Knowledge of the Raw Material

The Fundamental Ingredient: Soil

Earthen building materials is heavily dependent on the raw material. To understand earthen structures, it is of importance to also have knowledge about the basic ingredient: soil.

Soil can be described as a piece of the earth's top layer, which can vary greatly in thickness from a few centimetres to numerous metres.

Soil is influenced by physical, chemical and biological processes that are affected by the climate as well as animal and plant life (Auroville Earth Institute, n.d). The soil is divided into three layers - or horizons - that have different compositions and properties depending on where in the world the soil is taken.

1. The first horizon is called "topsoil" and is generally 10-20 cm thick. The topsoil is further subdivided into two portions; a darker upper portion and a lighter lower portion. The topsoil contains a high amount of organic matter and should be avoided for construction and rather be left for agriculture.

2. The second horizon is called "subsoil" and is usually 30-60 cm thick. The clay content in this layer is usually higher with fewer pore spaces. This layer is the most suitable for construction.

3. The third horizon is called the "soil parent" and can be from 4 cm-10 m thick - or in some cases it doesn't exist at all. This layer extends down to the bedrock. (Biologyonline, n.d).

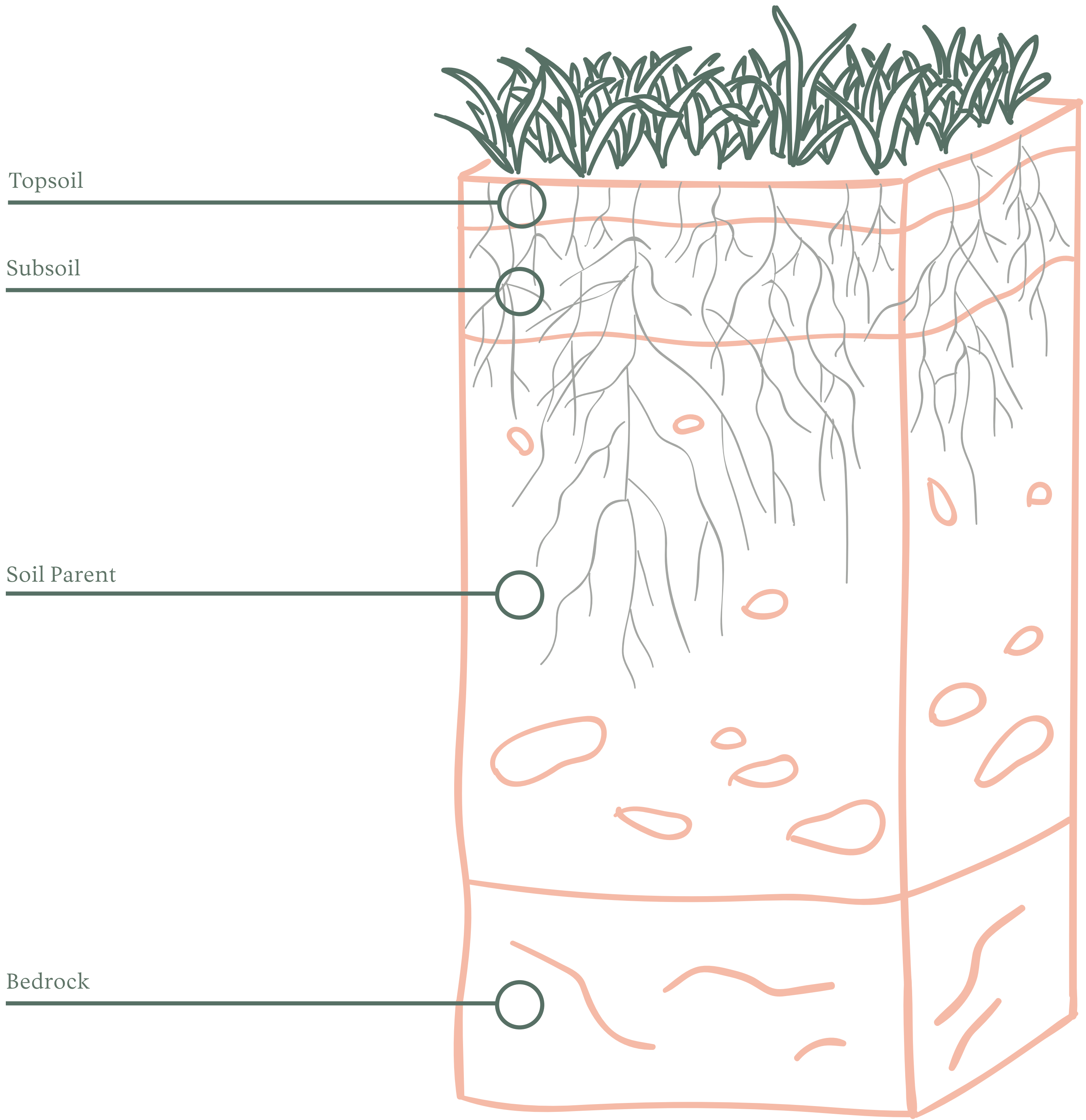


Figure 98

Figure 99

Loam

Sandy soil

Silty soil

Clayey soil

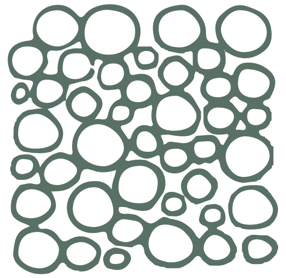
3.5.2 Soil Structure and Texture

Soil consists of four main substances; gases, liquids, organic matter and minerals. The minerals include gravel, sand, silt and clay. The gravel and sand are the inert minerals, also called the granular.

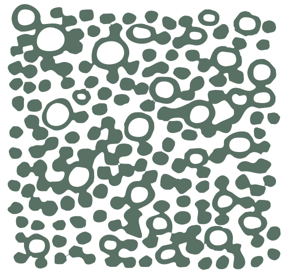
They are non-cohesive and their properties don't change when moistened. The silt and clay, also called the fines, are on the other hand the active particles and cohesive. Under the influence of water, they swell and shrink and act as a binder of the soil.

However, this applies far more for clay than for silt. Around the world there is a large variation of different soil types. There are differences in soil composition, soil structures and textures, leading to different characteristics and constructional capacities.

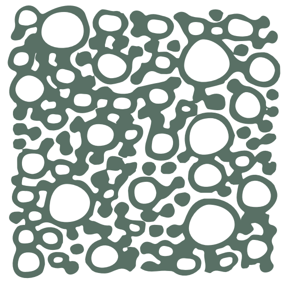
There are three general soil structures that have an effect on the physical properties of the soil; granular, fragmented and continuous(Schildkamp, 2009).



Granular structure:
Gravely, hardly any clay present



Fragmented structure:
Crumbly, has some clay content



Continuous structure:
Mix of all different grains

The grain size distribution of soil is also called granularity or texture and represents the percentage content of different grain sizes. This classification of grain size is based on the standard ISO 14688 1 2017 (Geotechnical investigation and testing of soils) and is adopted by a large number of laboratories (Auroville Earth Institute, n.d. The different grain sizes in a soil are:

Gravel (20 to 2 mm)

Gravel is made of small grains of rough material coming from the parent rock after disintegration. It forces a limit to the capillarity and shrinkage of the soil. Gravel does not demonstrate cohesion nor change when wet.

Sand (2 to 0.06 mm)

Sand is often composed of particles of silica and quartz. Sand grains will not hold itself together and therefore not demonstrate cohesion very well. It is also not prone to swelling and shrinkage. Sand is characterised by its open structure and high permeability.

Silt (0.06 to 0.002 mm)

Silt is smaller in size than sand but they are otherwise similar from a physical and chemical point of view. Silt grains stabilise the soil by increasing its internal friction and fills the voids between the grains. Silt has a water film around the surface, therefore giving a certain degree of cohesion to the soil. Silty soils are prone to small-scale swelling and shrinking.
(UN Habitat, 1992).

Clay (0.002 to 0 mm)

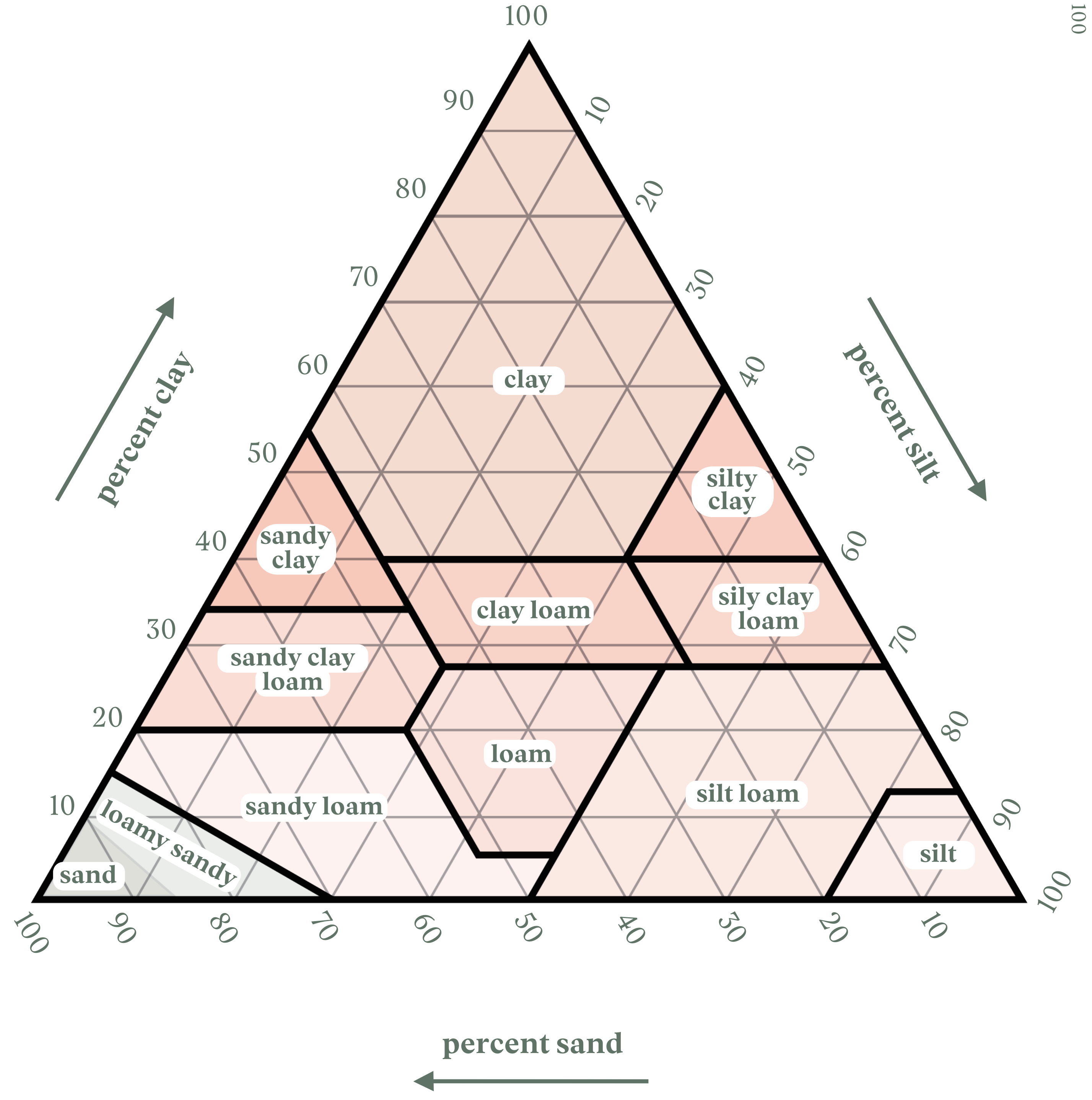
Clay particles are even smaller than silt and are only visible with an electron microscope. Clay grains differ from the other grains in their physical and chemical properties. In chemical terms they are called hydrated aluminosilicates.

The clay grains are individually called micelles and have a flat and platy shape (Biologyonline, n.d). As they are negatively charged, they attract the positively charged parts of water molecules. As a result, the clay molecule absorbs water, swells, and sticks to its surroundings and therefore acts as a binder (Foundation Repairs, 2021). This force that creates the cohesive and mechanical strength of clay is called Van der Waals forces (Schildkamp, 2009). Clay is also the chief of something called mineral colloids, which can be defined as the gluey paste coating sandy materials. Other colloids are byproducts of decomposition of organic matter. These are called humus and bacterial glues (UN Habitat, 1992).

As mentioned above, the texture shows the proportions in percentage between the different grains sizes in a soil. There is an infinite amount of different proportions, resulting in many different textures (soil types). It is the dominant grain in the soil that characterises the fundamental properties and behaviour of it (Schildkamp, 2009).

Scientists have categorised the many types of soil into 12 categories, all of which are represented on the soil triangle seen to the right (Schildkamp, 2009).

Figure 100



3.5.3 Soil for Construction

For construction, it is desirable to use soil with a continuous structure, which in scientific terms is referred to as loam (Minke, 2006). For most modern constructions, the ideal soil consists of approximately 15% gravel, 50% sand, 15% silt and 20% clay. However, the ratio varies depending on construction technique.

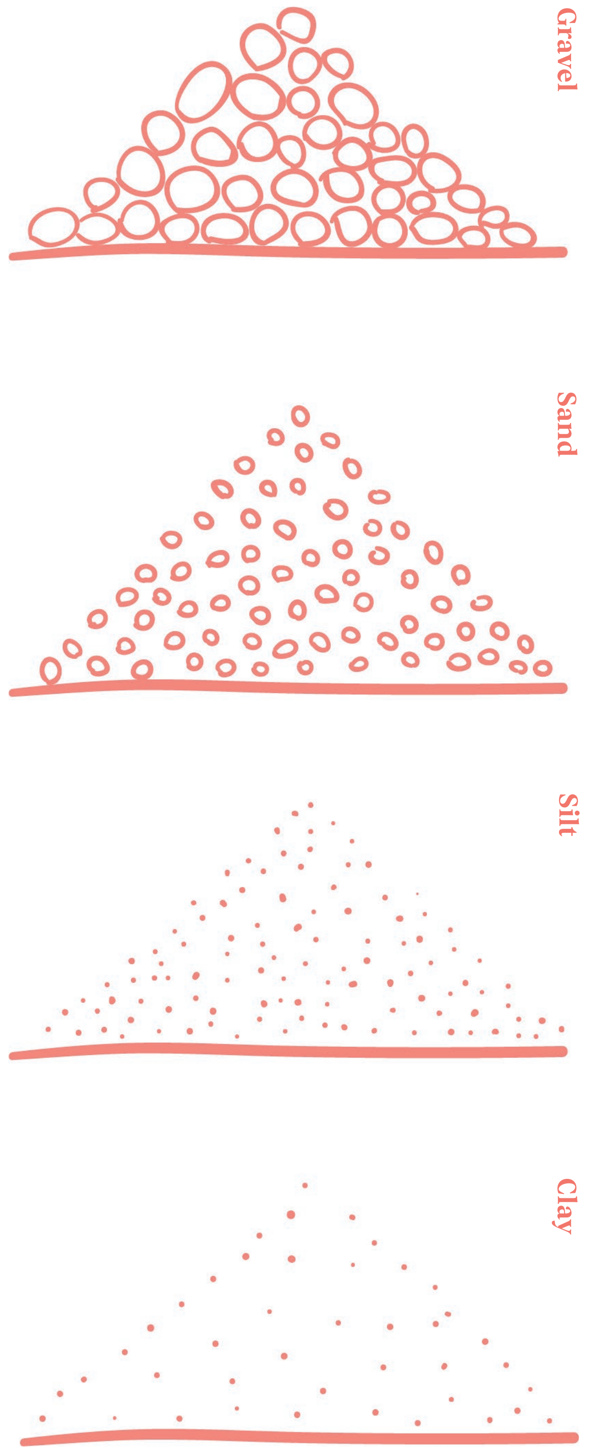
Gravel and sand act as a skeleton in the soil and give the material its strength. Too much gravel and sand will cause the material to lack cohesive strength as it can not hold itself together.

Silt has a somewhat intermediate function where too much use of it can have a negative effect on the strength and durability as the silt particles create gaps in the stabilisation process. Last but not least is the matter of clay.

Clay is the glue that holds the structure together (like cement in concrete) and does not contribute much to the structural strength. The amount of clay needs to be handled with precaution. Too little clay will result in difficulties for the soil to hold itself together.

However, if the soil is too clayey, the earth structure will shrink and crack due to its sensitivity to variations in humidity. This is because the clay in the soil will increase in volume when wet, as the film of absorbed water around the clay particles becomes thicker. When the structure becomes dry again it will shrink, resulting in visible

Figure 101



cracks through which water can penetrate the material and cause damage.

To determine what soils are suitable for construction purposes and furthermore what earthen techniques it can best be used for, geotechnical identification tests are required prior to construction to check the quality of the soil. The following are some of the most fundamental soil properties that are of importance to identify for construction purposes (Schildkamp. 2009):

1. Granularity or texture

The grain size distribution in percentage.

2. Compressibility

The ability of a soil to be compressed to the maximum and the potential to reduce its porosity to a minimum. The compressibility is defined by the OMC (optimum moisture content). The more the density can be increased, the harder it is for water to penetrate.

3. Plasticity

The possibility of a soil to be submitted to deformation without cracking or crumbling (elastic failure) under the action of external force and remain deformed.

4. Cohesion

The capacity of the soil grains to remain together when exposed to tensile stress. The cohesion of the soil depends on adhesive qualities and strongly correlates with the plasticity (ibid).

Figure 102

3.5.4 Soil Testing Methods

Figure 103

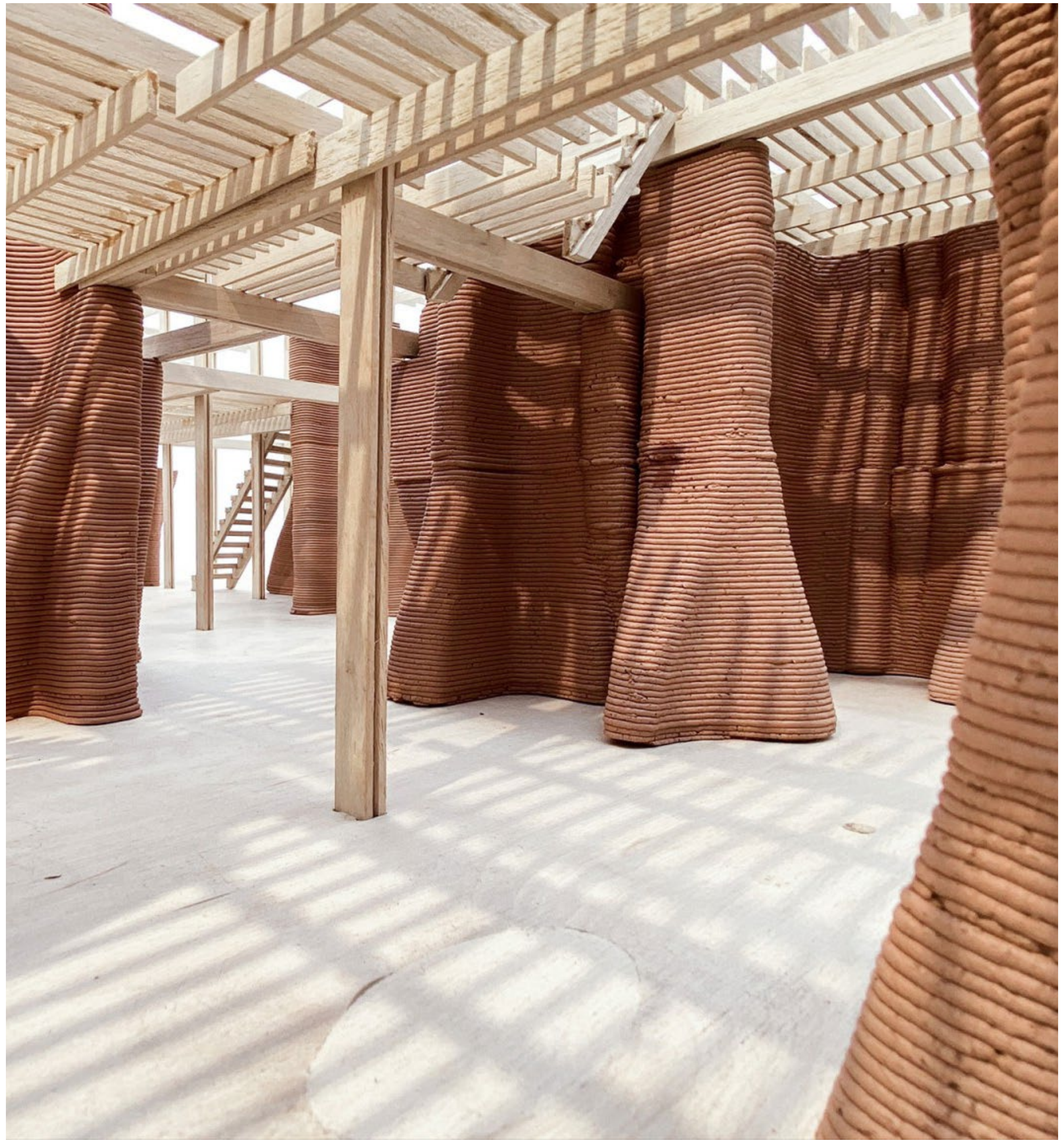
To decide the quality of soil for earth constructions there are various tests that can be conducted. Some are carried out in the field and others in a laboratory. Both field tests and laboratory tests can be carried out with reliable results, but are more or less appropriate methods depending on the circumstances. For example, laboratory tests might be difficult to implement in areas that suffer from frequent power cuts as the equipment requires electricity. Laboratory tests are therefore often unsuitable for many developing countries, especially in rural areas, not only due to the unstable power supply, but also due to the unavailability of affordable machines and other necessary materials that are needed to execute the tests. In this case, field tests might be the more appropriate method as they are less expensive and can be carried out directly on site and require little or no equipment. The advantages with these tests are that they can be performed by anybody after some training. However, some of them require a lot of practice as they need to be interpreted correctly (Schildkamp, 2009). In Chapter 7.1, a selection of the most common field- and laboratory tests will be described. These tests are made to characterise the soil, i.e. give information of the properties which will later function as indicators of whether or not the soil is suitable for different earth constructions.

3.6 Technical Properties of Earth

1. Mechanical Properties

The mechanical properties of earthen materials are heavily dependent on the soil type, i.e. the grain size distribution. Factors that also influence the results are manufacturing methods as well as testing conditions. For this reason, there is no global and general data on the mechanical behaviour of earthen materials. Tests need to be conducted for every soil mix to determine the compressive and tensile strengths. However, according to the 2022 State-of-the-Art Report: Testing and Characterization of Earth based Building Materials and Elements by RILEM, the compressive strength for unstabilised rammed earth varies between 0.3 and 7 MPa and for earth blocks (adobe specifically) between 0.29 and 4.5 MPa. Cob is the least studied technique in terms of compressive strength, but usually ranges between 0.6 and 1.3 MPa (Fabbri et.al. 2022). This can be compared to the compressive strength of concrete, that normally ranges between 15 MPa up to 30 MPa, but can be higher (The Constructor, n.d.) The tensile strength of earthen materials are of no relevance, as they should avoid being under tension (Minke, 2006).

Figure 104



3D-printed clay model investigating the potential of earthen structures. Project made by the students Nzar Faiq Naqueshbandi and Mohamad Fouad Hanifa at IAAC (Institute of Advanced Architecture of Catalonia), 2019-2020.

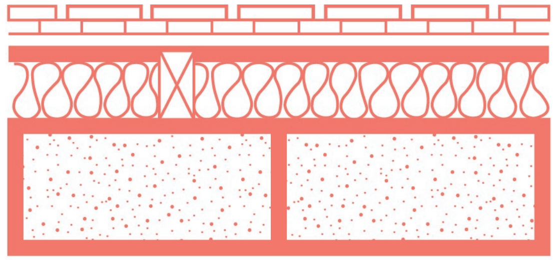
2. Thermal Properties

Together with the design and construction of a building, the thermal properties of the materials used drastically influence the energy usage of a building as well as comfortable indoor climates. In the 2022 State-of-the-Art Report by RILEM, and in Building with Earth: Design and Technology of a Sustainable Architecture, 2006, the following conclusions can be found regarding the thermal properties of earthen materials.

Insulating Capacity

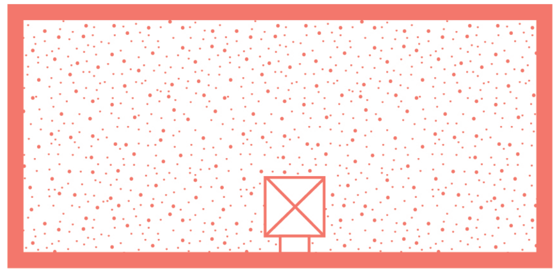
The insulation properties of earthen materials highly depends on the density, i.e. the amount and volume of voids that exist within the material as well as on its moisture content. The lighter the material, the higher the insulation effect, i.e. the lower U-value. The higher the moisture content, the lower the insulation effect, i.e. the higher U-value. If no light aggregates such as straw is used in the earth mixture, earth walls do not insulate very well.

The thermal insulation can be increased by adding porous aggregates such as for example straw, seaweed, expanded clay or sawdust (Minke, 2006). The insulation properties are highly linked to the thermal conductivity (K-value) i.e. the ability of a material to transfer heat. The lower the thermal conductivity, the better the insulation. The K-value for earthen materials also varies depending on density and moisture content. According to State-of-the-Art Report by RILEM, 2022, the



A

Lid Batten Panel
Thermal Insulation (λ= 0.04)
Load-Bearing Earth Blocks (λ= 0.7)



B

Lime Plaster
Mineral Lightweight Loam (λ= 0.18)
Timber Skeleton
Lightweight Loam Plaster

Figure 105

K-value for earthen materials (not clear if aggregates were used or not) in wet state was found around 2.4 W/mK, and can go down to 0.6 W/mK in perfectly dry state (Fabbri et.al. 2022).

As earth walls have insufficient thermal insulation capacities for colder climates, the development of walls with an appropriate U-value for colder climates is ongoing, especially for rammed earth. The U-value for exterior walls necessary

Figure 106

The insulation technique behind Alnatura Campus can be described as insulation material sandwiched in between the rammed earth structure. The structure was completed in 2019.

in many European countries is below 0.5 W/m2 K. Although the numbers vary, it is fairly normal for a 30 cm thick rammed earth wall to have a U-value of 1.9 to 2.0 W/m2 K, which is far too high (Minke, 2006). In Building with Earth: Design and Technology of a Sustainable Architecture, various potential construction methods are described on how to make rammed earth walls with improved thermal insulation capacities. Two of these examples are presented on figure 105, to the left.

The figures show horizontal sections of two soil walls with a U-value of 0.3 W/m2 K. Section A is a load-bearing wall consisting of timber boards, wind shelter, thermal insulation, load-bearing rammed earth. Section B is a simpler non-load bearing wall consisting of lime plaster, low-density lightweight soil, timber skeleton, lightweight soil plaster. These examples are not only displaying an improvement of thermal insulation, but also have sufficient thermal mass to balance indoor temperature and humidity. Except for adding layers of thermal insulation, two other measures that can be made in order to obtain a lower U-value of a rammed earth wall are to either make the wall thicker or construct it with lightweight soil (Minke, 2006).

Lightweight soil is soil mixed with other insulating materials such as cut straw, wooden chips, reed etc. The density of the lightweight soil is then lower than regular soil and will therefore have better insulation capacities. However, these walls will not be able to carry loads and need to be combined with other load bearing structures (Schlesier et. al. N.d).

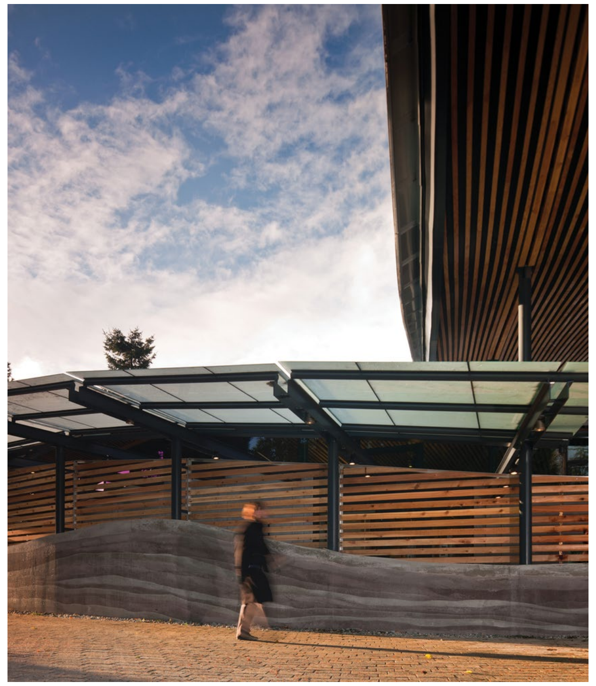


Figure 107

Figure 108

The LEED Platinum and Living Building Challenge Petal certified building have rammed earth walls. Perkins & Will, 2011.

Thermal Inertia and Time Lag

Thermal inertia is the capacity of a material to store heat, i.e. resist a change in temperature (Fabbri et.al. 2022). A wall with high thermal inertia will increase the time necessary for the outside temperature to be transferred to the inside, which is defined as time lag. Earthen materials have good thermal storage capacity which is preferable in climates with hot days and cold nights in order to create a comfortable indoor climate.

In Cairo, a study has been made of two buildings, one built of 50-cm-thick earth walls and the other one of 10-cm-thick precast concrete. The diurnal variation of the outside temperature was 13°C, but inside the earth building the temperature only varied by 4°C whereas in the concrete building it varied by 16°C. (Minke, 2006).

Similar examples with similar results are presented in State-of-the-Art Report by RILEM, 2022, where conclusions are that earthen buildings are naturally cooler in the summer and warmer in the winter than conventional building systems, consequently needing fewer energy using equipment in order to maintain a comfortable indoor climate (Fabbri et.al. 2022).

Hygroscopic Properties

Earthen materials are highly hygroscopic, i.e.they allow water to circulate within the material and function well as passive humidity regulation systems.

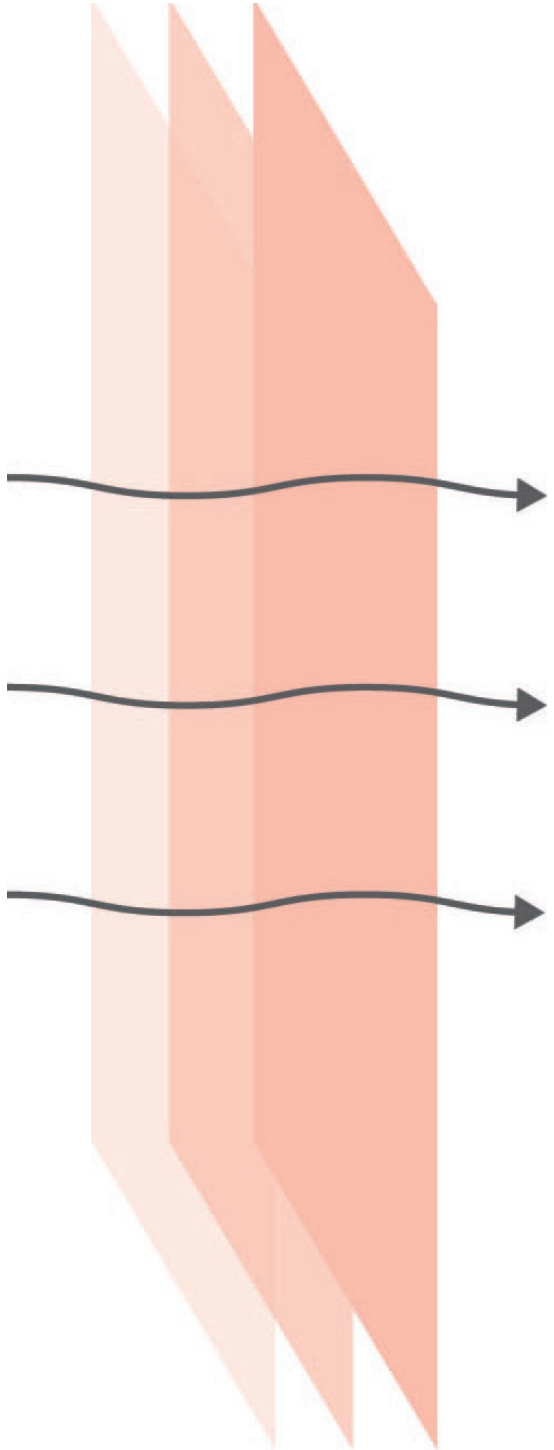


Figure 109

The porous network of the microstructure of any earthen building technique composed of gravel, sand, silt and clay, enables fluids and gas to flow through the material, making it quite permeable. Therefore, they have great potential to balance indoor air quality and enhance thermal comfort.

The thermal comfort within a building is of great importance as it significantly can influence their inhabitant's health and productivity. If the relative humidity (RH) is too low (below 40) or too high (above 60) it can cause respiratory problems (Fabbri et.al. 2022).

One experiment was made in a newly built house in Germany with walls made of earth. Measurements showed that during a period of eight years the relative humidity was almost constantly 50%. The building was able to reduce humidity in the summer and elevate it in the winter (Minke, 2006).

The hygroscopic properties of earthen materials also have an effect on the thermal behaviour of it, as water that is contained into the pores will evaporate when exposed to sun radiations. The vapour can then move within the pores towards colder zones and then re-condensate.

Due to water latent energy, heat will be released and temperature will increase. These properties of earthen materials can lead to energy savings during the life of a building (Fabbri et.al. 2022).

3.7 Impact of Weathering Agents

Durability of Earth

In the 2022 State-of-the-Art Report by RILEM, there is a chapter reviewing the impact of six environmental agents: water, ice, wind, fire, solar radiation and chemical attack (Fabbri et.al. 2022). The conclusions are presented below.

Water

Water is the most harmful weather agent as it can seriously affect the capillary tension and inner-particle bonding when entering the pores of the earth, which in turn decreases the strength of the structure. If water is present in solid form within the pores, it can cause cracking due to the water expansion upon freezing. Furthermore, water can also penetrate the building in a variety of ways, for example through rainfall, though the foundation, from ambient humidity or leakage from utilities.

Ice

Durability to freezing has been little investigated as the majority of the research has been made in areas where negative temperatures are rare. For that reason, the impact of ice can not yet be evaluated.

Fire

Equally to ice, more investigation is needed in order to evaluate the impact of fire on earth buildings properly. However, the exposure of earth to fire may even increase the structural capacity just as the mechanical properties of earth during the production of burnt bricks are improved. This speculation is also supported by the fact that ancient ruins have remained quite well preserved despite having been exposed to fire during their lifetime.

Solar radiation

Solar radiation promotes water evaporation and through that also the inter-particle bonding within the material. It has therefore in general a beneficial effect on the stability of earth buildings. If the earth, however, is stabilised with organic binders, solar radiation can have a damaging effect as the bonds between the earth grains might be weakened and therefore also the entire structure.

Wind

Wind does not cause significant damage to earthen structures. This can be proven by looking at the good condition of many historic earth buildings in windy regions.

Chemical attack

Earth is largely unaffected by chemicals, although salt crystals inside the water in pores of the material can cause material cracking. Stabilised earth can however be more sensitive to chemicals through material degradation, which is the case for many conventional building materials as well.

Figure 110

Pyramid of the Sun. A large pyramid in the ancient city of Teotihuacán, Mexico, that was built about 100 CE. Like many Mesoamerican pyramids, it is constructed around a core of rubble held in place by retaining walls. The walls are faced with adobe bricks, and covered with limestone.

3.8 Additives and Treatments

Improving the Performance of Earth

Stabilisation has been used for thousands of years to improve the structural performance of earthen materials. The different stabilisations methods can be classified as either organic or inorganic, and can be used separately or together in so-called hybrid-stabilisation methods. The organic stabilisations make use of waterproofing additives of organic origin, while the inorganic ones rely on the addition of chemical binders. Traditionally, organic products from plants and animals have been used to stabilise earth, such as straw, husk, linseed oil or cow dung. Nowadays, it is common practice to add inorganic stabilisers such as cement or lime. Between lime and cement, cement increases the strength and durability the most, but does on the other hand exhibit higher environmental impact in terms of carbon footprint (Fabbri et.al. 2022). Usually between 3-10 percent cement is added, which can be compared with concrete where it commonly composes 10-20 percent of the mixture (Isaksson and Mrema, 2016). By adding chemically based additives, particularly cement, two of the main advantages with earthen materials are lost: its hygroscopic properties and its recyclability. If no additives are used in an earthen building, the components of the structure can be folded back into the ground to decompose or be reused in another earthen project (Heringer et.al. 2019). Precautions also need to be taken when determining the amount of cement or lime added, as their presence in some cases can have the opposite effect than desired. If the amount of cement or lime is lower than 5 percent, they interfere with the binding force of the clay minerals, then resulting in a decreased compressive strength (Minke, 2006).

Figure III

Oxara investigates and developes mineral-based chemicals as additives that are non-toxic and non-hazardous.

Modern Research on more Eco-friendly Alternatives

Old earth constructions over the world prove their ability to withstand both time and harsh weather conditions, without containing chemical binders. Unfortunately, much of the knowledge concerning building techniques and stabilisation methods seems to have been forgotten as the material successively has been replaced. To date, there aren't many studies on natural organic stabilisers, although that would certainly be the most sustainable solution that preferably should be developed in the future. Research institutes and universities around the world are however investigating eco-friendly additives and surface treatments in order to find other ways to improve the performance of earthen constructions without sacrificing our planet as well as valuable physical properties of the material. One of the research projects proposed the use of geopolymers as a substitute to cement. Geopolymers are inorganic alkaline activated materials (AAM's), having substantially lower environmental impact than cement.

Another research project shows that hygroscopic silicone-based admixtures can be added in order to make the earthen materials less vulnerable to water penetration without affecting the hycroscoping properties (Vyncke et.al., 2018). One more option for stabilising earthen materials is through adding natural or artificial pozzolans. It is an attractive option as most pozzolans displayed a lower environmental impact than other inorganic stabilisers. A study was made on the behaviour of monolithic rammed earth walls stabilised with lime and pozzolan.

After having been immersed in water for six months, they showed no signs of deterioration (Fabbri et.al. 2022). Organic stabilisation methods can also be achieved by adding natural or synthetic recycled fibres, preferably from industrial or household waste, resulting in a reduction of environmental impact and embodied energy (Fabbri et.al. 2022). To stabilise earth with linseed oil is also proven to increase both the compressive and tensile strength of earthen materials, as well as the resistance to water penetration. However, it has a negative impact on water buffering capacity of the material (Fabbri et.al. 2022). Treating the surface can also improve the resistance to water action significantly, and there are many existing coatings, sealings and renders. There is ongoing research striving to develop environmentally friendly surface treatments that protect the structure as well as being vapour-permeable (Vyncke et.al., 2018). Recently considered are for example bio-products that are used to improve the durability of earth plasters, with results showing a reduction of moisture absorption and damage after contact with water (Fabbri et.al. 2022).

The choice of stabilisation depends on the physical and mineralogical characteristics of each earth. This should therefore be carefully investigated and considered in order to achieve the best balance between strength, durability, environmental impact and financial costs. At large, stabilisation improves the strength and durability of earthen materials. On the other hand they often worsen their hygroscopic properties and therefore also the moisture buffering capacity (Fabbri et.al. 2022).

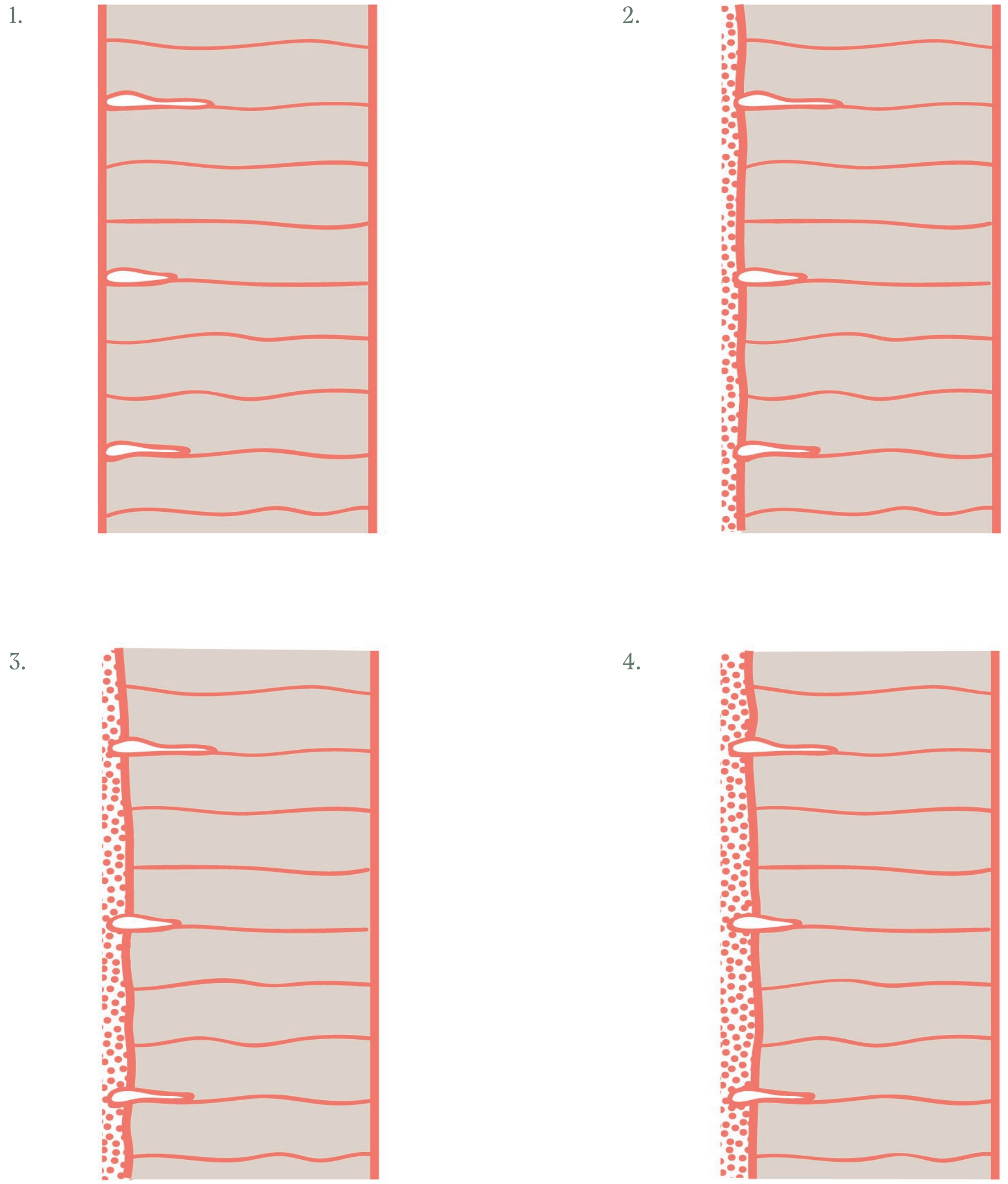
Calculated erosions

To protect earthen buildings from weathering and environmental action, the principle of calculated erosion can be used instead of additives, especially in rammed earth constructions. Calculated erosion means that an additional thickness between 2 to 3 cm is added on top of the facade. Countless projects world-wide relying on this system, having proven that the facade ceases its reduction under regular conditions after the initial withering of several centimetres. That is if the quality of the earth mixture is sufficient and its compacted correctly (Heringer et.al. 2019). The principle of calculated erosion is used for the project Haus Raus, which is explained more on page 158-159.

Figure 112

Calculated erosion has been used in Haus Rauch. An addition of two extra centimiters are added.

Figure 113



The illustration shows the different stages of calculated erosion, where the facade becomes weathered to expose horizontal tiles installed to protect the facade from external forces.

Chapter 4

4.1 Prominent Architects in the Field

A change is needed to improve the current state of our planet. The discussion is not only about climate change, inequality and injustice but also unhappiness. The fact that people are not being happy on a societal level is a farfetched result of the ongoing stress the world is facing today. To create a profound change in mindsets, attitudes and outlook we have to take care of each other and our resources. In this chapter we will introduce some of the people that show a positive change of direction when it comes to tackling these issues. These architects have a shared interest for earthen material and work with them with a pioneering approach, investigating the potential of earthen materials in terms of environmental-, social- and economical sustainability. It is from that point of view they are highlighted in this following chapter.

Figure 114

ANNA HERINGER

‘The process is just as important as the product.’ (RIBA, 2021)

Figure 115

Origin: Germany
Year of Birth: 1977
Profession: Architect, Design Critique at Harvard and honorary professor at the UNESCO Chair of Earthen Architecture

Recognized for her belief to rely on locally available materials and resources as well as her focus on the architectural process, Anna Heringer plays a significant role in sustainable architecture (Kucharek, 2020). Her work commonly includes local labour where material is chosen to correspond with available craftsmanship and not depend on external factors. Her philosophy is to use architecture as a medium to strengthen cultural and independent confidence, where the local economy should be positively affected (Rethinking The Future, n.d.a). She is the principal architect of her own firm, Studio Anna Heringer located in Germany.Throughout the years she has received numerous honours, among these are Aga Khan Award for Architecture in 2007 and Obel Award in 2020. Her work is highly notable with exhibitions on MoMa with many widely published projects across the globe. She also holds the position as honorary professor at the UNESCO Chair of Earthen Architecture, Building Cultures, and Sustainable Development where she focuses on natural building materials, and therefore her work commonly incorporates earth and bamboo (Heringer, 2022).

Figure 116

METI School

Year: 2004-2006
Location: Rudrapur, Bangladesh
Architect: Anna Heringer and Eike Roswag
Construction: Cob earth walls reinforced with straw, load bearing, 325 m2
(Heringer, Blair Howe and Rauch, 2019)

Figure 117

Year: 2020
Location: Koudougou, Burkina Faso
Architect: Kéré Architecture
Construction: Poured clay mixed with aggregates and cement, casted in-situ. 1000 sqm

Burkina Institute of Technology (BIT)

Diébédo Francis Kéré

‘Getting the community to be part of a construction is very beneficial because you’re passing on knowledge, you’re reducing the costs of a potential building, because of local labour, but you’re also empowering people’ (Designboom, 2021a)

Origin: Burkina Faso
Year of Birth: 1965
Profession: Architect

On the basis of treating architecture as an objective rather than an object Kéré won the 2022 Pritzker Prize (The Pritzker Architecture Prize, 2022). Informed by tradition, his Berlin-based firm Kéré Architecture is focusing on the process and new ways of construction in which long-lived materials and techniques can be used. By working with local materials and resources combined with a participatory design approach, the aim is to establish a design practice beyond the existing framework (Kéré Architecture, 2022). He frequently uses earth along with thatch and wooden poles. The renowned architect can titulate himself as winner of 2004 Aga Khan Award for Architecture, 2012 Global Holcim Award and 2019 London Serpentine Pavilion winner (Rethinking Architecture, n.d.c : Architectural Digest, 2019).

Figure 118

Figure 119

Year: 2008-2010
Location: Pondicherry, India
Architect: Anupama Kundoo Architects
Construction: Mud house baked in-situ
(a rare technology pioneered by Ray Meeker).

Volontariat Homes for Homeless Children

Anupama Kundoo

‘Academia is not there to just give information and repeat. The knowledge that is established we must question.’ (RIBA, 2021)

Figure 120

Origin: India
Year of Birth: 1967
Profession: Architect, Lecturer and Researcher

Supported by intense research and experimentation with locally sourced materials, Kundoo presents an innovative approach in the architectural field. She believes that current construction methods are causing more problems than they can solve. Since 1990 she has been working in the architectural field and is a renowned architect, author, lecturer and researcher, with main focus on materials (Rethinking the Future. n.d.b). After her studies, she worked for several years in different projects in the town Auroville in India before she continued with academic research in Australia, US and Europe. She promotes critical thinking, innovative solutions and the use of waste material and unskilled labour, to challenge how we build and the very way we exist in the world. Her practice is holistic, combining research with building and teaching which results in an architecture outside of the mainstream commercial, developer-driven world. In 2021 she received the RIBA Charles Jencks Award (Hopkirk, 2021).

Wang Shu

"Reducing tradition to a decorative symbol and then applying it to the surface of a modern construction... that's exactly what kills the true meaning of tradition.' (Anetta, 2018)

Origin: China
Year of Birth: 1963
Profession: Head of Architecture School at China Academy of Art in Hangzhou, Craftsman and Architect

As the winner of the respected Pritzker Prize in 2012, Wang Shu poses as the first and only Chinese recipient. With a background in calligraphy, academic degrees in architecture and craftsmanship experience he considers himself primarily a scholar followed by a craftsman and lastly an architect (Britannica, 2022). Together with his wife Lu Wenyu, he shares the position as partner of the architectural firm Amateur Architecture Studio since 1997 (The Hyatt Foundation, 2022). Additionally, he works as a professor and head of the architecture school at China Academy of Art in Hangzhou. His interest lies in vernacular Chinese architecture and its traditional techniques, local materials and craftsmanship. By using an uncompromising and responsible practice, specific for the concerned culture and place, it challenges the role of contemporary Chinese and international architecture (Anetta, 2018).


Figure 121


Figure 122

Year: 2008
Location: Ningbo, China
Architect: Wang Shu, Amateur Architecture Studio
Construction: Rammed Earth

Ningbo Historic Museum

Mariam Kamara

‘We seem to think that a lot of what’s happening with the environment is someone else’s fault. A lot of it is ours. We can make choices.’ (Designboom, 2021b)

Figure 123

Origin: Nigeria
Year of Birth: 1972
Profession: Architect and Software Developer

Mariam Kamara, the software developer who turned into an architect. As the founder of Atelier masōmī, the architect practises a design philosophy based on the belief that architecture has the potential of changing the way of life. For her, the most important parts of the architectural process are the research phase and the on-the-ground interactions (Designboom, 2021b). By using context, people and cultural heritage as building blocks for each project she works towards the aim of creating spaces that have a sense of dignity, a power to elevate and means to provide a better quality of life (Atelier masōmī, 2022). She has previously worked as an adjunct associate professor in Urban Planning at Brown University. She has been one of the founding members of the Seattle-based NGO united4design, where she participated in two major projects in West Africa (HOLCIM Foundation, 2021).

Figure 124

Hikma Community Complex

Year: 2018
Location: Dandaji, Niger
Architect: Atelier Masomi
Construction: CEB, clay plaster, raw clay packed and moulded by hand, adobe. 5238 sqm

Figure 125

4.2 Earth Projects Around the World

Convincing an audience consisting of highly sceptical contractors, institutions, architects and other professionals that earthen materials have a spot for the future built environment require well-documented projects displaying good enough performance to meet modern standards, as well as a balance between technical innovation and local labour.

Due to the fact that there is a lack of codes and standards, many projects that we have come across in our search for contemporary earthen architecture have had a “learning by doing” kind of nature, resulting in a reintroduction of practical knowledge that used to be widespread but now mostly is forgotten.

In the coming pages we will present a variety of flagship earth projects around the world that have attracted attention as they show a development and optimisation of the material itself, but also because they display an attempt to establish a more sustainable building practice.

Tucson Mountain House

Oldie Goldie: Brining Earthen Materials Back to the Table

Year: 2001
Loacation: Arizona, USA
Architect: Rick Joy Architects
Details: Stabilised load-bearing rammed earth walls, with 3 percent cement, 185 sqm

Tucked into the secluded valley in the Sonoran Desert is one of Rick Joy's signature buildings. The over 5 m high private home with a butterfly roof and striking viewpoints is designed to blend into the surrounding landscape both aesthetically and environmentally. Unlike traditional low-slung adobe dwellings in the area, the Tucson Mountain House is constructed out of rammed earth. It endows the building with the nuances and textures of the valley, creating a dynamic colour play ranging from deep rust to pale taupe. The wall dimension is adapted to the harsh climate, where searing heat alternates with nighttime chills. By using a wall-thickness of 0,6 m, a sufficient thermal mass to withstand the changing temperatures is provided. During the construction the reddish desert soil was mixed with 3 percent Portland cement to then be poured into wooden moulds. After being tampered down to layers the stabilised soil mixture hardens and the moulds are removed, revealing a striated, porous and textured result that contrastes to the smoothly polished concrete foundation (Green Design, 2022).

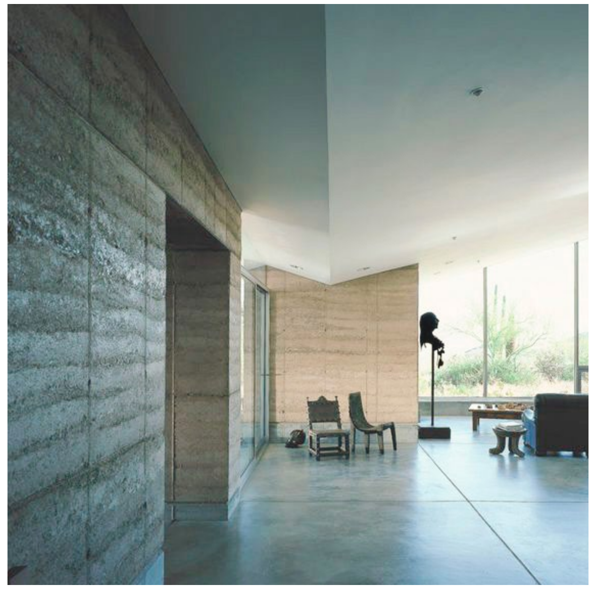


Figure 126

Figure 127

House Rauch

Residential House Using Calculated Erosion

Year: 2005-2008
Loacation: Schlins, Austria
Architect: Martin Rauch and Roger Boltshauser
Details: Load-bearing rammed earth walls, 690 sqm

On a steep south slanted hill, overlooking the village of Schlins, stands a monolithic rammed earth structure pressed upward from the underlying earth. The rhythmic facade is defined by erosion checks consisting of handmade clay tiles protruding the exterior wall. They are used to slow the flow of water on the rammed earth surface in order to protect the building from weathering. The horizontal stripes created by these tiles bestows the building compound with a softness that interplays with the rammed earth wall's low-key nuances. The haptic qualities of the earth is emphasised in the interior spaces as well as creating a well balanced, tranquil and warm atmosphere (EUmiesawards, 2011).

"When you remove the formwork from a rammed earth wall, the human energy put into it manifests itself before your eyes. The layers are like the striation of the earth itself. And the impact of its power is only truly visible at the very end of the process, when the building is completed. Bricks and concrete simply do not have this symbiosis." Martin Rauch (Heringer et.al. 2019)

When designing the house the architects acknowledged the changing nature of earth and used calculated erosion as a means to tackle it. They anticipated the facade to weather about two centimetres and as a consequence, the clay tiles didn't protrude enough to preclude further runoff in the beginning. With earth, the weathering starts immediately. In other materials, it is not present in such a direct way. The impact is recognized much later, usually followed by the consequence of restoring or replacing material. In Upscaling Earth, Martin Rauch writes that this is something that psychologically affects you (Heringer et.al. 2019). The erosion was made visible during the first two to three years. The homeowner himself confessed feeling a bit nervous the first years during heavy rainfalls and storms. But he did not need to fear. As the weather passed and time went by, he developed a bigger sense of trust in the material.

Figure 128

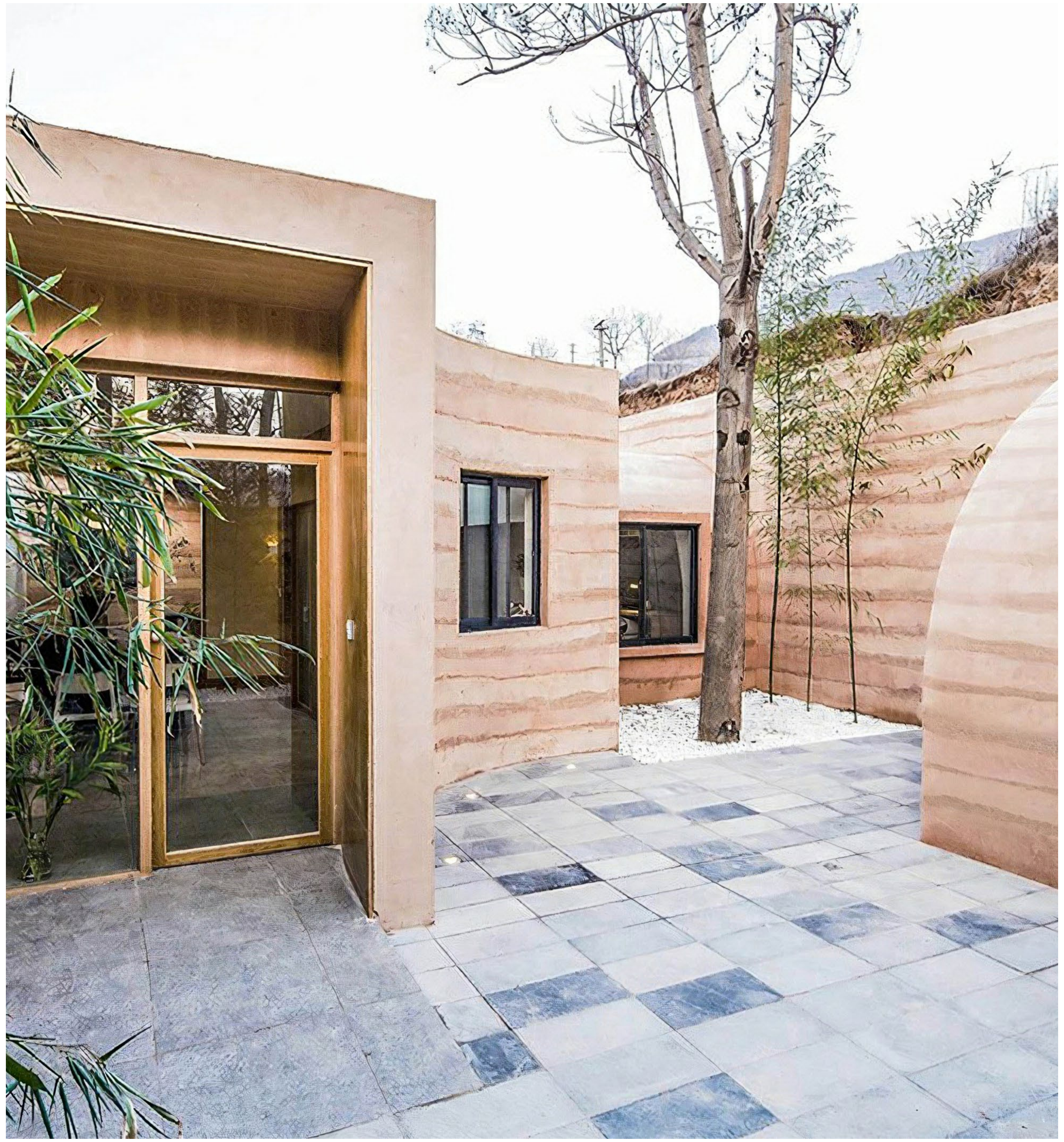


Figure 129

Cave House

Where Cultural Heritage Meets Contemporary Architecture

Year: 2016
Loacation: Loess Plateau, China
Architect: HyperSity Architects
Details: Rammed earth, renovation project, 278 sqm

The cave houses known as "yaodong", have been a permanent element on the snowy hillsides of Loess plateau in China since the second millennium B.C.E. Excavated into the hills, these earth-shelters consist of a sunken central courtyard with facing facades. The traditional dwellings make use of the natural insulation properties of earth, keeping the interior cool in the summers and warm during the cold winters. Despite their ancient ancestry they are still among the most popular dwellings in the area and home to an estimated 40 million people (Dornob, 2022). Among one of these was a cave in a serious state of disrepair, with tilting and crumbling walls, almost in collapsed condition which now has been given a new appearance (Archdaily, 2017).

The architects' intentions have been to honour the tradition of the site, integrating the new building with the local context. By keeping the same dimensions as the original yangdong as well as identifying the elements of it, an empathic design strategy was used. The cave to the north has mostly been left intact, whereas the spaces to the south and west have been torn down due to their bad conditions, making space for five scattered courtyards created within the compound. The courtyards draw parallels to the Chinese garden and are connected through a zigzag path. The arched wall is another architectural feature preserved from the yangdong (Wang, 2017).

Rammed earth has been an important element in the construction of the new house by both addressing a contemporary form language but also speak to the root of the site. The application of rammed earth does not only reflect the local building tradition. Through its materiality it speaks of the origin's strength and warmth, originating from the surrounding mountains creating an almost poetical approach to its surroundings. The colour and shape of the earth is almost wood-like at first glance, adding an intriguing aspect.

TECLA Houses

A Step Towards the Future

Year: 2021
Loacation: Massa Lombarda, Italy
Architect: Mario Cucinella
Details: 3D-printed clay with rice fibre as a binding agent,
60 sqm/ module

"This is not just the first 3D-printed house, it is the first project of a house that can adapt to different climates and that is the real challenge." Cucinella (Moro, 2021)

Figure 130

What do you get if you combine technology with clay? If you let Mario Cucinella and WASP decide you get TECLA, a 3D-printed house that is completely disposable. The only equipment needed is a single machine, that is able to be transported in a regular container. The innovative circular housing intertwines vernacular construction practices with bioclimatic principles and natural locally available materials. The result is a soft aesthetic that reminisces of two combined beehives. Constructed out of an uninterrupted sine curve they culminate in two circular skylights that convey a 'zenith light' (Pintos, 2021).

In order for the technique to work there has to be a specific proportion of sand, silt and clay where the secret ratio is thirty-thirty-thirty. In case the proportions are off, the soil is recombined to achieve the right balance. Rice fibres were then added to be mixed together with the soil in a millstone. The choice of rice fibre is based on its ability not to degrade when exposed to water. The blend was then pushed through concrete-like pumps designed particularly for the purpose. An extruder dosed the material that is poured from a high-precision cran with a millimetre precision, shaping the building complex. The finished result was completed within a couple of days (Moro, 2022).

Figure 131

Figure 132

The Great Wall of WA

Talk About Merging with the Landscape

Year: 2016
Loacation: Pilbara, Australia
Architect: Luigi Rosselli
Details: Rammed earth, 230 m long wall

Concealed within an existing sand dune, embedded in a blanket of vegetation lies The Great Wall of Western Australia. With the main architectural feature of a 230 m long zigzag shaped rammed earth wall, it poses as the longest one in the country, possibly even in the South Hemisphere. With the main purpose to function as a short-term accommodation for a cattle station during the mustering season complex, the 12 residences provide a striking architectural feature in the serene Pilbara region. The aesthetic of the project is enhanced by choosing an earthen construction technique, where the materiality, texture and colours of the landscape make the building components merge with the surrounding copper-toned landscape. In remote and isolated locations using local materials enable a major advantage, its availability. The dominant feature of the site is iron rich, sandy clay which is used for the rammed earth walls. The material suits the hot and harsh climate well, as the hygroscopic characteristics help to reduce the temperature of the wall through evaporative cooling (Archdaily, 2016). Furthermore, it secures supply chains, decreases the management and provides a more affordable option. It is mainly thanks to the choice of construction material that the incongruous geometry blends in while also strongly contrasting to the arid landscape. It enables bold shapes while still exhibiting a balanced and humble element. In addition to rammed earth, corten steel, aluminium windows, steel columns, concrete and timber cladding have been used. The building took six months to build at a cost of $1.5 million Australian dollars (Binks, 2017). In 2017, the building won the international price TERRA Award for the most creative earth architecture project of the year (Dethier, 2020b).

Figure 133

Casa Lasso

Intertwining Local Building Traditions with Contemporary Form Language

Year: 2019
Loacation: San José, Ecuador
Architect: RAMA estudio
Details: Lime stabilised rammed earth, 350 sqm

Placed in the alpine tundra of Cotopaxi, Ecuador, stands the residential get-away-house. The location, in the central Andes region with a neo-tropical climate displays a wide variety of flora and fauna, that Rama Estudio believed requires a well-considered project, hence the importance of integrating passive design techniques. The house design derived from the choice of material, based on local building techniques, such as bareque (Cogley, 2019). It is a technique that involves wall elements constructed out of intertvoven reeds or branches and earth to form a kind of wattle-and-daub, suitable for seismic areas such as the Andes.

The main construction material is lime stabilised rammed earth, but wood, stone and concrete are used as well, where the latter two compose the foundation (Rama Estudio, 2019). The 40-centimetre thick exterior walls act as the load-bearing element (Structuralia, 2015). Buttresses of 80 cm are arranged according to a structural and utilitarian study of furniture that are recessed to the walls (Arquitectura Viva, 2022). It creates a custom made and well-balanced expression that considers each aspect of architecture, from the large scale elements down to the mobile, small scale details such as the placement of a cupboard, making the Caso Lasso a gesamtkunstwerk. On the inside, mobile partitions formed from a sequence of pivoting wood panels are used to enable air circulation as well as meet the changing needs of the occupants. Wood is furthermore used for the flooring as well as the large cross-beams holding up the asymmetrical gable roof. The golden nuances of the wood goes well along with the warm tones of the earth, creating a visibly appealing outlook. Apart from the environmentally sustainable aspect of the project, the integration of local traditions and materials have strongly influenced the outcome of the project. By emphasising tradecraft and local labour, the architects have deliberately expanded the concept of sustainability to involve social aspects as well (Floornature Architecture & Surfaces, 2019).

Figure 134

Chapel of Reconciliation

Soil as a Carrier of Meaning

Year: 1990-2000
Loacation: Berlin, Germany
Architect: Rudolf Reitermann and Peter Sassenroth
Details: Load-bearing rammed earth, 180 sqm

Placed on the same site as a previous neo-Gothic church stands the Chapel of Reconciliation. Posing as the first in-situ, load-bearing rammed earth building in Germany constructed in the last ninety years, the chapel poses as more than a building. Constructed out of the remains of the former church that was deliberately demolished in 1985 by the East German authorities to eradicate the symbol of hope and freedom during the years of a divided country, the chapel constitutes a memorial as well. The choice of earth was therefore a highly symbolic material of the project where the former building got a second life in the new chapel. Today it has become a place for remembrance composing a physical manifestation of progress, hope and reconciliation.

The original plan was actually to construct the chapel out of concrete but the pastor Pfarrerr Nabfred Fischer opposed, arguing that concrete was the material of war. Instead, he proposed earth and timber. It escalated into a conflict between the client and the architects to such an extent that the regional church of Berlin had to intervene. They commissioned the expert in concrete construction and TU Berlin professor Klaus Dirks to convince Fischer and his community that concrete was the way to go. Instead, Dirks did the opposite, promoting rammed earth. By uplifting contemporary examples of newly constructed rammed earth buildings, the architect' prejudices of earth as an unmodern material was shattered, changing their minds (Heringer et.al 2019).

The testing procedures from which the result is presented below were conducted at the Technical University of Berlin and later accepted by the local building authority (Lehm ton Erde, 2022):

- **Compressive strength:** 2,40 N/mm2
- **Bending tensile strength:** 0,52 N/mm2
- **Shear strength:** 0,62 N/mm2 (Mixing in fibres, flax or hay can result in a enhancement of these characteristics)
- **Material shrinkage:** 0,25 %
- **Thermal conductivity:** 0,64W/mK up to 0,93W/mK

Sharanam Centre for Rural Development

Where Sculptural Qualities Meet the Spatial

Year: 2014
Loacation: Usteri Lake, India
Architect: Jateen Lad
Details: CSEB, 5 percent cement, rammed earth, 1,728 sqm

"Hand-built by local people trained on the job using rudimentary tools and local materials, this cultural centre in rural southern India is both an exemplar sustainable development and a force for social change in the area." Jateen Lad (Lad, 2016)

In the aftermath of the devastating Indian Ocean tsunami in 2004, the training and administrative Sharanam Centre for Rural Development was conceived (Sri Aurobindo Society, 2022). It is built in the outskirts of Puducherry, overlooking a lush, rural landscape ravaged by illegal quarrying. The aim of the project was to host various community and learning driven initiatives. The materials used in the construction had low embodied energy, highly qualitative and durable, minimising future maintenance. Most of the centre is constructed out of CSEB; used for the walls, columns and roof, rammed earth foundations and earth mortars- and plasters for the finishes (Janteen Lad Architect, 2020). The loam excavated from the site was considered ideal for earth construction technologies for its ratios of 50 percent sand, 20 percent clay, 15 percent gravel and 15 percent silt. A small reservoir for harvesting surface water to run-off is formed out of the 'pit' created by the excavated loam (FuturArc. 2016).

The superstructure's most striking architectural element is the roof composed out of six masonry vaults arrayed along an east-western axis that displays a captivating lightplay. The 9.5 metre spanning vaults are only 9 centimetres thick at the keystone and constructed out of CSEB using a self-supporting technique without any formwork. The blocks are stabilised with 5 percent cement and left to be cured under the hot sun for one month. The blocks are completely made by hand and over 250 000 CSEB with nine different dimensions were constructed. For one-third of the price and one-tenth of the embodied energy of market bricks, the unfired earth blocks constructed on site displayed a three times better compressive strength compared to market bricks when tested (FuturArc. 2016).

Figure 135

Library of Muyinga

A Reinvestment in the Local Economy

Year: 2012
Loacation: Muyinga, Burundi
Architect: BC Architects
Details: CEB and concrete columns, 140 sqm

In a context where most of the culture is strongly marked by its oral and informal nature, deaf people suffer from exclusion affecting not only their social interaction but also education. The aim of the learning school, Library of Muyinga, is to provide a link between deaf children and the wider community of Muyinga (Thebault, 2022).

The library is a good example on how different materials can be used to optimise the use of each material. The project is divided into four phases to optimise the construction (BC Architects & Studies, n.d). For phase 1, the pilot project, CEB are used for the walling component enabling the blocks to be fouled back into the ground when demolished. A lightweight concrete skeleton was used inside the CEB columns. The aim is to eliminate the structural use of concrete in the prospective phases. Baked clay tiles used for the roof replaced imported corrugated iron sheets. The choice of material did not only cut costs and unnecessary supply chains but revalued locally available materials. Eucalyptus wood is used for the load bearing beams supporting the roof (BC Architects & Studies, 2022).

The column system gives the building a rhythmic, harmonic and well-balanced expression, prominent on both the exterior and interior. The general form of the building is designed around the spacing of 1,3 metre, a result springing from a structural logic. The column system has to be able to carry the load of the heavy baked clay tiles. The roof is designed with a 35 percent angle and a large overhang to protect the CEB. An overdimensioned hallway porch embraces the Burundian housing tradition and supports social interactions since it is usually there people gather. To increase the interaction between the porch and the interior, transparent doors are placed between the columns creating a linkage between them both.

The future school is designed with consideration about the existing landscape, forming playgrounds and courtyards around existing trees and slopes. Until all phases are completed the library will function as an autonomous building (BC Architects & Studies, n.d).

Figure 136

The materiality of the library is easy to read in this well-composed design. The ring-beam speaks of the load-bearing system and the use of perforated walls provides a compelling light-play.

Figure 137

Morocco Pavilion Expo 2020

Earthen Structures and Sustainability in the Spotlight

Year: 2021
Loacation: Dubai, United Arab Emirates
Architect: OUALALOU + CHOI
Details: Prefabricated rammed earth panels coupled with a lightweight concrete frame, 6057 sqm

Posing as the highest building constructed out of rammed earth is the Morocco Pavilion Expo 2020. The 34-metre-high facade is a pioneering advancement for the construction method, made possible through the usage of prefabricated panels coupled with a lightweight concrete frame (OUALALOU + CHOI, 2022). The architects wanted to lift the vernacular technique strongly rooted in the Moroccon building tradition into an industrial dimension (NACOSTI, 2022).

"The firm's design attempts to recreate the experience of the country, rather than its iconic aesthetics, by tying the pavilion's galleries together with a continuous ramp that recalls the narrow and dynamic streets of the Moroccan medinas". (Reiner-Roth, 2020)

The superstructure is built like a Moroccan village consisting of twenty two rectangular volumes stacked on top of each other, centred around the characteristic feature of the riad homes; the courtyard. The pavilion encompasses fourteen exhibition spaces, ten hanging gardens, tea rooms, restaurants, shops and offices. By the implementation of various passive cooling techniques such as multiple vertical gardens, large central patio, wooden interior facades with doubles as sunscreens and the wall-thickness of the rammed earth, the pavilion answers fully to the criterias of LEED (OUALALOU + CHOI, 2022). The usage of 0,6 metre-thick walls enables the interior spaces to be up to 15 degrees Celsius cooler than outside (Prisco, 2021). In line with the commitment of sustainability, the pavilion will be transformed into apartment complexes and communal spaces when the Expo has ended.

Women's House Ouled Merzoug

A Play with Tactility

Year: 2019
Loacation: Idelsane, Morocco
Architect: Building Beyond Borders Hasselt University
Details: Adobe and granite, 130 sqm

On top of a hilly site of Ouled Merzoug, stands the Women's House, a meeting-, working- and learning place. The aim is to provide a space where women can share and sell their crafts with the community and visitors. With views over the Atlas Mountain to the east and a river to the west, the project is split into two volumes each main facade angled to face one of these astonishing views. Completely constructed out of local craftsmanship techniques, the project is a result of a participatory approach where local women and workers come together to complete the building. With a wall element consisting of two materials a tactile dynamic is created (Pintos, 2022). Locally produced adobe blocks are wrapped by granite blocks dug out from the surrounding hills. The rough facade texture of the granite blocks contrasts to the smoothly plastered adobe blocks that constitute the interior face. The brown-reddish plaster seen on both walls and floors are made out of different combinations of local earth, river sand, lime and straw. The thatched roof constructed out of nearby growing reeds are placed on top of eucalyptus beams. The same wood is used for the doors, window frames and kitchen counters (Block, 2020). Each square metre was estimated to cost 330 EUR, making up a total amount 39 600 EUR (ULULE, 2019).

The project is a result of a close collaboration with Building Beyond Borders, that constituted a group of architecture postgraduates and academics from Universiteit Hasselt School in Belgium, and the then recently founded women's association: AFOM (Association des Femmes d'Ouled Merzoug). The project displays considerations about all three sustainability aspects. In the design, the public character of the centre is emphasised by placing the heart of the building on the intersection of two important informal paths. This heart connects the two volumes of the centre; the workshop space and the communal baking house. Both volumes have their own enclosed courtyard, designed and furnished to enhance the program of each adjacent space as well as provide leisure and resting areas (Pintos, 2022).

Figure 138

Figure 139

Gando Primary School

The Power of the Community

Year: 2001
Loacation: Gando, Burkina Faso
Architect: Kéré Architecture
Details: CSEB, 6 percent cement, 310 sqm

Just one year after the construction of the small primary school built in Gando, the hometown of the then architecture student Kéré was asked to send money for its upkeep. Soon after, he realised that his and his community's efforts were of little long-term benefit. Instead, cheered by his fellow students in Berlin, he started to take the matter into a new direction. Through an extensive dialogue with the villagers, a solicited collaboration that ensured that the community would come together and participate in the construction was made (Lepik, 2010).

To be able to construct the primary school a fundraising project was raised. After a lot of trouble Kéré succeeded and collected 50 000 USD. He returned to his home in Gando to tell the good news. The villagers were stoked, until they realised that it was supposed to be constructed out of earth. The material was already familiar to them. Actually all of their houses were constructed out of it. The problem however was that they didn't see any innovation with earth. Instead they were expecting and hoping for a concrete building. After many long hours of conversation the villagers were convinced and agreed on using earth (Kéré. 2013).

The result consists of three detached rectangular classrooms placed in a row, gathered under a large roof. Thanks to the generous ceiling height the rooms are experienced as spacious and well-circulated as well as provides a good thermal comfort. The corrugated roof rests atop a light structure of girders. Below the girders are a concrete frame holding a ceiling composed out of earth tiles, fitted into metal supports giving the ceiling both insulative and sound-absorbing properties. For the walls, CSEB formed by a single machine, powered by two people, were used for the straightened and uniform expression. A traditional compressed earth technique was used for the floor, stomped, beaten and stone-polished until smooth (Kéré 2013).

With most of the labour supplied by the villagers, the construction of the school was truly a community endeavour. After the completion of the project some of the participants trained in CSEB making and construction have found work as skilled labourers at other sites in the country (Lepik, 2010). Usually to be able to support their families people, mostly young men, left the village or even the country to never come back (Kéré, 2013). This change of course really shows the power of architecture.

Wa Shan Guesthouse

A Poetic and Nuanced Piece of Architecture

Year: 2013
Loacation: Xiangshan, China
Architect: Wang Shu
Details: Rammed earth, 5000 sqm

Brought together by mountains and water, the components for the architectural design of Wa Shan Guesthouse represents a physical manifestation of the long lived literati tradition. The aim is to give visitors a rounded experience of a mountain. The visitor centre is part of the Xiangshan campus where the most eye-catching element is the roof structure. Inspired by Hangshou's heritage, the campus plan and the site itself -placed by the bank of a river and at the foot of a mountain-, the architect attempted to convert the two-dimensional traditional Chinese landscape paintings into a three-dimensional spatial experience. The artform was not attempting to convey realistic representations, but rather a series of feelings or experiences (Denison and Yu Ren, 2013).

The roof is the design's central element which possesses a strong symbolic, both physically and conceptually, with the mountainscape. It is used as a unifying medium in the same way as the literati painters did. With pathways snaking over the peaks of the grey tiled covered roof with gardens and courtyards, it creates a dynamic scenery like the surrounding landscape themselves. These pathways run all the way through the building complex's cave-like ground floor, up through the wooden beams of the roof and across the roofscape to reconnect with the surrounding, creating a kind of vertical landscape. By using layers of materials, textures and shapes, the building complex offers various scenes with multiple journeys and explorations. The choice of material enhances the contrasts and experience of each journey where rammed earth forms buttresses and internal walls that complement the myriad surface textures within and outside the building. The 0.6 metre-thick walls divide the building into six independent units and are protected by the 120 metre long roof (Area, 2014). By building out of stone, bricks, concrete, steel, tile, timber and bamboo along with rammed earth this project displays how heritage, tradition and technology can come together to form a modernistic and compelling result.

Figure 140

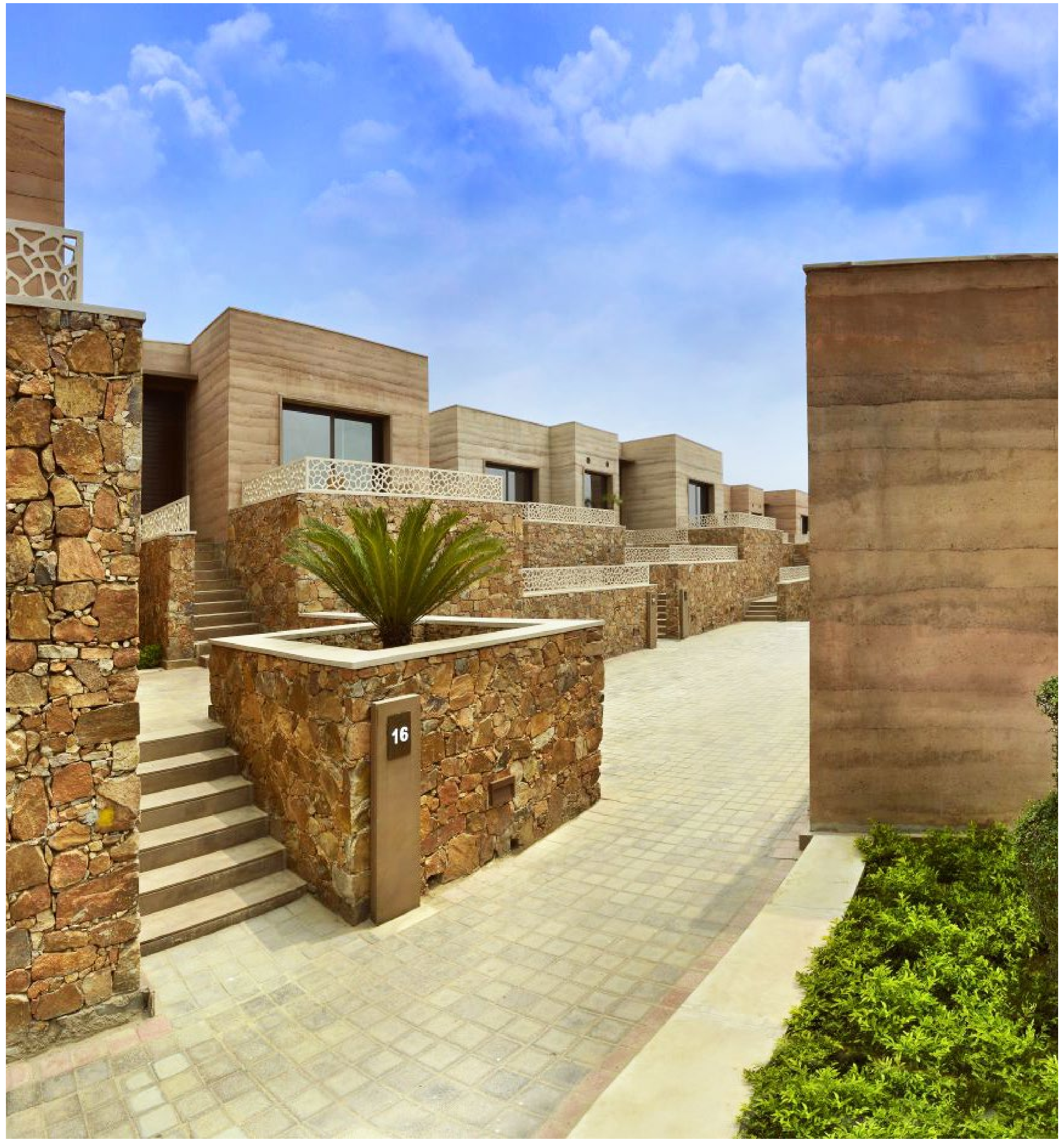


Figure 141

The LaLit Mangar

A Monolithic Structure

Year: 2016
Loacation: Mangar Bani Valley, India
Architect: Ashwin Alva
Details: Stabilised load-bearing rammed earth, 9 percent cement, 5000 sqm

The luxury gateway The LaLit Mangar placed on the rocky-outcrop of the Aravalli Hills near Delhi, has refreshed the view on technology and its role in the architectural expression. More than 80 percent of the superstructure is constructed out of the raw material found on site. With a design rooted in the typical organic growth of Indian villages, the design was centred around a series of courtyards. The rooms are placed in clusters with a south-facing orientation to increase the thermal control (Gupta, 2019).

To construct the 40-room hotel complex, a formwork was developed used as a repetitive module. The 4 metre tall mould was moved back and forth on the construction site which is the key behind the architectural expression. It created a mass that is not only monolithic but read monolithically too. The lack of norms and relevant codes led to the usage of rebars to cater the seismic norms of the zone, specially designed to permit ramming within and around the rebar cages (Gupta, 2019). The thermal performance is improved through the development of an insulated cavity between two 175 mm wide stabilised rammed earth walls, where the inner section is load bearing and becomes the finished face of the interior whilst the external wall section constitutes the building facade (SIREWALL, 2022a). The stabilised rammed earth wall consists of 9 percent cement (SIREWALL, 2022b). In total this continuous insulation envelope wrapped over both the vertical and horizontal faces, it runs all the way around the 220 metre long property making it the largest insulated rammed earth building in the world.

The choice of constructing the complex out of rammed earth affected the whole building process. The architect's role was prominent not only in the design phase but also during the coordination of all services and the implementation of the technique from start to finish. It increased the influence of the architect as well as enabling check-ups to confirm that the architectural expression was reached. (Gupta, 2019).

Figure 142

King Abdulaziz Centre for World Culture

Pushing Earthen Material to New Extremes

Year: 2007-2018
Loacation: Dhahran, Saudi Arabia
Architect: Snøhetta
Details: Prefabricated, rammed earth walls, steel pipes, concrete, corten steel, 100 000 sqm among these 2 823 sqm rammed earth

Rising up from the eastern deserts of Saudi Arabia, the King Abdulaziz Center for World Culture stands as the biggest earth project constructed in modern times (Heringer et. al. 2019). Its geological, almost pebble-like, form is rendered in rammed earth, concrete and stainless steel pipes. The immense complex serves as a crossroads for many cultures, and will host diverse cultural facilities such as an auditorium, cinema, library, exhibition hall, education centre, museum, and archive (Bell, 2016).

The country has a rich history in building with earth, for instance the Royal palace of Riyadh. However, many earth buildings were not maintained resulting in the demolition of several structures in the 1970s. It is not until recent days a revival for earthen materials is seen. Trust in the material was built after the architectural team and the clients participated in a three-day workshop at the Ricola Kräuterzentrum building site. A demonstration over the compressive strength of unstabilised rammed earth followed by a logistical coordination of large-scale construction on a complex building site turned them over. It resulted in the construction of an extremely complex building with a high degree of technology, yet it uses no stabilisation, chemical additives or integrated reinforcement. Due to the inexpensive labour of the country most of the actual construction was set in place by large teams of workers rather than machines. In total, over 7 000 people were on the building site (Heringer et. al. 2019).

Figure 143

Oficinas del Centro de Ecología Aplicada (CEA)

A Collage of Different Earthen Techniques

Year: 2010-2011
Loacation: Santiago, Chile
Architect: Marcelo Cortés
Details: Metallic wattle-and-daub (technobarro) for walls, earth and straw for roof, rammed earth, light earth, adobe, 1200 sqm

With an interesting hybrid design between industrial- and non-industrial technologies, stands the three-storey high CEA. The technique developed by the Chilean architect Marcelo Cortes is named "quincha metallica". "Quincha" is a traditional wattle-and-daub technique used throughout the whole continent of South America. Used since pre-Hispanic times it reached its peak during the 17th-18th century. The word itself derives from the Quechua language meaning wall or enclosure (Lopez, 2022). In total seven construction techniques are applied to this "metallic quincha", giving the building a great aesthetic and technical richness.

The main part of the building is composed out of the technique "technobarro", also named metallic wattle-and-daub has been used. Simply put, it can be explained as a wattle-and-daub technique, where an earth-and-straw mix is put on top of a load bearing metallic formwork instead of the more traditional branch structures. Rammed earth with incorporated reinforced concrete slabs every 0.5 metre are used for parts of the western and northern facade. On the second floor of the western facade, light earth - a mixture mainly consisting of straw - is placed in between a metallic formwork, used to improve the thermal insulation. For the same reason an earth and straw mixture, with other proportions however, was used for the roof. Instead of being placed in between a metallic formwork, poultry nets and a wooden frame make up the formwork. For the remaining parts of the northern facade, framed in the metal structure are coloured adobe bricks used. Metal chains are used to tie them together every fourth to fifth row (Rivera, 2011).

Figure 144

Manufacture-sur-Seine in Ivry

Reuse of Earthen Materials on a City Scale

Year: 2017-2030
Loacation: Paris, France
Architect: Quartus, Amateur Architecture Studio - Wang Shu & Lu Wenyu, JOLY&LOIRET, LIPSKY + ROLLET and TOPAGER
Details: Raw Earth (mainly rammed earth) and Wood, 20 000 sqm

The transformation project of the former water treatment plant in Ivry-sur-Seine, Paris, will be the first project in the world building a new district on stilts out of raw earth. Constituting a total of 6 hectare, it truly makes up a large-scale project. It will result in the construction of 350 housing blocks with three-four floors, student accommodations and faculty as well as more than 20 000 sqm of workspaces, services and amenities. Along with wood, the construction will mainly be out of earth (Dethier, 2020b).

Under the aegis of Quartis the design proposal is made by a collaboration between Amateur Architecture Studio, JOLY&LOIRET, LIPSKY + ROLLET and TOPAGER while CRAterre will provide technical assistance. The aim is to be finished by 2030 (CRAterre, 2020).

Essential for the project have been to establish and work around a circular economy. By using earth excavated from the urban subsoil deriving from the construction of the new rapid transit line Grand Paris Express, a resource usually seen and treated as waste material will be turned into prefabricated rammed earth panels, bricks, panels and raw earth mortars (Dethier, 2020b).

The architecture will therefore manifest a literal expression of the soil itself. The existing open-air filtrated basins as well as “the nave”, a large industrial building, will be integrated into the new project (Grand Paris Development, 2018).

Figure 145

Figure 146

During the week-long workshop “Claystorming” taught at various Universities around the world, students work in small teams to practice Anna Heringer’s method of 3D sketching on clay models. Here is a picture of some GSD students at Harvard practising the unique approach to designing humane and sustainable spaces in 2018.

4.3 Network, Education & Innovation

Figure 147

Companies, universities, organisations, professionals and students all over the world are showing an interest in earthen materials and working in projects that can guide them to rebuilding and developing the foundation of knowledge for earthen architecture. This has become particularly interesting due to the challenges we face today and the need to act fast. A joint effort between public institutions and private operators that are engaged in scientific research is beginning to be structured as a new wave of innovation is framing earth as a potential way forward. The coming pages will give a brief introduction to some of the initiatives taken in the world of earthen architecture.

1. UNESCO Chair Earthen Architecture

The UNESCO chair "Earthen architecture, construction cultures and sustainable development" is led by CRAterre-ENSAG with the aim to accelerate the scientific research on earthen materials worldwide. They cover research on for example material technologies, economy of production with local building materials, construction know-how and environmental issues. Priority is given to the development of training programmes in institutions for higher education and courses for professionals on national and regional levels (Auroville Earth Institute, n.d.).

1. Figure 148

2. CRAterre at the ENSAG (Grenoble School of Architecture)

Since 1979, the research laboratory CRAterre has been based at the ENSAG. All first year students study the fundamentals of earth architecture, and the university also offers a "professional postgraduate qualification" under the UNESCO Chair on Earthen Architecture, Building Cultures and Sustainable Development. In 2000, a specialised master's degree was introduced in which the uses of earth for construction are taught alongside other materials such as concrete, wood and steel (Dethier, 2020b).

2. Figure 149

3. EBAA (Earth Building Association of Australia)

EBAA is an organisation working to promote earthen materials in Australia. Their members consist of contractors, builders, architects, consultants, suppliers, teachers and students and has since the start in 1990 been focusing on communicating constructively with all levels of the Australian government that concern the Building practice and its regulations. Every year they arrange EBAA´s Annual Conference (EBAA, 2022).

3. Figure 150

4. EBUKI (Earth Building UK & Ireland)

EBUKI is an organisation that works towards fostering the development of earth buildings. EBUKI was initiated in 2007 by a group of academics, builders, researchers, trainers, architects and engineers who were all interested in increasing and normalising earth in construction. EBUKI acts like an umbrella for research and development in the field of earthen buildings and aims at gathering, spreading and developing knowledge. They work with National and International partners to write and publish standards on earthen materials, as well as organise events with expert speakers and workshop leaders (EBUKI, n.d.).

4. Figure 151

5. University of Bath, UK

The University of Bath has implemented the introductory course "Natural Building Technologies" to undergraduate Civil & Architectural Engineering and fifth year MArch Architecture students. Course content include for example lectures on climate change and sustainable development, earthen constructions, natural binders and pozzolans and future for natural building (Uni-Terra, n.d.).

5. Figure 152

6. AVEI (Auroville Earth Institute), India

AVEI is one of the world's top centres for expertise and education in earth architecture. They work in 35 countries in order to transfer knowledge and they also represent Asia in the UNESCO Chair on Earthen Architecture. They have since 1986 offered training courses in how to build with earth and have had thousands of students from 76 different countries (Auroville Earth Institute, 2020).

6. Figure 153

7. TERRA Conferences

TERRA conferences have been held every 4 years since 1972 and have been supported by UNESCO, CRAterre-EAG and ICOMOS among others. This has led to an institutional collaboration where research is combined with education, planning and communication (Moriset et.al., 2021). The upcoming conference, Terra 2022, is the 13th World Congress on Earthen Architectural Heritage. The congress is expected to host 600 experts in the field of conservation, architecture, engineering, scientific research among others (Terra, 2022).

7. Figure 154

8. TERRA Award

The TERRA Award was created in 2016 with the support from CRAterre/ENSAG and other partners. The purpose of the award is to identify earth projects, highlight the possibilities of using earth in order to promote broader uses in the future. Furthermore, it is intended to enhance the prestige of using earth for modern architecture. The first edition received 300 applications from architects and builders from all over the world. The entries were evaluated through a range of topics such as architectural quality, environmental approach, energy performance and social intensity (TERRA Award, n.d.).

8. Figure 155

9. International RILEM Conference on Earthen Construction

In March 2022, the conference was held by RILEM, presenting the latest conclusions from their research to demonstrate the full potential of earthen constructions in the future (Conf-earth, n.d.).

9.

Figure 156

10. Oxara

An exciting initiative investigating stabilisation of earth is the Zürich based company Oxara. The company aims to facilitate the re-use of construction waste to enable access to sustainable and affordable housing. They are working with the development of a cement-free admixture in order to transform excavation material into sustainable building materials. The company was founded by Dr Gnanli Landrou after the finalisation of his PhD about the development of self-compacting clay concrete at the ETH Chair of Sustainable Construction. In 2020, the company won SEIF Award 2020 for Social Innovation (Oxara, n.d.).

10.

Figure 157

11. Lehm Ton Erde

Martin Rauch, the founder of the Austrian company Lehm Ton Erde, has worked with earthen constructions for 30 years. He is experimenting with prefabrication of rammed earth and has held numerous lectures and workshops across Europe, USA, Bangladesh, South Africa and Egypt. He is also involved in a variety of contemporary earth building projects and since 2010, he is a UNESCO Honorary Professor of the Chair of Earthen Architecture, Building Cultures and Sustainable Development (Heringer, et.al. 2019).

11.

Figure 158

12. “Clay Storming”

Anna Heringer, together with Martin Rauch, has developed the workshop “Clay Storming” that she teaches at different universities around the world. For one week, the students get to elaborate with 3D sketching on clay models while discussing the essence of architecture and exploring design based on material understanding (Harvard University, 2018). In 2012, the small-scale modelling in the classroom turned into a full-scale installation in front of Harvard’s Graduate School of Design called “Mud Works”. The project involved over 150 students and 30 tons of earth and aimed to challenge conventional thinking about green building (Heringer, n.d).

12.

Figure 159

13. Clayworks

By offering various kinds of clay plasters, Clayworks have developed qualitative plasters with high performance. Consisting of unburnt clays mixed with minerals and pigments the result is non-toxic, recyclable, compostable and re-usable (Clayworks, 2022).

13.

Figure 160

14. TerraPerforma

At the Iaac (Institute for advanced architecture of Catalonia) in Barcelona, the TerraPerforma project was developed in 2016-2017 and focused on large-scale 3D printing of complex geometries with unburnt clay. The aim with the project was to pair clay with contemporary technology to develop prototype walls that would position clay as a possible construction material for the contemporary architectural field. Physical tests (using self-developed machines such as Hygrothermal Monitoring Apparatus and Load Machine) and digital simulations (using software such as Rhino, Ladybug and Caramba) were carried out on the prototypes in order to test their structural and thermal capacities (Iaac, n.d).

14.

Figure 161

15. SIREWALL

SIREWALL stands for Structural Insulated Rammed Earth and is a company in the US that develops custom-made wall systems of rammed earth. In 2010, SIREWALL was selected for the Living Building Challenge and LEED Platinum through the project Van Dusen Botanical Gardens in Vancouver, BC (SIREWALL. 2022c). In 2018, a SIREWALL wall system was used for Telenor ‘345’ Head Office in Pakistan and was at the time posing as the tallest rammed earth structure on earth with a height of 30.48 metres (SIREWALL, 2022d).

15.

Figure 162

16. Hive Earth Studio

Hive Earth Studio is a company based in Ghana that specialises in locally sourced materials with earth as the primary material. Their team consists of rammed earth construction specialists, consultants, designers and architects that develop and offer earth walls and other installations in different colours and textures for the use of construction, interior decor, art and design. They also provide online courses in rammed earth constructions (Hive Earth Studio, 2022).

16.

Figure 163

Chapter 5

5.1 Challenges of Earthen Materials and How to Overcome Them

The Image of Earth

Figure 164

Local vs. Traditional

When we have read texts treating, discussing or describing earthen materials, a frequent use of the words “local” and “traditional” is seen. In this context, these two words are usually used as synonyms to one another. Perhaps, it is partly due to this phenomena that the perception of earth for contemporary use is affected negatively. The word “traditional” is often associated with something old, outdated or regressive.

These traits are usually applied to earthen materials and drive the perception of them as vernacular structures rooted in poverty. Local does not have to mean traditional, it just happens to be traditional too. Before industrialisation, and still today in many developing countries, people didn’t have much of a choice but to use building materials available close by. There is a need to change the associations to the word “local” by demonstrating that local materials are not necessarily linked to traditional architecture.

The conception of earthen material as means for low-income construction, does not only have an unglamorous aura, but also gives the material the perception of being fragile, ephemeral and even dangerous.

Materials such as concrete, steel and glass, on the other hand, are seen as representatives of modernity, progress and opportunity. For many people, especially in developing countries, having a home constructed out of these industrialised materials represents a benchmark of advancement for generation, a belief driven by international development interests. The same goes for governments and its politicians in developing countries, where constructions out of concrete and glass are a symbol of a nation’s, region’s or city’s wealth (Heringer et.al. 2019).

Even though earth as a building material contains the ability to operate across the entire gradient of high-labour to high technology methods, it became stigmatised during the colonial era and the view upon it as regressive has stuck until this day. Colonisation during the 19th century began to reshape the image of earthen architecture. Before, the natural building material was used in all kinds of building typologies in colonised countries, independent of whether it was a building occupied by rich or poor or if it was a public or private building. The difference was rather seen in scale and ornamentation. Through colonisation, introduction of industrialised materials and technologies along with the hierarchical European building culture was made. The changing aesthetics, scale and materiality during this era recasted the image of earthen buildings. Bricks and brick making techniques played a particularly important role in this change of perception towards earthen materials (Heringer et.al. 2019).

Figure 165

To change the image of earth and make it more attractive, it is necessary that earthen buildings use a contemporary design language that pushes boundaries, explores shapes, and breathes innovation. Integration of modern technology such as 3D printing and computer simulations surely have great potential in the future design of earthen architecture.

This can change its status on a fundamental level, in combination with development of its structural capabilities, more developed standards and more examples of modern buildings that show that the aesthetics of earth buildings using local materials do not appear outdated.

Figure 166

Concerns regarding Earthquake Resistance

Earthen materials have not yet recovered from the perceptions and associations that were spread during the colonial era. Today, professionals, contractors, developers, institutions and governments remain sceptical towards earthen constructions, especially regarding their load-bearing capacities. Prohibition against earth as a load-bearing building material is quietly spreading across more and more countries such as Italy, Colombia and Nicaragua where it has become a predominant construction challenge (Heringer et.al. 2019). The reason behind this trend is mainly due to the risk of earthquakes. Earth alone is not seismically safe, but that isn't the case for concrete either. The loss of credibility in this area is mostly because modern earthen constructions cannot withstand earthquakes.

A census conducted by the Salvadoran government in January 2001 - after an earthquake of 7.6 on the Richter Scale in Salvador -, came to the conclusion that adobe houses were not worse affected by the seismic activity than other kinds of constructions. Furthermore, multiple historical earthen buildings have withstood several severe earthquakes around the globe, among these are the condominiums of the Hakas in China, solid rammed earth fincas in Argentina as well as the ductile (flexible) wattle-daub constructions in Guatemala (Minke, 2006).

The formula "structural quality = resistance x ductility" expresses the withstanding potential of an earthquake-resistant structure.

What it explains is the relationship between resistance and flexibility. The lower the resistance, the higher the flexibility has to be, and the other way around. It leads to the important conclusion that it is not earth as a building material that is the reason for the structural failings, but the structural system of a given building. When careful considerations about structural systems, dimensions, layout of openings and corner solutions are made, earthen construction can prove to be earthquake-resistant (Minke, 2006).

Figure 167

The Consequences of Scepticism: Two built Examples

An interesting example can be found in Morocco, a country that has a long tradition of building with earth. In this context, it is not the aesthetics of earthen architecture that prevented the use of it, but rather the mistrust in its structural capabilities. Recently constructed buildings made out of concrete are painted to resemble earth. The aim is to achieve an earthy aesthetic, but the mistrust of earthen properties results in a pastiche. Another example is the Alnatura Arbeitswelt project in Darmstadt, Germany, consisting of rammed earth walls with integrated insulation. In this case, the issue was not the lack of innovation of new earthen technologies, but rather to get the required certificates for the machine. This resulted in a drawn-out and expensive process (Heringer et.al. 2019). Building without set standards and regulation positions earthen constructions in a grey zone, resulting in issues that puts investors, developers and contractors in riskful positions in terms of insurance coverings, drawn-out process and a lot of administrative costs to getting required certificates.

Figure 168

Guelmim Technology School by Saad El Kabbaj, Driss Kettani and Mohamed Amine Siana, has an earthen aesthetic but is made out of concrete. 2021, Morocco.

Figure 169

Casa Sal in Mexico by RIMA Design Group in 2020. The residential house is made out of rammed earth and cement.

5.1.2 Stabilisers to Compensate for the Distrust

The structural ability of earthen material is highly discussed and viewed upon with a variety of glasses. There is a general lack in literature regarding technical data quantifying the performance of earthen structures and therefore also insufficient reliable guidelines on how to construct in order to optimise the performance of the material, which results in many experimental projects. Some display good structural performance, others do not. This is perhaps due to structural inadequacies, or simply because they are not executed appropriately.

However, it must be said that earthen materials are not as good as conventional materials, such as concrete, in terms of compressive strength and resistance to water. Today, earth is not primarily used as a load-bearing material, although it seems to be capable of acting as one judging by some of the projects we have presented earlier in this work such as Kapelle der Versöhnung in Germany, METI school in Bangladesh and Haus Rauch in Austria.

Due to the distrust of the material, contemporary practices tend to use stabilisers to assure adequate compressive strength and withstandal of material erosion. This is the case for the renowned architects such as Fancis Kéré, Rick Joy and Luigi Rosselli whose projects contain as much as 10 percent cement (Heringer et.al. 2019). That is a shame, since there is evidence showing that it might not be needed. To protect earthen buildings from weathering and environmental conditions, the principle of calculated erosion has potential to be used instead of additives. Furthermore, protection from weathering agents can largely be solved by taking proper architectural measures in the design of the building. "A large hat and a good pair of boots" is usually the way to describe the architectural approach when designing earth buildings, meaning a large roof overhang and a good footing. This can to some extent protect the structure from water damage, but can however limit the architectural expression desired. Shrinkage cracks can also occur due to water evaporation. The amount of shrinkage depends on the type of soil (texture) and can be minimised by optimising the grain size distribution or using additives. Good drainage and using appropriate surface coatings are other ways to protect the building from water (Minke, 2006).

5.1.3 Prefabrication and Economic Issues

Figure 170

Since some earthen techniques are not industrialised, the execution of the construction process is highly dependent on manual labour. In countries where man-powered constructions are expensive, which is the case in many Western modern economies, using these techniques for modern architecture would not be economically justifiable for larger projects. The development of industrial production of earthen material is therefore crucial (Fabbri et.al. 2022). Numerous companies all over the world are committed to facilitating the use of prefabricated earthen materials for construction, such as Lehm Ton Erde in Austria that we have mentioned in earlier chapters. However, despite the fact that these companies strive towards delivering healthy and sustainable construction materials, their prefabricated building elements might require long distance transportations to the building site. Since prefabricated earthen elements are furthermore usually thick and heavy, it results in transportations with high environmental and economic costs, which is of course counterproductive. However, external prefabrication of earthen elements can be considered if made in high dense urban areas close to the building site.

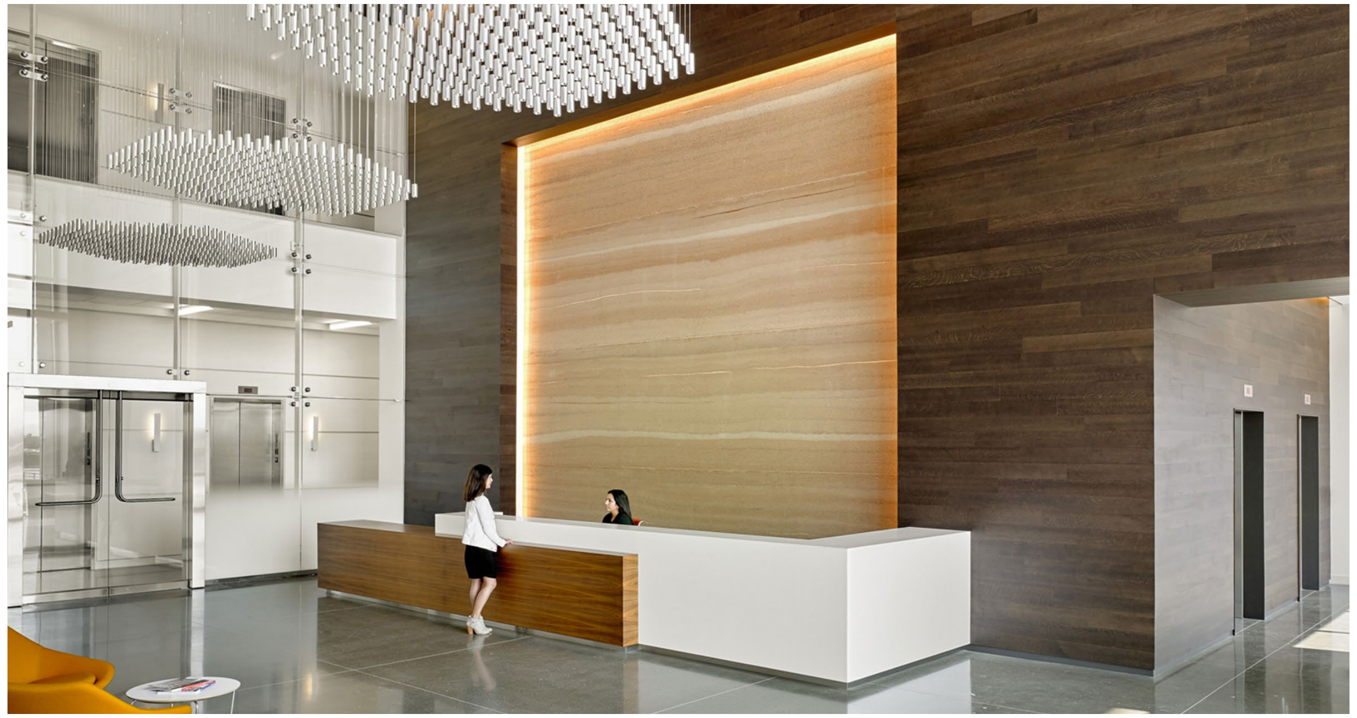


Figure 171

For the lobby of Spear Street Stadium Tech Center in California, designed by Smith Group in 2016, consists of four pre-fabricated rammed earth panels stacked on top of each other to form the focus point of the room. Each panel 1,5 m high by 6,7 m long and only a few centimeters wide made in a factory in Napa, California by by Rammed Earth Works (Rammed Earth Works, n.d.).

Training people to do on-site prefabrication seems to be a better option in order to reduce environmental impact and to some degree also economic costs. If comparing the costs of prefabricated wall constructions per square metre, earthen constructions are rarely competitive to conventional ones. Furthermore, erecting earthen buildings often requires high labour which adds to the costs where human labour is expensive. On the other hand, these extra costs can provide job opportunities and therefore strengthen the local economy. If earthen materials are to be competitive, long-term cost calculations must be made instead of short-term ones. Once earth buildings are in use, they can instead reduce both energy and maintenance costs, as well as costs related to health. As the most common industrialised materials do not only generate carbon emissions and toxic byproducts that have a negative impact on air quality, these materials can also emit organic compounds that might be harmful to residents. Poor indoor air quality caused by unhealthy materials will not only have negative physical health effects, but also result in heavy costs for both citizens and national healthcare systems (Moriset et.al., 2021).

5.1.4 A Need for Codes and Standards

Earth structures have generally not been considered an engineered construction technique, and back in the days the knowledge of earthen constructions was considered unnecessary to write down as it was seen as "common building knowledge". For that reason, earthen materials have not been commercialised and are not associated with the industrialised building practice. Guidelines on the production of materials, construction, quality control methods and design are demanded for any engineered construction. There is a lack of such guidelines for earthen constructions, favouring the use of conventional building materials with appropriate codes and standards. Standards are generally grouped under global, regional and national standards. The International Standards Organisation (ISO) form the global standards, and there are hardly any ISO standards on earth constructions. However, today there are about 70 regional and national standards that exist across the globe on earth constructions. The development of standards emerged during the industrial revolution in the 16-19th century, whereupon the development stopped due to the dominance of modern materials for housing construction.

Building homes with earth became of interest again after natural or man-made disasters, which can be seen in large-scale rehabilitation works in Asia and other parts of the world. Furthermore, after WWII, many dwellings were constructed out of earth in Germany as the need for housing became urgent. As a consequence, a German standard on earthen buildings was created in the 1950s, but was pulled back twenty years later. Mainly due to the interest in decreasing emissions and creating healthy indoor conditions, a revival of interest in earth construction and development of standards has been seen during the last 60 years (Fabbri et.al. 2022).

Even though there are many attempts in developing regional and national standards on various types of earthen products for construction in different regions all over the world, there is an incoherence among these standards as the technical information varies and there are neither uniform laboratory test methods nor a globally accepted terminology (Vyncke et.al., 2018). The absence of global standards depends largely on earthen materials' high variability and reliance on local specificities. For that reason, it is difficult to establish universal solutions. The material's high variability gives rise to many challenges. They could be addressed with different strategies, perhaps taking inspiration from the ones applied to wood as it is also a natural building material with many species with great variability. Regulations and performance standards have been developed through grouping species according to their structural properties and appearance to ensure consistency with the objectives of conventional standards. Similar methods could potentially be used for earthen materials too (Ben-Alon et.al. 2019). In order to encourage designers to build with earth as well as to convince government authorities that earth is relevant for construction, it is a necessity to develop new international laboratory standards for testing earthen materials. New codes and standards need to be established to avoid difficult building approval processes, and they need to address the following:

- Soil composition
- Moulds and machinery
- Production or manufacturing techniques
- Testing and quality control
- Design guidance including earthquake resistant guidelines
- Construction methodology and construction procedure
- Thermal performance, hygroscopicity and moisture buffering
- Durability, limitations and maintenance
- Uniform terminology on earthen products

RILEM Technical Committee TC TCE, consisting of more than 30 active specialists from all over the globe, has in regard to the regaining interest of earth construction identified a clear need for further development of quality standards and could therefore play a pioneering role in this context. The 2022 State-of-the-Art Report "Testing and Characterisation of Earth-based Building Materials and Elements" could surely provide the underlying scientific fundamentals on which such standards are based (Fabbri et.al. 2022).

Figure 172

5.2 Earth: A Sustainable Option?

Potential for Earth in regards to Environmental Sustainability

Figure 173

Saves Natural Resources

As widely available wastes from the construction industry in terms of excavation soil can be reused to make earthen materials, natural resources might be saved that are otherwise required for conventional building material production. Furthermore, the reuse of this soil can avoid unnecessary landfilling. In France for instance, 0.6 million tons (23%) of waste from the construction industry could be used for earth buildings (Fabbri et.al. 2022). The opportunity to reuse this waste has given rise to Cycle Terre, an innovative project in France started in 2018 supported by the European Union. The aim is to develop a new model of town planning that is based on the use of local resources. The innovation lies in transforming extracted soil from excavation sites into building elements such as bricks, clay panels and earth plasters. The advantages of this urban production of local building materials are potentially many. Local employment is provided, massive volumes of extracted soil can avoid being taken out of the city and dumped elsewhere which in turn can reduce fuel consumption, carbon emissions and truck traffic, consequently improving the air quality for inhabitants. Furthermore, the project secures material availability and promotes low carbon urbanisation and reversible buildings. The project also aims at designing an industrial system that is easily duplicated and adapted to other regions as well as other countries in Europe (Cycle Terre, n.d.).

Saves Energy and has Low Carbon Footprint

40% of the global energy use comes from the building sector. Since the 2000s, the proportion of embodied energy for buildings has increased in relation to operational energy due to the development of more efficient equipment and insulations that pushes down the operational energy use. If looking at historical earth buildings, their embodied energy is almost zero as animal energy was used and the building material was unprocessed (Fabbri et.al. 2022).

One of the main advantages of using earth for construction is that it can usually be found and used locally. As it does not require heavy industrial transformation processes before use, if used locally without mechanical equipment and additives, it requires only about 1% of the energy needed for producing, transporting and handling baked bricks or reinforced concrete (Minke, 2006). However, in many Western countries nowadays, as mechanical diggers are used to extract the soil, upon which the material is transported to other sites and implemented using mechanical means, the embodied energy of earth buildings increases. Despite this, the embodied energy of unstabilized earth remains very low in comparison to conventional building materials and is therefore considered having a low carbon footprint. If stabilised, however, earthen materials consume a large amount of energy (Fabbri et.al. 2022).

In terms of operational energy use, earth based buildings need to be studied more before it is possible to make any firm conclusions. However, as mentioned in earlier chapters regarding thermal properties, just as with all heavy materials with high thermal mass, earthen buildings have good thermal storage capacity and are therefore naturally cooler in the summer and warmer in the winter. In climates with high diurnal temperature differences, earth buildings can balance the indoor climate, consequently maintaining a good thermal comfort without the use of energy using equipment (Minke 2006).

Figure 174

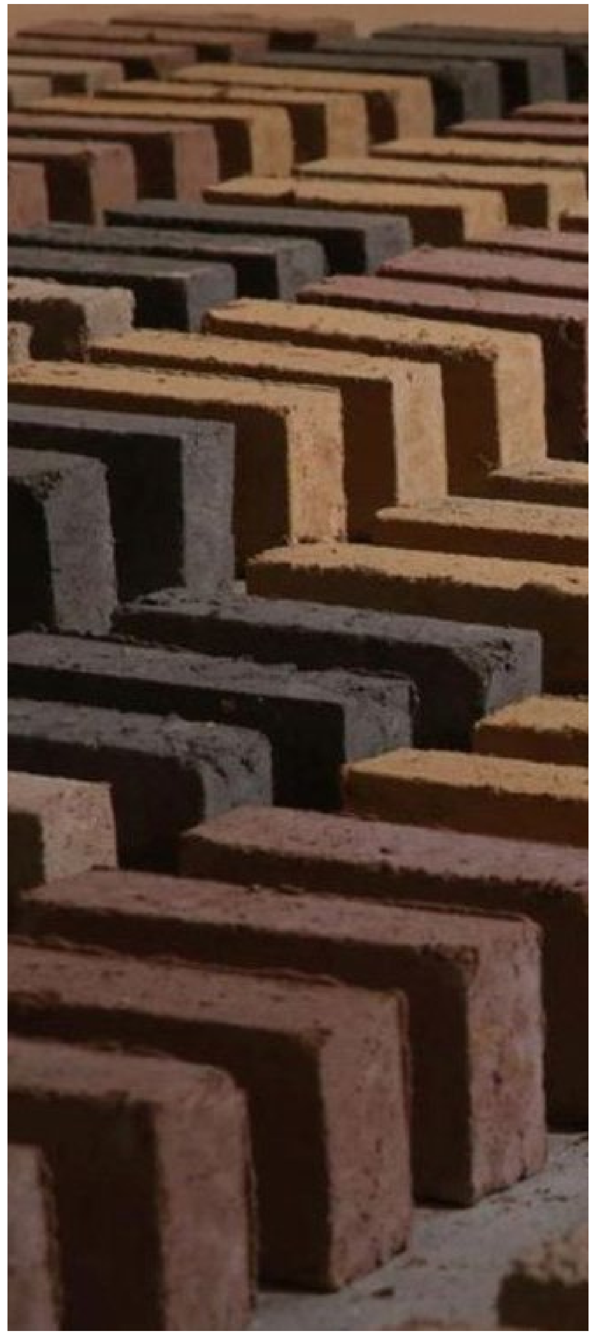


Figure 175

The first brick factory making bricks from excavated earth from the Grand Paris Express made by Cycle Terre.

Recyclable

When using earthen materials without additives it can be recycled infinite times, leaving no toxic waste material behind when demolished. It can furthermore be reused for other construction projects or be returned to agricultural land. If excavation material from the construction sector is used for making earth based materials and if they are not stabilised, they can be regarded as one of the materials that could best meet the challenges of a circular economy (Fabbri et.al. 2022).

Figure 176

Figure 177

Werkstatt Rauch, 1990-1994. The workshop became a demonstration of experimental building where various kinds of earthen building techniques are combined with more conventional alternatives. The planning was carried out together with the architect Robert Felber, the construction was done by Martin Rauch and his team on self initiative.

5.2.2 Potential for Earth as a Catalyst for Social and Economic sustainability

Figure 178

Supports Health and Wellbeing

Since people in moderate to cold climates nowadays spend much of their time indoors, indoor climate is an important factor for well-being. Indoor air quality is however a global issue. Studies suggest that indoor air pollutants are increasing and affecting human health and well-being by causing a range of health issues. The concentrations of pollutants are driven by factors such as chemicals and toxins in building materials, inadequate ventilation, heating and cooling systems and humidification devices as well as temperatures and humidity levels (NIEHS, 2021).

As earthen materials in their purest form are natural and non-toxic, have high thermal mass and excellent hygroscopic properties, they are considered beneficial for health and well-being of the occupants.

Earth absorbs and releases moisture faster than any other material and therefore balances indoor humidity levels, which are closely linked to indoor air quality. It also buffers outdoor temperature variations and can accumulate solar energy during the day and release it during the night, providing inhabitants with good thermal comfort as it balances temperatures, making it a preferable material to use in climate zones with high diurnal temperature differences. There are studies showing other beneficial properties of earthen buildings such as good acoustic characteristics due to their open porous structure. They therefore tend to create quiet and peaceful indoor spaces that resonate solidness. Some studies also suggest that earthen materials have capacity to absorb pollutants, but this is, however, yet to be clearly demonstrated through more studies (Fabbri et.al. 2022).

Figure 179

Contribute to local economic development

If building with locally available earth, the profits do not need to be extracted from localities to enrich large global corporations. Instead, money invested in the project can flow back to its beneficiaries. This can be visualised as a gradient between projects that rely on external suppliers and industrialization and those that are carried out by local human labour. Every project can be placed somewhere on this gradient, corresponding to different factors such as available resources, costs of human labour, local aesthetic preferences and climate. The closer a project positions itself towards human labour implementation and by those who will later occupy it, the more probable it is for the structure to be skillfully maintained as the building knowledge stays within the community and repairing work is easily done by local craftsmen. This will profit local economies as well as generate a positive social impact (Heringer et.al. 2019). Furthermore, earth construction creates jobs that can not be relocated since the building techniques depend on local conditions and the required skills vary from one place to another. This expertise will then be recognized by other actors of the construction, consequently making the profession more attractive. It also increases their responsibility which can contribute to a reduction of construction defects (Fabbri et.al. 2022).

Earth is not only a material but also the embodiment of socially and economically responsible construction. As a building material, it has the potential to generate stronger local communities and building cultures. Most people can be involved in the building process - young as well as old - giving this type of construction project a kind of “catalyst nature”. People not only get a new building but also knowledge that can generate more job opportunities in the future. In a low-income context, a project like this could make an incredible difference for people, both when it comes to the physically built environment, but also for social reasons as working together it can strengthen relationships among villagers and furthermore build trust in their local resources.

Figure 180

Supports Affordable Housing

Building with earthen materials could have a positive impact on affordability all over the world, but above all in developing countries where there is a strong demand for affordable and decent housing due to overpopulation. Conventional materials usually require industrial processing, importation and transportation which push the prices up. Local materials like earth, significantly reduce construction costs. The use of excavation soil can also reduce the cost notably, even if the soil is transported from other construction sites. For developed countries, earthen structures are not necessarily more affordable than conventional ones given the lack of implementation in common building practice, even though the material itself can be considered as free. The cost depends almost exclusively on salaries, local taxes and lack of standards (Fabbri et.al. 2022). Nevertheless, they could however position themselves as a financially viable alternative for the building material market if prices for industrial building materials continue to increase along with the decrease of resources on our planet. Sustainable building products are more and more coming to dominate the decision-making processes of both consumers and companies, pushing actors to invest in alternative products (Heringer et.al. 2019). Additionally, due to the COVID-19 pandemic, shortages and price escalations can already be seen due to transport restrictions which further suggests that stakeholders will be required to use local building materials such as earth that is not affected by these fluctuations to the same extent (Moriset et.al., 2021).

In industrialised parts of the world where human labour is expensive, prefabrication of earthen elements is essential. Within this framework, prefabricated rammed earth elements have particular potential if costs in the production process can be cut through technical innovation. The profitability could then be improved, making the material more established and competitive on the open market and in the long run also contribute to more affordable buildings (Heringer et.al. 2019).

Figure 181

10×10 Low-Cost Housing by MMA Architects. The residential house from 2008 in South Africa is constructed out of timber frame structure filled with sandbags which are then plastered. By using this technique the resulting design landed on the humble price tag of $6,000 (Yoenda, 2008).

Figure 182

Labour Intensive and Suitable for Untrained Builders

The labour intensive earthen techniques can also be a great advantage in countries where human labour is cheap and where there is a need for job opportunities. Earthen constructions in such countries have great potential, as many people can be involved in the building process. Since the material allows participation, it can enhance social and economic capital, which in modern times has somewhat faded away from common practice in the building industry (Heringer et.al. 2019).
In the mainstream construction practice today, a number of hazardous substances can be exposed to construction workers, leading to various health issues. Substances such as dust, gases, chemicals and potentially harmful mixtures in for instance paints, are common to be exposed to for construction workers (ESUB, 2017). In developing countries, the extra cost for personal safety equipment (PSE) might not be financially covered. This can be seen on construction sites in Tanzania, where equipment such as face masks, gloves and helmets are not always supplied to the workers. As earthen materials are toxic free, hazardous substances are minimised if not non-existent, consequently providing a healthier and safer environment for construction workers. This is undeniably also beneficial for construction projects that are not carried out by professional builders, something that is likely to come across in developing countries. Earth has the advantage of being a relatively easy material to build with as non-professionals with little or no previous experience in construction can be taught quite fast after some training, making earthen materials suitable for self-builders. This goes for earth in general, but for certain techniques in particular. Usually even larger projects can be executed with only a handful of experienced individuals teaching and supervising untrained builders, since the process of identifying soil and the actual construction are usually more labour-intensive and time consuming than difficult (Minke, 2006).

Support Local Building Cultures and Cultural Heritage

Architecture can be described as the embodied representation of its society, and therefore cultural heritage provides a place with a certain soul and context. Traditional buildings used to respond to its environment; cultural needs and the local climate. We believe that extra attention should be given this in a world where we are increasingly moving towards a society where much contemporary architecture looks the same all over the world, giving no clue to where a building is located.

To cherish our cultural heritage is necessary, not only to inspire more varied and interesting architecture, but more importantly to not let valuable building knowledge of climate appropriate design fall into oblivion. One of the major issues for earth based materials is the lack of documented knowledge. Instead, it has been passed on from hand to hand through practical learning. There is a lot of such knowledge that can be gained by looking at old earth buildings, both in terms of structural stability but also energy efficiency. With the loss of vernacular know-how, the built heritage is the last witness of these strategies. Despite being such an ancient material, many people around the world want to live in earth buildings, and also still know how to build with earth.

By flourishing this knowledge, local building cultures and cultural heritage can be protected and furthermore be used as a source of inspiration and ideas for modern architecture.

Figure 183

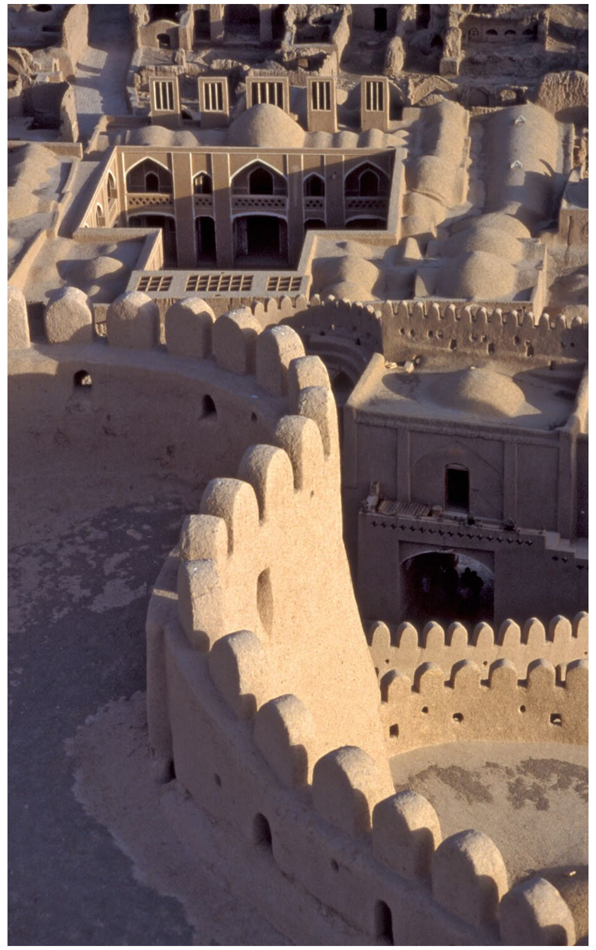


Figure 184

Bam Citadel, Iran is protected by Unesco World Heritage for its earthen architecture.

5.3 The Hybrid

Combining Building Materials

Figure 185

There isn't one single building material that can meet all needs. As architects, we need to design appropriately to enable a combination of materials and take advantage of their different strengths to the fullest. Until more standards and codes are developed for unstabilized earthen materials, we believe that prospective use of them in modern architecture is most likely to be seen in various kinds of hybrid buildings where conventional load bearing and durable materials such as concrete, baked bricks, wood and steel are used where they are most needed. Earth has the potential to fill the gaps within such structures, potentially resulting in an architectural solution that is environmentally, economically and culturally appropriate. The philosophy should not be to replace one material with another, but rather to minimise the use of highly processed conventional building materials. In these hybrid buildings, the beneficial properties of each material is amplified to generate optimised structures.
Earth can favourably be used in combination with wooden structures. As soil has moisture buffering properties and is slightly less moist than wood, it conserves and protects wooden and other organic materials such

Figure 186

Plazza Pintga Stable in Almens, Switzerland.

as straw and bamboo by keeping them dry. It also protects these materials from fungi or insects as they usually need an environment with higher moisture content to survive (Minke, 2006). One example of a project combining wood and earth is the Plazza Pintga Stable in Almens, Switzerland. The three-storey house was converted from a stable to a residential house in 2010 with timber carrying the loads in the exterior walls, while the interior walls contain 160 load-bearing rammed earth elements. This project not only poses as a good example of how earth can be combined with wood, but it also represents advancements in innovation with rammed earth and highlights the connection between architectural form and material. Furthermore, no steel is used in the structure, not even for nails or screws. There is a heating-pipe system integrated into the rammed earth parts that enables the walls to be thermally activated across all three stories. The house does not need ducts or pipes for ventilation, as it can regulate its own humidity. This made the project not just more affordable, but also climatically appropriate and aesthetically pleasing (Heringer et.al. 2019).

As many buildings nowadays are often "overspecified", meaning that they are

Figure 187

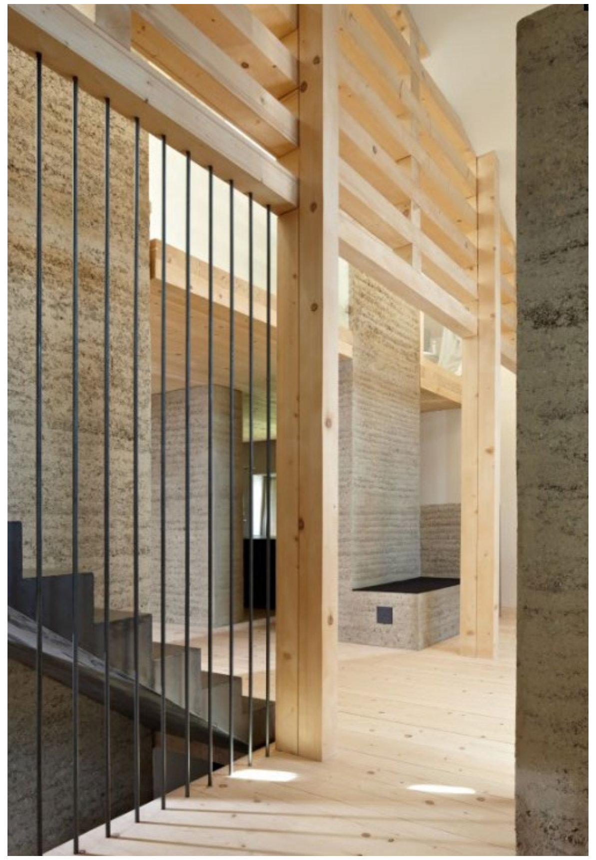


Figure 188

Plazza Pintga Stable in Almens, Switzerland.

(Lehm Ton Erde, 2010)

constructed with more material than necessary, there is undeniably room for making more material-efficient structures. This margin is partly because there is a need to guarantee resistance and stability, but also due to the fact that it would be more expensive to design slender structures as they would require innovative technical solutions through computer-assisted design. Studies in the UK have been made showing that the use of steel in buildings could be reduced to up to 46 percent without jeopardising the resistance and stability. Furthermore, it has been estimated that the use of concrete could be reduced by 10 percent (Le Den, 2020). Earthen materials could in this context be a potential material to use as a complement in load-bearing structures. To integrate earthen materials is further supported by Peter Walker who works at the BRE Centre in Innovative Construction Materials at Bath University. He puts forward the following strategies if a wider use of earthen materials is to be possible in the contemporary building practice:

- Recognise what earth materials can do best
- Need hybrid solutions incorporating earth products
- Need to fit with modular/prefabricated construction
- Need reliable and accessible LCA data to inform decision making
- Need circular manufacturing solutions

According to Walker, earthen materials have, at the time being, great opportunities to be used as:

- Internal finishes (plasters, boards)
- Composite insulation materials
- Thermal massing; hygrothermal regulation
- Structural masonry elements (stabilised blocks) with low strength

However, for now, he believes that earthen materials are unlikely to make a significant impact in modern construction soloutions due to these factors (Walker, 2021):

- Too slow
- Too weather dependent
- Too expensive
- Too thick
- Too heavy
- Low strength
- Poor insulation
- Durability concerns
- Procurement limitations

Although we acknowledge the problems stated by Walker, we believe that the potential is probably greater than what he expresses, and that earthen materials can handle more as we see such large complexes built out of merely earth that have withstood time. The outlook on the potential of earthen material varies heavily, where pioneers mentioned in Chapter 4 on the other hand prove that an enhanced performance in these materials are possible. These differences of opinion leave the future to enfold the truth behind the real potential of earth.

Figure 189

Haus K and its interior walls of rammed earth.

Figure 190

Wood and earthen materials are beneficial to combine. This is seen in Haus K by Seilerlinhart and Svenskt Trä, where the wooden house has interior walls of rammed earth showing an interesting example of hybrid architecture. Located in Alpnach, Switzerland, the residential house was completed in 2018.

Figure 191

Te Hononga Hundertwasser Memorial Park, New Zealand, combines rammed earth and timber. The design is by Avail Pacific in 2020.

Walls

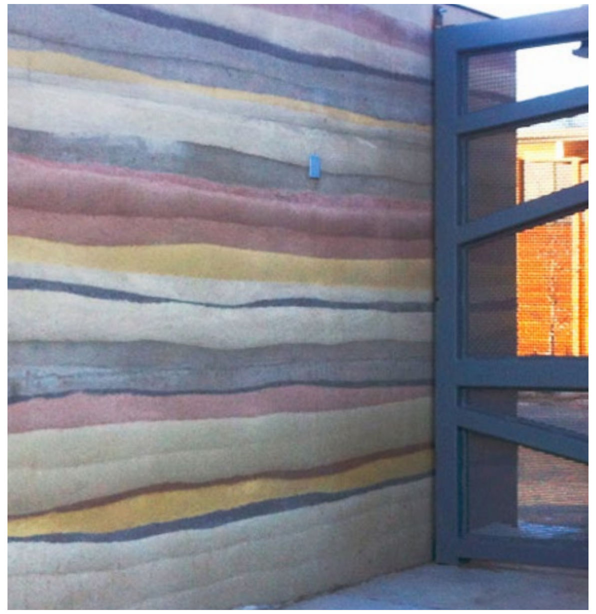


Figure 192

Rammed earth wall of Edmonton Valley Zoo.

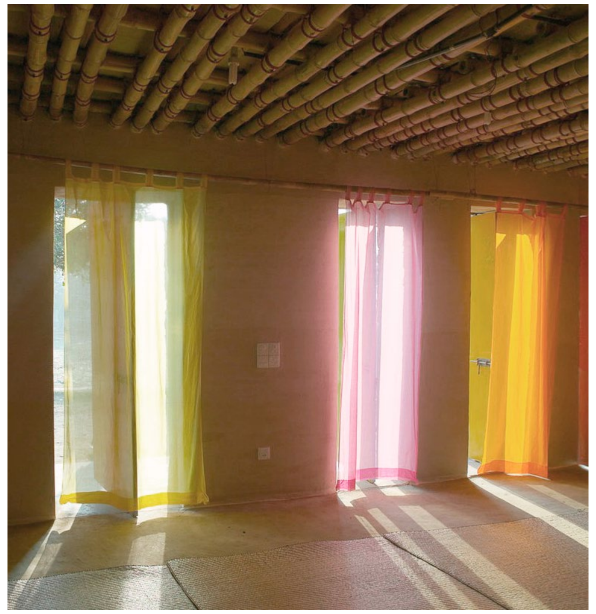


Figure 193

The interior of METI School by Anna Heringer.

Floor


Figure 194

Manually tamped earth floor, polished by hand with stones, Gando Primary School by Keré Architects.


Figure 195

Floor tiles made of earth aggregates and shea butter compose water resistant, non-toxix floors by Hive Earth Studio.

Built in Furniture


Figure 196

Seating area constructed out of cob.


Figure 197

Omicron Monolith by Anna Heringer and Martin Rauch, 2014, Klaus, Austria. Earth walls shaped by hand, reinforced with geotextile webbing and clay vessels.

Furniture and Decoration


Figure 198

Terra bio furniture by Adital Ela made by compressed earth is fully renewable and compostable.


Figure 199

Decorative tiles of rammed earth made by Hive Earth Studio.

5.3.1 Building Heights: High-Rise Buildings a Symbol of the Past?

Figure 200

In recent days there has been a lot of discussion about engineered timber, high-rise buildings also referred to as plyscrapers, as a means to move towards more sustainable structures. However, as buildings become higher, more material has to be added to support the upper stories. The most efficient way for urban areas is according to previously mentioned Peter Walker, to develop medium constructions between 6-12 stories, if the aim is to minimise the embodied carbon while maximising the use of floor space (Walker, 2021). This is remarkable because one of the main arguments for not building with earthen material in future constructions is its inability to form high-rise buildings. But as a matter of fact, future urbanisation might not be composed of high-rise buildings. As the structures themselves are being questioned both from an environmentally friendly point of view as well as in terms of livability, the high-rise buildings might be a structure from the past. In *Soft City* by David Sim, the former partner and now urban expert at Gehl Architects recognized for designing cities for humans, argues that the optimal building height is even lower, between 4-5 stories. By designing enclosed building blocks to the very edge of the property a density with lower heights is provided suitable for the human scale (Sim, 2019). If the design philosophy is moving towards this direction then the usage and potential of earthen material might be uplifted.

Figure 201

High-rise buildings in Moscow City, Russia.

Chapter 6

6.1 The Potential of Earth for Future Architecture

Conclusions & Required Steps

‘To make earth building normal requires more research, more teaching and training, more standards, more assessment, more information, more networking, more built examples, more experienced professionals.’ (EBUKI, n.d.)

Figure 202

Why Build With Earth?

Environmental Reasons

The building construction industry is today responsible for almost 40 percent of the global carbon dioxide emissions. Extraction, production, and transportation of materials accounts for around 11 percent, where concrete poses as one of the main producers of these emissions. It is therefore crucial to urgently decarbonise the building- and construction sector. To rely on conventional building materials at a global level is mostly unsustainable as they leave behind a great environmental footprint. Along with the need to properly take care of the existing building stock, is the demand for new buildings that have zero emission impact on the environment. Sustainable new buildings are crucial for the direction of the future, especially in developing countries where the need for new construction is particularly high due to rapid urbanisation. The UN Environment Programme stresses that environmentally friendly, local and affordable building materials for new buildings is one of the ways to tackle environmental, social and economic issues around the world. For this reason, an increased interest in earthen building materials has been seen because of their low environmental impact. The amount of scientific studies of earthen materials have increased substantially during the last twenty years, most likely due to climate change. One of the main advantages of using earth for construction is its abundance: it can usually be found and used locally. The embodied energy of earth is significantly lower than conventional building materials as they do not require heavy industrial transformation processes before use. When using earthen materials without additives it can be recycled infinite times, leaving no toxic waste material behind when demolished. Furthermore, widely available wastes from the construction industry in terms of excavation soil can be reused for earthen materials. In Europe, 50% of all waste production comes from the construction sector and among these, 75% consists of soils and stones that could be reused for earthen materials. This is of particular interest since it is increasingly hard to find suitable landfill areas for this waste. An innovative project that started in 2018 is Cycle Terre in France, where extracted soil from excavation sites is transformed into earthen building elements. This project aims at using local resources and through that secure material availability and promote low carbon urbanisation and reversible buildings. Local employment is provided as well as a decrease in fuel consumption, carbon emissions and truck traffic. The Zürich based company Oxara is another exciting initiative aiming to facilitate the re-use of construction waste. If excavation material from the construction sector is used for making earth based materials and if not stabilised, they can be regarded as one of the materials that could best meet the challenges of a circular economy.

Figure 203

Social and Economic Reasons

Since people in moderate to cold climates nowadays spend much of their time indoors, the indoor climate is an important factor for well-being. As earthen materials are natural and non-toxic, have high thermal mass and excellent hygroscopic properties, they are considered very beneficial for the indoor climate.

Earth can balance indoor humidity and temperature levels, which are closely linked to indoor air quality and thermal comfort. Studies also show that earth has good acoustic characteristics that tend to create quiet and peaceful indoor spaces. Some studies also suggest that earthen materials have capacity to absorb pollutants. As earthen materials are non-toxic, hazardous substances are minimised if not non-existent, consequently providing a healthier and safer environment for construction workers. This is particularly beneficial for building projects that are not carried out by professional builders, something that is likely to come across in developing countries such as Tanzania.

Earth also has the potential to generate stronger local communities, due to its “catalyst nature”. If building with locally available materials like earth, the profits do not need to be extracted from localities to enrich large global corporations. This will benefit local economies as well as generate a positive social impact. Furthermore, earth construction creates jobs that can not be relocated since the building techniques depend on local conditions and the required building skills vary from one place

Figure 204

to another. The labour intensive earthen techniques can also be a great advantage in low-income developing countries where human labour is cheap and where there is a need for job opportunities. Earthen constructions in such countries have great potential, as many people can be involved in the building process. Usually even larger projects can be executed with only a handful of experienced individuals teaching and supervising untrained builders, since the building process is usually more labour-intensive and time consuming than difficult. A project built with local materials could make an incredible difference for people, both when it comes to their physically built environment, but also for social reasons as working together can

strengthen relationships among villagers and furthermore build trust in their local resources.

Affordable housing is a global issue. Building with earthen materials could have a positive impact on affordable housing anywhere in the world, but especially in developing countries, where there is a great need for affordable and decent housing due to overpopulation. Available local materials can significantly reduce construction costs. In industrialised countries, where human labour is expensive, prefabricated rammed earth then has particular potential if costs in the production process can be reduced through technical innovation. Profitability could then be improved, making the material more established and competitive on the open market and able to contribute to more affordable buildings in the long term.

Figure 205

Lastly, by flourishing the knowledge of earthen building materials, local building cultures and cultural heritage can be protected. Traditional buildings used to respond to cultural needs and the local climate. We believe that extra attention should be given this in a world where we are increasingly moving towards societies where much contemporary architecture looks the same everywhere. Old earthen buildings can be used as a source of inspiration and ideas for modern architecture.

Architectural Reasons

One of the most significant architectural benefits of designing and building with earthen materials is its versatility in form - it provides the designer with the ability to choose a broad spectrum of architectural styles. The modesty and natural character of earthen materials also brings out a feeling of holiness, peace and authenticity. Beauty is often seen in its simplicity. The varying design expressions of earthen material can demonstrate the minimalistic and monolithic aesthetics of concrete, display the playfulness and contrasts of bricks while carrying the warmth and life of wood. In terms of colour, texture and decorative features, earth can be composed in a variety of ways to form artistic- and sculptural aesthetics that can create eye-catching results. Earth also has the potential to bring forth the human presence through its formability and vitality, which creates a sense of belonging, safety and recognition - qualities too important to lose.

Where in the World?

The regain of interest in earthen building materials can be seen in many countries with a variety of climates. As seen in the presented earth building examples in this work, the collected projects cover countries with different climates and socioeconomic situations, such as Tanzania, Germany, Iran, Sweden, Uzbekistan, Egypt, Mali, Japan, Paraguay, Canada, Ghana, Bangladesh, Niger, USA, Austria, China, Italy, Australia, Ecuador, India, Burundi, United Arab Emirates, Morocco, Burkina Faso, Saudi Arabia, Chile, France, Mexico, South Africa, Switzerland and New Zealand. Earthen materials seem to have the potential to play an important role in future architecture in almost any country if executed appropriately. If proper architectural measures, soil testing, material production and implementations are made, earth can be a relevant building material not only for low-income developing countries due to its abundance and low cost, but also in industrialised countries where it has an important advantage over modern building materials for reasons of environmental sustainability and health.

Figure 206

Different earthen building techniques suit different contexts, depending on factors such as available technology and machines, aesthetic preferences, climate conditions, costs of human labour and existing standards. With regard to where earth constructions can make their greatest impact, perhaps it is in areas that are under an enormous population growth such as Africa, where they can certainly make a great contribution as earth is usually locally available and cheap.

Cob and earth blocks might be particularly relevant for developing countries where human labour is cheap as these techniques are time-consuming and require a large workforce, which can be inappropriate in developed industrialised countries. Rammed earth would be more suitable in countries where human labour is expensive, as it allows itself to be prefabricated.

The ability to prefabricate rammed earth does not only optimise the construction process, but also secures the consistency

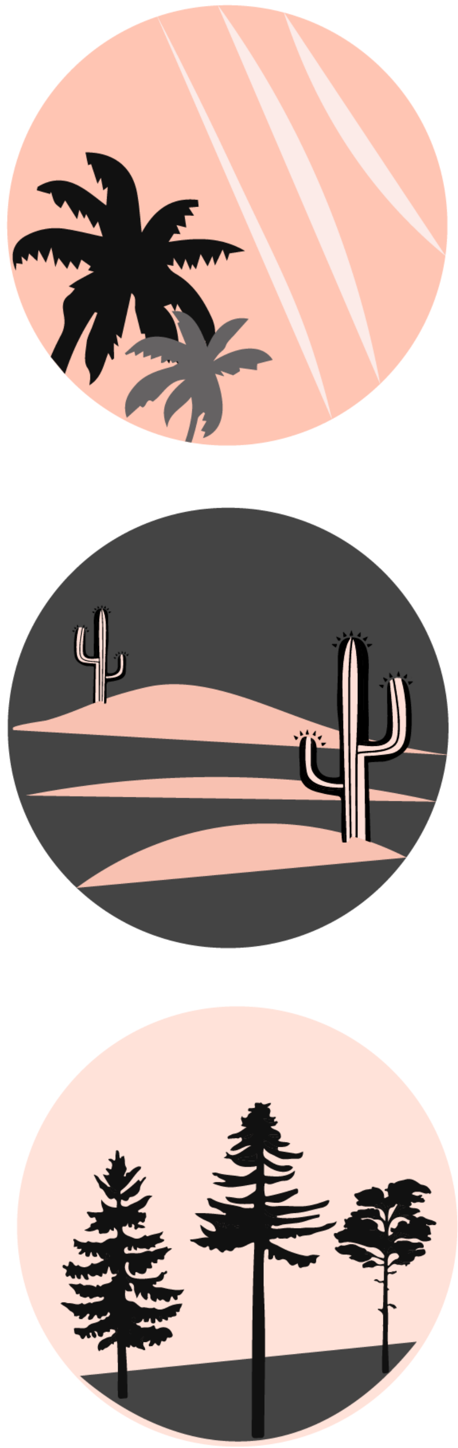


Figure 207

of the material quality which facilitates the establishment of norms and standards. In terms of circular economy, even earth blocks, including stabilised ones, could have potential to be of use in industrialised countries as they are allowed to be reused for other building projects. Furthermore, if mass production of earth blocks through automatic presses speeds up, they could also be useful in industrialised countries as the masonry work with unburnt bricks reasonably shouldn't be significantly more time consuming than with burnt bricks.

The use of earth is particularly beneficial in climates with high diurnal temperature differences, as it buffers heat and keeps the interior cool in summer and warm in winter. If earthen materials are to be of greater use in colder climates with high thermal insulation requirements, they still need to be improved.

The development of earth walls with an appropriate insulating capacity and structural stability is ongoing by different companies, for example Lehm Ton Erde in Austria. One of their most technically built projects is Alnatura Arbeitswelt in Darmstadt, Germany, which represents the capabilities of prefabricated rammed earth walls to meet the high German standards in terms of insulation.

For Whom?

As shown in many of the projects we have presented earlier, people at different income levels, including high-income earners, appreciate building with and living in earthen buildings. High-income earners have chosen earth for modern constructions despite having the means to choose any material on the market, mainly due to its ecological, health and aesthetic qualities. This group of people seems to be increasing, indicating that the image of earthen materials as a “material for the poor” is slowly moving towards a change. They are willing to pay extra for sometimes complicated and expensive processes in order to get required certificates and approval due to the lack of standards and regulations for earthen buildings. Investors, developers and contractors do not only put themselves in a riskful position in regards to financial costs for the construction, but also in terms of insurance coverings. We believe this to be worth mentioning as it indicates a certain level of increased trust in the material that is rarely supported by higher authorities. Building with earth for contemporary architecture could furthermore be of interest for architects in search to find a more sustainable way of designing buildings, both for residential and public buildings. The critical situation we face today in terms of environmental, social and economic issues forces us to thoughtfully consider the building materials we chose for our designs. We need to acknowledge the problems with the most commonly used conventional building materials and find ways to use them in a

Figure 208

more efficient way. Anna Heringer and Diébédo Francis Kéré pose as two examples of contemporary architects that show a will and an attempt to tackle these issues. They share an interest in earthen materials and strive towards integrating them in their projects with a pioneering approach.

Earthen materials also have potential to be of use for various actors in the building sector, including contractors, that are required to invest in local building materials due to shortages and price escalations for conventional materials. Sustainable building products with low environmental footprint are furthermore increasingly coming to dominate the decision-making processes of both consumers and companies, pushing actors to expand their investments towards alternative products.

Last but not least, earthen materials could be highly relevant and make a great contribution for people in low-income developing countries as they can enable affordable housing. Tanzania is one of many countries where a lot of people have insufficient financial resources and can simply not afford to live in houses built with conventional building materials. This applies to people in both rural and high dense urban areas where they today lack decent shelter and are forced to live in extremely poorly constructed and even dangerous houses. In such contexts, the only obvious viable solution is for them to use locally available building materials.

For What Structures and Building Components?

Until more standards and codes are developed for unstabilized earth building materials, we believe their future use in modern architecture, at least in industrialised countries with high building standards, is most likely to be seen in various types of hybrid buildings where conventional load-bearing and durable materials such as concrete, burnt brick, wood, and steel are used where they are most needed. Earth has the potential to fill the gaps in such structures to create an architectural solution that is environmentally, economically and culturally appropriate. It comes down to the matter of integrating earth and using the right material in the right place. The philosophy should not be to completely substitute structurally reliable materials with earthen materials, but rather to minimise the use of highly processed building materials that have high embodied carbon. Earth would then have the potential to be integrated in both small and large scale projects, as their structural limitations would not be that much of an issue if the structure is supported by other materials that are more suitable for heavy loads and impact of different weathering agents such as rain and frost.

Even though earth is generally considered insufficient as a load-bearing building material, it is capable of acting as one judging by some of the projects we have put forward earlier in this work, such as Kapelle der Versöhnung in Germany, METI school in Bangladesh and Haus Rauch in Austria. In terms of building components, earth can be used for a variety of things, for example exterior walls if protected from water, interior walls, earth plasters, floors and furniture.

Figure 209

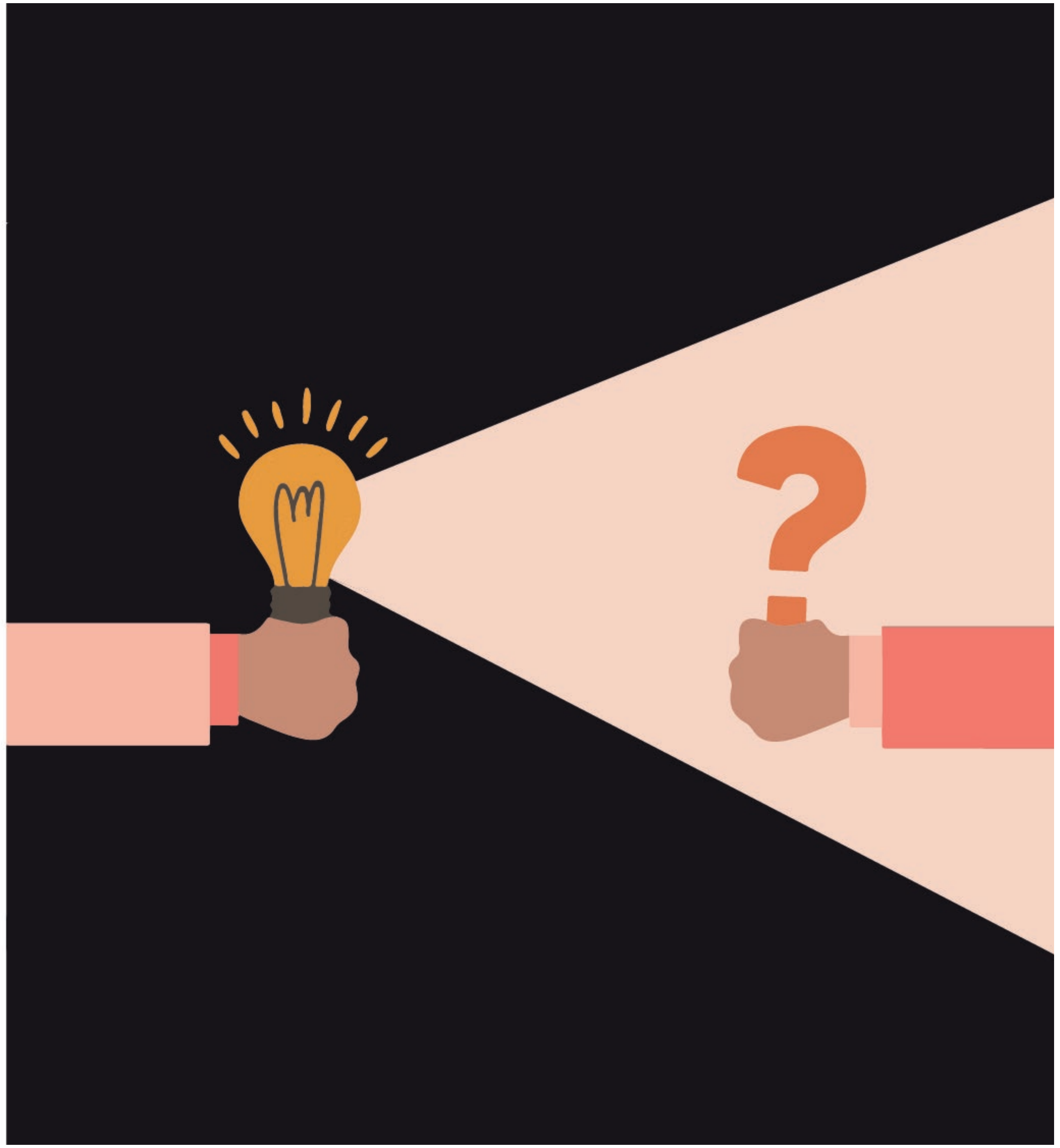


Figure 210

Why Not Build With Earth?

Earthen building materials are not associated with the industrialised building practice and are often linked with something old, outdated or regressive. This drives the perception of them as vernacular structures rooted in poverty. The conception of earthen material as means for low-income construction does not only have an unglamorous aura, but also gives the material the perception of being fragile, ephemeral and even dangerous which results in a neglect of earth as a modern building material. Today, professionals, contractors, developers, institutions and governments remain sceptical towards earthen constructions, especially regarding their structural abilities. Guidelines on the production of materials, construction, quality control methods and design are demanded for any engineered construction. There is a lack of such guidelines for earth, favouring the use of conventional building materials with appropriate codes and standards. This results in many experimental projects, where some display good structural performance, others not. This is perhaps due to structural inadequacies, or simply because they are not executed appropriately. However, it should be emphasised that earthen materials do not perform as well as other materials, such as concrete, in terms of structural strength and resistance to water. Even though there are many attempts in developing regional and national standards on various types of earthen products for construction in different regions all over the world, there is an incoherence among these standards as the technical information varies and there are neither uniform laboratory test methods nor a globally accepted terminology. The absence of global standards depends largely on earthen materials' high variability and reliance on local specificities. Since earthen materials have not been commercialised, the execution of the construction process is sometimes very time-consuming and dependent on manual labour. In countries where man-powered constructions are expensive, which is the case in many Western modern economies, using these techniques for modern architecture would not be economically justifiable for larger projects. Even though the material itself can be considered as free for industrialised countries, earthen structures are not necessarily more affordable than conventional ones given the lack of implementation in common building practice. The cost depends almost exclusively on salaries, local taxes and lack of guidelines and standards.

Figure 211

Figure 212

How to Increase the Desire to Build with Earth?

Perhaps one of the most important things to do in order to convince a wider audience of the potential of earthen materials for contemporary building practice is to provide information and well-documented earthen flagship projects. To change the image of earth and make it more attractive, it is necessary to bring forward built projects that use a contemporary design language that pushes boundaries, explores shapes and breathes innovation.

The development of earth applications such as stabilisers and additives is a key aspect in order for earth to be competitive on the building material market. Research institutes and universities around the world are presently investigating alternatives in order to phase out the use of cement and instead find ways to improve the performance of earthen constructions without sacrificing our planet as well as valuable physical properties of the material. In 2016, the RILEM Technical Committee TC TCE was initiated, and published in 2022 the State-of-the-Art Report “Testing and Characterisation of Earth-based Building Materials and Elements” with the goal to define testing procedures for unstabilised as well as stabilised earthen materials. They are also doing evaluations of their performance in terms of sustainability, strength, durability and hygrothermal capacities through laboratory testing. These activities could surely play a pioneering role in the development of earthen materials as well as provide the underlying scientific fundamentals on which building codes, guidelines and standards are based.

There are attempts to develop codes and standards around the globe and today there are about 70 existing regional and national standards on earthen materials. However, more and better is needed. In order to encourage designers to build with earth as well as to convince government authorities that earth is relevant for construction, it is a necessity to develop both new international laboratory standards for testing earthen materials, as well as making sure that earthen materials are comprehensively represented in building codes and standards. Furthermore it is important to stress the significance of proper evaluations of their environmental impact. LCAs (Life Cycle Assessments) need to incorporate the production of the materials, the building process and also the

Figure 213

energy usage throughout the use and end-of-life phase of a building. To combine LCA models with thermal and durability models is a key research issue.

Earthen materials could furthermore to a very high degree benefit from technical innovation. Integration of modern technology such as 3D-printing and computer simulations surely have great potential in the future design of earthen architecture. This can change its status on a fundamental level if the aesthetics of earth buildings start to speak a modern design language. The TECLA house in Italy is one such example, where architect Mario Cucinella together with the 3D printing specialist WASP created the world’s first 3D-printed house out of local earth in 2021. The innovative circular housing intertwines vernacular construction practices with bioclimatic principles and natural locally available materials.

More research, more education, more investments and more projects are needed in order for earth to be revived for modern architecture. A joint effort between public institutions and private operators that are engaged in scientific research is beginning to be structured as a new wave of innovation is framing earth as a potential way forward. Companies, universities, organisations, professionals and students all over the world are already showing an interest in earthen materials. UNESCO Chair Earthen Architecture, CRAterre, EBUKI and RILEM are some of the organisations contributing to research and initiatives that can benefit the development of earth architecture. There are very few dedicated earth building study courses when looking around the world. CRAterre offers all first year architecture students at the ENSAG (Grenoble School of Architecture) courses on the fundamentals of earth architecture, and also a “professional postgraduate qualification” under the UNESCO Chair on Earthen Architecture, Building Cultures and Sustainable Development. There are also opportunities to study earthen materials at the AVEI (Auroville Earth Institute) in India, being one of the world’s top centres for expertise and education in earth architecture. University of Bath in the UK has also implemented the introductory course “Natural Building Technologies” to undergraduate Civil & Architectural Engineering and fifth year MArch Architecture students. More professional education for architects, engineers, builders and contractors needs to be implemented, both in terms of theoretical and practical learning using the already existing knowledge and earth buildings as a foundation and inspiration for future projects. Innovative earthen material products also need to be produced and promoted for builders, such as prefabricated rammed earth elements. Furthermore, hybrid construction techniques using conventional materials in combination with earth needs to be taught.

Many of the contemporary flagship earthen projects that are shown in this work have received great public response

Figure 214

and are published in various books and international architecture and design magazines, mainly due to their sustainable and generative nature. They have mostly gained their success due to the expertise of individual enthusiasts and some of these projects have been carried out in countries without proper codes and standards for earth buildings. Despite their recognition and appreciation, they can not be globally accepted without the introduction of proper codes and standards in industrialised countries.

The Desire to Live a Modern Life

In order for earthen materials to be looked upon as a modern building material, it is necessary for industrialised countries to show that it - in fact - can be a modern building material. Today, we perceive the world around us through films, TV-series and media in general, and the lifestyles and architecture displayed through these channels affect the view of what is modern. When talking to people in Tanzania, we were frequently asked to show pictures of Sweden. They wanted to see our homes, our schools, our cities. They asked what building materials we normally use because for them, that is the future way of building.

The visibility of the implementation of earth in contemporary architecture in developed countries is of great importance in order to show how this ancient material can be linked to a modern lifestyle. A

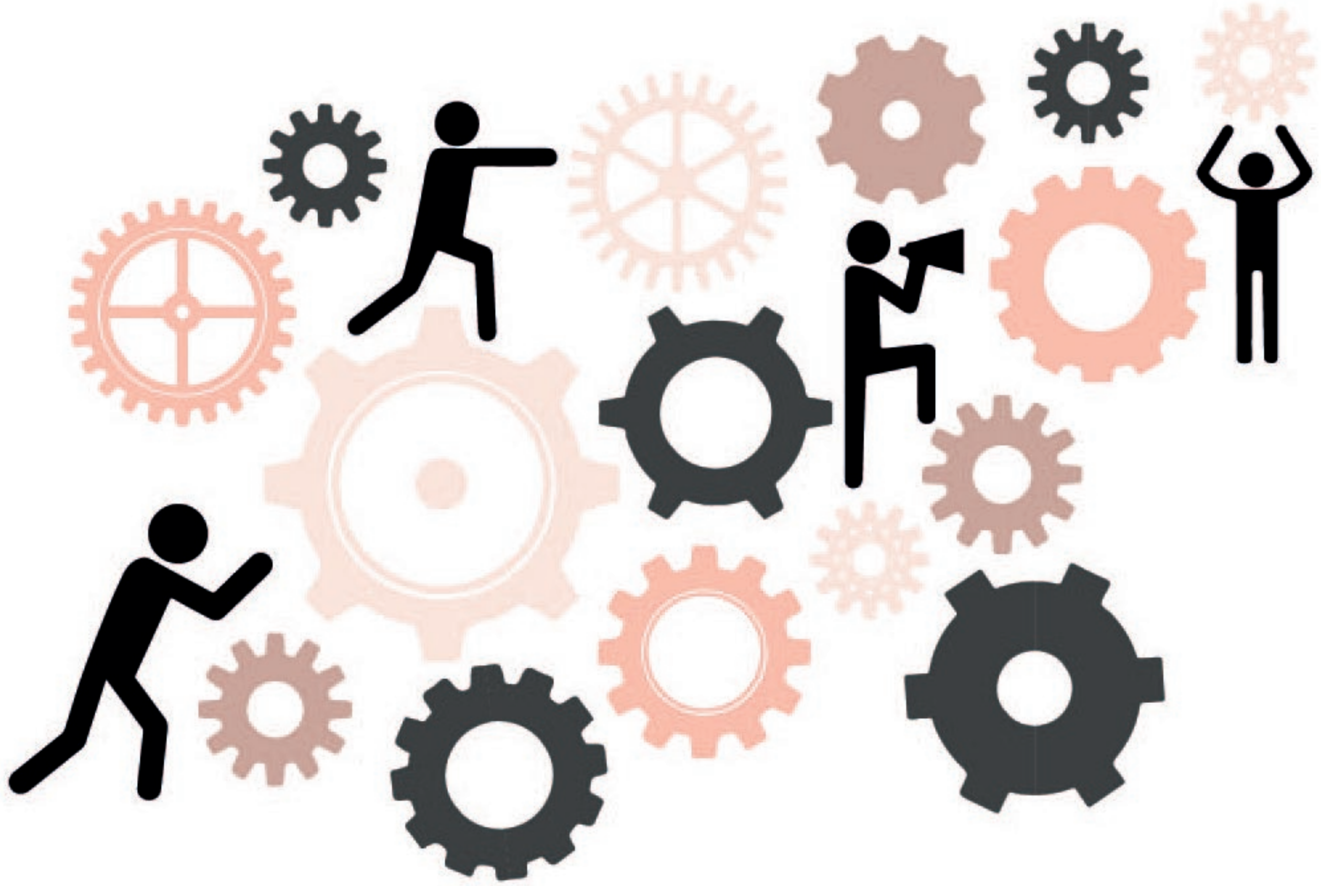


Figure 215

building project can actively stand in the way of sustainable development by using harmful and toxic materials that not only require an excessive amount of energy for manufacturing, but also need to be transported across the globe. The same building project can equally advocate multiple forms of sustainability through using local building materials and so become a positive catalyst.

We believe that earth as a building material has the potential to play a greater role in architecture in the future than we see today in many parts of the world. However, there is still a long way to go. If earth was to be used more for contemporary structures in industrialised countries, it would require a drastic change. As we mentioned earlier we believe that hybrid buildings are the way forward. When building with earthen materials it is arguably favourable to use raw earth combined with other materials instead of using stabilised earth. This, since the main advantages of earth are preserved and the material can be folded back into

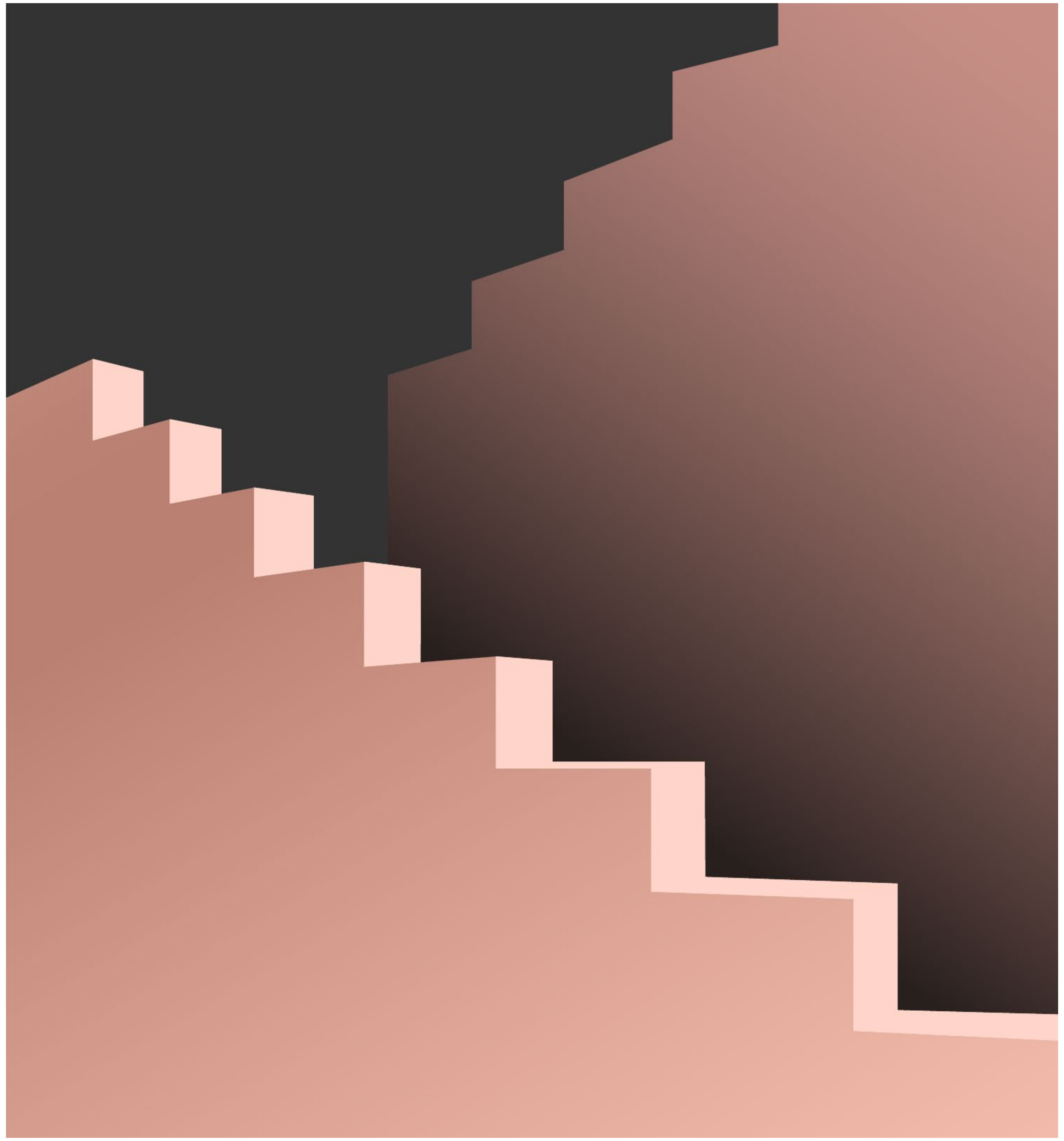


Figure 216

the ground when demolished. Current construction practice would need to be adapted to local building materials and context, and not the other way around. It would require skilled architects, craftsmen, well developed testing methods as well as guidelines and standards. Since products and services available on the market are often driven by the demand from customers it is certainly important to increase the desire to build with earth. If customers ask for earthen products, the incentives for actors to develop and produce them will be much higher. The desire arises from inspiration, and for that reason it is crucial to display and communicate what qualities earthen materials can provide for contemporary architecture. The visual aspect is certainly a major player when it comes to selling any product in the design field, and if built earth projects can visually attract the interest of architects and customers, the desire to design with earth could increase and consequently also the will to learn more about its strengths and limitations as a building material. Successful and well-documented built projects of earth give us proof that earth works in reality, which is why the importance of illuminating such projects can not be stressed enough.

Architects play a great role in changing the perception of earthen materials through design. Solid knowledge of materials offer architects good conditions for creating durable and appealing architecture that is technically and aesthetically responsive to our modern built environment. This will also advocate a change in direction for the building sector. Although earthen materials have their limitations, their unique advantages might eventually become predominant in the light of the challenges we face today in terms of climate change and poverty. Using the best of the old and the best of the new could be one way to achieve sustainable architecture. If translating traditional building materials to fit current design language through innovation and technology, modern architecture does not have to be limited by these materials. The architect's role is to find ways to integrate the materials into a desired design. It is therefore important to have the building materials in mind from the start to create a design that is as beneficial as possible for each material. If such reflection is given to how design and materials can interact, neither will limit the other. A good architect sees opportunities with the given materials, and can thus create good architecture.

Figure 217

Chapter 7

Soil Testing

7.1 Soil Testing Methods

To decide the quality of soil for earth constructions there are various tests that can be conducted. Some are carried out in the field and others in a laboratory. Both field tests and laboratory tests can be carried out with reliable results, but are more or less appropriate methods depending on the circumstances. For example, laboratory tests might be difficult to implement in areas that suffer from frequent power cuts as the equipment requires electricity. Laboratory tests are therefore often unsuitable for many developing countries, especially in rural areas, not only due to the unstable power supply, but also due to the unavailability of affordable machines and other necessary materials that are needed to execute the tests. In this case, field tests might be the more appropriate method as they are less expensive and can be carried out directly on site and require little or no equipment. The advantages with these tests are that they can be performed by anybody after some training. However, some of them require a lot of practice as they need to be interpreted correctly (Schildkamp, 2009). In the coming section, a selection of the most common field- and laboratory tests will be described. These tests are made to characterise the soil, i.e. give information of the properties which will later function as indicators of whether or not the soil is suitable for different earth constructions.

Field Tests

Field tests give an indication of the soil properties and should be carried out systematically and repeatedly in order to make a fair estimation of soil quality. They rely on human senses and therefore mainly require your hands, eyes, nose and mouth. For some of these tests, other necessary tools are water, salt, bottles and knives.

Granularity or Texture

The first four tests can easily be executed on site but might be hard to interpret correctly without long experience in soil identification. The fifth will show the ratio of the grains to make a proper classification of the soil.

Visual Test

The first four tests can easily be executed on site but might be hard to interpret correctly without long experience in soil identification. The fifth will show the ratio of the grains to make a proper classification of the soil.

Touch Test

After removing the larger grains as well as most of the gravel, crumble the soil in your hand by rubbing the soil between your fingers and the palm of the hand. You can make an evaluation of the soil from the following characteristics: Rough and sharp sensation = sandy soil. Fairly rough sensation and some cohesion = silty. Crushes fairly easily and powdery when moistened = silty soil. Hard to crush and becomes sticky and plastic = clayey soil.

Smell Test

Smell the soil directly after taking the sample. If the soil smells damp or perhaps rotten, the content of organic matter is high and the soil is unsuitable for construction purposes.

Taste Test

Take a pinch of soil and crush it lightly between the teeth. If it grinds between the teeth, the soil is sandy. If it grinds slightly between the teeth and is smoother than sand, the soil is silty. If the soil is smooth and powdery and sticks to the tongue, it is clayey.

The Jar Test

- Fill the bottle a quarter full of soil and the remaining three quarters with clean water
- Add a teaspoon of salt (will help with separation of particles)- Shake well for 2 minutes
- Leave the bottle to rest for an hour
- Shake again for 2 minutes and let it rest for 24 hours.

When examining the bottle after a day, you will see that the gravel has sunken to the bottom. On top of that, you will find a layer of sand, silt and clay. Organic matter will float on the surface of the water. The next step is to measure the overall depth of all layers combined, and then measure each layer. Generally, if the silt and the clay layer constitutes between 25 and 50% of the total, the soil could be suitable for earth constructions.

Compressibility

The tests below determine four characteristics of the soil: the compression, the strength, the OMC and the presence of clay.

Compression test

Select a sample of soil in a size so it fits your hand. Make the soil a little moist by adding a few drops of water. Press the sample in your hand 5 times. Through this, you can evaluate the pressure needed and the cohesion of the soil. The compressibility correlates with the amount of rough and fine grains. The rougher, the lower the compressibility, i.e. if the soil requires a lot of strength to press, the soil is gravely. If the compressibility is high, the soil is clayey.

Drop test

Take a sample of soil, wet enough to make a ball but dry enough for it to not get stuck on your hand. Drop it from shoulder height on a hard surface. If the ball does not break, there is either a lot of clay in it, or too much water. If the soil breaks into many small pieces, the soil contains too much sand or lacks water. If it breaks into 4 to 6 pieces it indicates a well-graded soil with potential for construction.

Biscuit test

This test is also called a dry strength test. The aim is to define the clay presence as well as get an indication of shrinkage. The soil used should consist of only fine grains. Add some water to the soil to turn it into a plastic state. Then shape the soil into a few shapes of 3 cm in diameter and 1 cm high. Leave them for about a day until they are completely dry and then break the biscuits in half and then try to make a powder of it. If it reduces to a powder easily, the dry strength is low and the soil contains a lot of fine sand and silt, but not much clay. If the biscuit pulverises after a little effort, the dry strength is medium and indicates a silty or sandy clay soil. If the biscuit is difficult to break and breaks with a snap, the dry strength is high and the soil contains a lot of clay. Other indicators of high clay content is if the biscuit has undergone shrinkage.

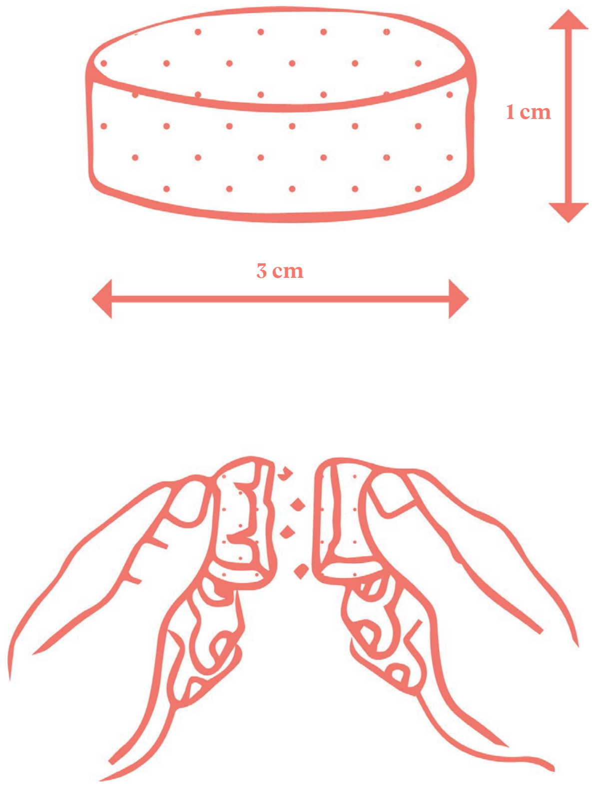


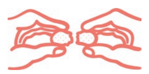
Figure 218

Plasticity

Most of these tests will provide information about both plasticity and cohesion.

Shape test

Add some water to the soil sample and form it into a cohesive unsticky ball. Try to shape it and notice if the plasticity is low, medium or high. If the soil is very hard to shape, it's gravely. If it's hard to shape, it's sandy. If it's easy to shape, it's silty and if it's very easy to shape, it's clayey.



Elasticity test

Add some water to the soil sample and form it into a cohesive unsticky ball. Pull the ball apart in the middle and notice the cohesion and elasticity. If the soil breaks apart very easily, it is gravely. If it breaks apart easily but shows a little bit of elasticity, it's sandy. If it breaks apart after some length and acts elastic, it's silty and if the ball reshapes into a long elastic string it's clayey.

Adhesion test

Add some water to the soil sample and form it into a cohesive unsticky ball. Stick a knife into the ball and pull it out again. Note how much soil sticks on the blade of the knife and check the level of adhesion. If the ball crumbles and is easy to penetrate and if there is no soil on the blade, the soil is gravely. If the ball is easy to penetrate and the knife is almost clean, the soil is sandy. If the ball is more difficult to penetrate and there are stains on the blade, the soil is silty. If the ball is very hard to penetrate and leaves the blade with a lot of stains, the soil is clayey.

Cohesion

The cohesion tests will give information about the presence of silt or clay in the soil sample.

Absorption test

Add some water to the soil sample and form it into a cohesive unsticky ball. Place the ball in the palm of your hand and make a hole in the middle. Pour some water in the hole and notice how fast it absorbs into the soil. If the cohesion of the soil is low, it's gravely. If it's high, the soil is clayey. The water disappears very fast in gravelly soil, fast in sandy soil and slowly in silty soil. If the soil is silty it will also crack after 3-4 minutes. If the soil is clayey, the water stays for a long time.

Ribbon test

Add enough water to the soil so that it can be rolled into a 15 mm thick "sausage". The soil should not be sticky. Place it in the palm of your hand and start to flatten it (3-6 mm thick) between the index finger and the thumb, at the same time as you push it off the edge of the palm down towards the ground. Make it as long as possible, and when it breaks, measure the soil part that falls to the ground. If no ribbon can be made, the soil contains little or no clay at all. A short ribbon (5-10 cm), indicates a fairly low clay content in the soil. A long ribbon (up to 30 cm) indicates a soil with very high clay content.

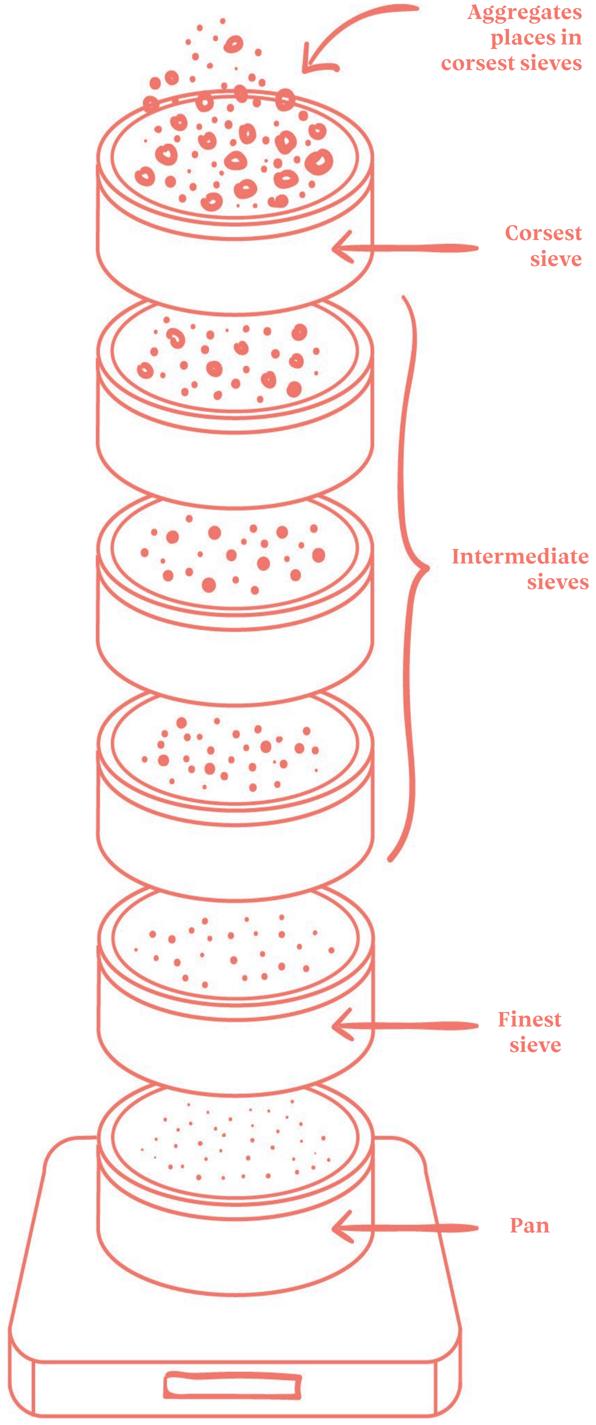


Figure 219

Siever Shaker Set

Laboratory Tests

When conducting laboratory tests on soil, strict protocols are required and the procedure is carried out under highly controlled conditions. Special devices and machines are needed, requiring regular calibrations and specialised handling. Below follows a selection of different laboratory tests.

Granularity or texture

Two separate procedures are used when determining the grain size distribution of a soil sample: the sieving test and the sedimentation test.

The sieve test is performed on the larger grains of the soil; the gravel and sand. Silt and clay are washed out by a 0.075 mm and the remaining sample is run through a chain of metal sieves, ranging from 4 to 0.075 mm in perforation size, supported by a mechanical shaking device. This test separates the different grain sizes from each other and therefore shows the proportions in percentage by measuring the weight of the respective grains.

Equipment needed: A sieve shaker set.

The sedimentation test is performed on the smaller particles; the silt and clays. A hydrometer is used to measure the density of soil suspension. The silt and the clay is deposited in a glass cylinder filled with distilled water. A dispersing agent - the most common being sodium hexametaphosphate - is added to separate the particles from each other. The size of the particles can be revealed by looking at how fast they settle. This enables us to calculate the proportions of the various sizes (Schildkamp 2009).

Compressibility

The optimum moisture content (OMC) is the amount of water needed for a soil to become most dense and achieve the maximum dry density. The moisture content can either be too high or too low. If too high, the pressure of the compacting machine will be lost as water is trapped between particles. If too low, there will be problems with compacting soil to its minimum volume as the particles are not lubricated enough. The test used to determine compaction characteristics of soil is called the Proctor compaction test.
A compression test can also be done on a dried earth block, then using a compression machine. The block has to be cured for 7 days and then infused with water for 2 days. The block is then put in the compression machine from which the compression strength can be calculated (Schildkamp, 2009).

Plasticity

Depending upon the water content, soil appears in either liquid states, plastic states or solid states, affecting the behaviour of the soil and consequently their properties. The boundaries of these different states are called the Atterberg limits. The liquid limit (LL) is the limit of the transition between the fluid and plastic state, and the plastic limit (PL) is the limit of the transition between plastic and solid state. LL-PL=PI, where PI is short for plasticity index, which determines the plastic behaviour of the soil. The combination of LL and PL gives information about the sensitivity of the soil to variations in humidity, therefore giving Atterberg limits a crucial role to play in order to ensure that the soil performs as expected. The liquid limit can be tested with a Casagrande apparatus, where only the fine grains are used. In this method, the cup is filled with soil with a cut of 12 mm in the middle made by a casagrande grooving tool. The cup is then raised 10 mm and then dropped repeatedly. The liquid limit is reached when the gap is 12 mm. Acceptable intervals differ, but optimal amount of blows is 25 (Helptheengineer, n.d). To determine the plastic limit the following devices are necessary: a glass plate, a glass roller device, a 3 mm thick steel rod and an apparatus for determining the moisture content. This test involves rolling a soil sample into a thread until crumbling occurs at 3 mm in diameter. Then the sample is weighed and dried in the oven before the moisture content can be determined (Schildkamp. 2009).

Cohesion

When measuring the cohesion capacity as well as the angle of internal friction of a soil it is usually determined in the laboratory from a test called the Direct Shear Test. Needed is a Direct Shear Test Apparatus, in which a sample of soil is put under both normal and shear stresses. From this test, a graph can be plotted through which information can be given on the cohesion strength (Theconstructor, n.d)

7.2 Testing of Soil Quality in Mhaga Village

Figure 220

After taking a sample from the loam used in the clay blocks produced at Mhaga Village, we went home to do some testing. The results are presented on the following pages:

1. Granularity or Texture

Visual Test

It appears to have a continuous structure. The estimated grain sizes are fine and we can also see some lumps which indicate clay content. The colour of the soil is rust-bown which implements high iron content. There are no traces of olive green or light brown nuances meaning that the content of organic matter is probably low.

Touch Test

When rubbing the soil between our palms, a slightly rough texture is felt. It indicates sand rather than silt although the texture is also somewhat flour like. However the soil contains some lumps that are hard to break which speaks of clay content. When moistened the soil becomes plastic, is easily formed and sticks to its shape which supports the belief of clay content. To summarise all categories can be noticed when doing this test and indicates a continuous soil structure.

Smell Test

The smell is mostly neutral but there are undertones of dampness, most likely due to the fact that the soil sample is slightly moistened. There are no signs of rotten odours, which in terms does not point towards high organic content.

The Jar Test

When examining the jar two days after it was shaken, we could calculate a total distribution of approximately 44 percent sand and gravel, 27 percent silt and 27 percent clay.

At the surface of the water we can see a thin layer of organic content, showing that the soil sample most likely is a subsoil, which is good . We are aware of the fact that silt and clay expand when wet (especially clay), hence we can draw the conclusion that the soil contains slightly less silt and clay than the jar test displays. Moreover, it is impossible for the eye alone to spot the difference between sand and gravel. We have therefore chosen to group them. The same difficulty goes for silt and clay as there appears to be no obvious visual boundary between them.

The overall conclusion we can draw from the jar test, is that the soil sample might contain too much silt and clay then what is preferable for earthen constructions. Generally between 25 to 50 percent of silt and clay constitute a suitable amount for earth constructions. The soil sample contains approximately 54 percent. The optimal ratio for a soil sample is 15 percent gravel, 50 percent sand, 15 percent silt followed by 20 percent clay.

2. Compressibility

Drop Test

We did this test three times. The first time the soil ball mainly kept its shape but broke into six smaller pieces around the edge. Due to the first result we wanted to find out whether the soil was too wet or if it contained too much clay. For this reason we added more soil to make the sample dryer. This time when releasing the soil ball from shoulder height, the soil ball broke into larger pieces. Once again to rule out the fact that the soil sample might contain too much water we added even more soil. The third time we dropped the soil ball didn't break at all. From this we can draw the conclusion that the soil sample might contain too much clay.

Biscuit Test

When looking at the dried biscuits we could hardly see any signs of shrinkage, indicating low clay content. When trying to break the biscuits in half, it resulted in a snappy sound. The biscuits felt dry in our hands and crumbled fairly easily when split into even smaller pieces. However it was hard to pulverise the larger pieces without adding so much force that the fingers started to hurt. The findings point us towards different directions in terms of soil content. The low shrinkage indicates low clay content. Although, the snappy sound points towards the opposite. The pulverisation process is not clear either, since the bigger pieces were difficult to pulverise (high clay content) while the smaller ones were not (high silt or sand content). This makes it hard for us to evaluate whether the soil sample has a clayey, silty or sandy character.

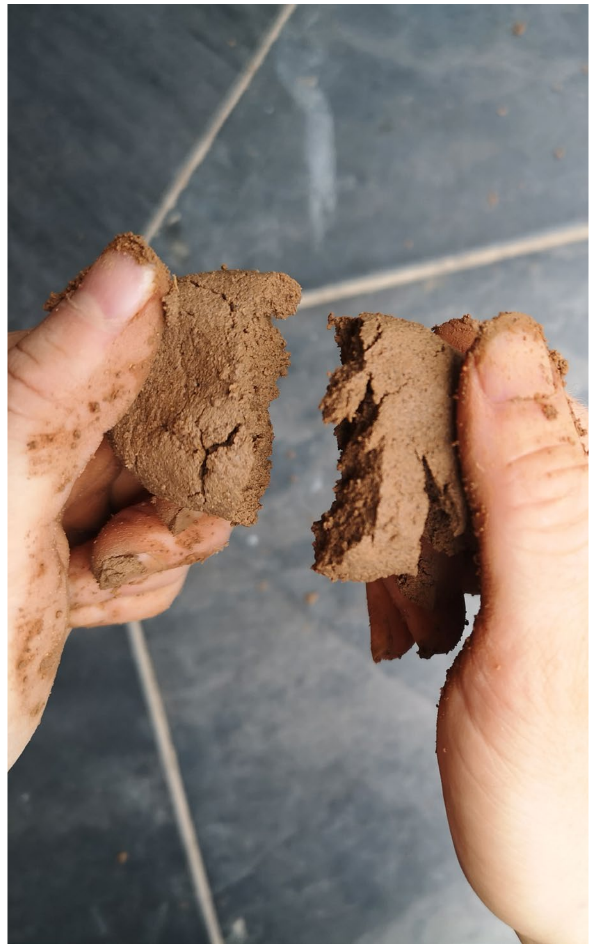


Figure 221

The biscuit test.

3. Plasticity

Shape Test

The soil sample is easily formed and keeps its shape when modelled in the hand. Some small cracks appear around the texture but overall it keeps its shape. From what we can tell it is somewhere between easily shaped and very easily shaped which indicates high clay content.

Elasticity Test

When pulling the soil ball apart it doesn't show many signs of elasticity as it breaks easily in the middle. Consequently, this indicates a gravely or sandy soil.

Adhesion Test

When sticking a knife into the soil ball, the sound of the penetration is crunchy, indicating sand content. There is also fairly little resistance when penetrating it which supports the belief of high sand content. When removing the knife, some stains can be observed on the blade pointing to some silt and clay content as well.

4. Cohesion

Absorption Test

This test was very interesting due to the level of difficulty when conducting a hole in the middle of the soil ball. As the soil sample cracked very easily it didn't keep its shape. When adding water into the centre it was quickly absorbed into the soil ball and shortly after the soil cracked as the water passed through it. We did the test three times with various moisture content but the result remained the same; quick absorption, between 5-15 seconds, to then crack into three up to seven pieces. This implies a fairly high amount of sand, but as the soil ball showed signs of cohesiveness it also indicates some clay content.

Ribbon Test

This test was difficult to make since the soil sample didn't stick together. It was troublesome to even form a sausage-like shape and even more difficult to flatten it out without having it breaking. The ribbon didn't get longer than 2,5 cm. The length of the ribbon points towards a quite high sand content and low clay content. A medium amount of clay content results in a ribbon length between 5 to 10 cm.

Figure 222

The soil sample from Mhaga Village, taken on the construction site.

5. Conclusion

When looking at the result from the different tests the outcome varies a lot. Some tests indicate high clay content, others the opposite while some point towards a continuous structure with an even distribution of different grain sizes. Something that became obvious was that it was difficult to analyse the result from the testing. We would have benefited from having two or more different soil types to compare with since we haven't performed these tests before. When using the soil texture triangle after the results from the jar test the soil is classified as a clay loam, but it is right at the border to sandy clay loam and loam as well. The loam found on the site haven't been classified by TAWAH. A general loam classification has instead been made for Mhaga Village, namely sandy clay loam . However, if we were to determine the characteristics of the soil sample after summarising all the tests we conducted, we would group it as loam, due to the inconsistency of the results.

Figure 223

Picture of one of the tests that we conducted. This one shows the beginning of the absorpton test, before water is added.

Chapter 8

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Figure 218: Edited from Schildkamp, Martijn. 2009. https://www.smartshelterfoundation.org/wp-content/uploads/2014/07/SSF-soil-testing-manual.pdf [2022-02-18]

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Figure 221: Halje, Caroline. 2022.

Figure 220: Halje, Caroline. 2022.

Figure 222: Halje, Caroline. 2022.

What is This Thesis About?

This thesis looks into the potential for earthen building materials for future architecture. The purpose is to increase the understanding of earth and investigate how a greater use of it can impact social, environmental and economic sustainability. The work highlights the latest research, presents contemporary earthen architecture, discusses architectural qualities and reviews challenges, potentials and required future steps. It also brings forward a construction project in Tanzania where we have carried out practical field work, where local earth was used as the main building material. By being physically in Tanzania, a country that struggles with major social and economic problems, we could study social sustainability on our own and gain valuable insights and knowledge that can be hard to find in literature.

This thesis is based on a will to - with architecture as a tool - contribute to a positive impact on the planet and the life of people. We have during our architecture studies come to understand that building with earth has potential to contribute to such an impact. Therefore, we believe that it is valuable to look into the subject of earthen building materials more thoroughly. We are convinced that material knowledge might be one of the most significant skills for architects in the future as it lies in their power to design structures with a greater social and environmental impact, something that is becoming increasingly important. Taking advantage of locally available resources can be the key to overcoming the challenges we are in the middle of today. Materials are highly intertwined with the early stages of designing as they make up the fabric of any structure. It is therefore important that the architect knows the possibilities and limitations of different materials, to be able to make good design decisions that nurture sustainability.