

Unlocking the potential of LOCAL CIRCULAR MATERIALS IN URBANISING AFRICA

Countries considered: Burkina Faso, Ghana, Kenya, Morocco, Nigeria, Rwanda, Senegal, South Africa and Uganda

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One Planet Network

The One Planet Network has been formed to implement the 10-Year Framework of Programmes on Sustainable Consumption and Production (SCP), which supports the global shift to SCP and the achievement of SDG 12. The One Planet Network acts as an enabler bringing actors from all regions to pool their expertise, resources, innovation and commitment towards a shift to more sustainable modes of production and consumption. The network comprises of six programmes: Sustainable Buildings and Construction, Sustainable Public Procurement, Sustainable Tourism, Consumer Information for SCP, Sustainable Lifestyles and Education, and Sustainable Food Systems Programme.

Sustainable Buildings and Construction Programme

The Sustainable Buildings and Construction Programme (SBC) aims to improve the knowledge of sustainable construction and to support and mainstream sustainable building solutions. Through the programme, all major sustainable construction activities can be brought together under the same umbrella. The work involves sharing good practices, launching implementation projects, creating cooperation networks and committing actors around the world to sustainable construction. The goal is to promote resource efficiency, mitigation and adaptation efforts, and the shift to SCP patterns in the buildings and construction sector. The SBC work in 2021-2022 focuses on circularity and responsible sourced materials.

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List of abbreviations

AAC	Autoclaved Aerated Concrete
BCS	Buildings and construction sector
CDW	Construction and demolition waste
CEB	Compressed earth brick or block
CLB	Cross-laminated bamboo
CLT	Cross-laminated timber
CsEB	Compressed stabilised earth brick or block
CO ₂	Carbon dioxide
INBAR	International Bamboo and Rattan Organization
LCA	Life Cycle Assessment
SBC	Sustainable buildings and construction
SDG	Sustainable Development Goal
SMEs	Small and medium-sized enterprises

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S U M M A R Y

This publication's focus is on the sustainable use of building materials in urbanising Africa. African countries face challenges with poverty, unemployment, rapid population growth and urbanisation, and housing backlogs resulting from the construction sector's failure to meet the demand arising from the exponential growth of cities. This sector is growing fast and is often reliant on an informal unskilled workforce and imported materials that have high negative environmental impacts. Traditional bio-climatic construction is being replaced by modern construction at a fast pace, and the resultant changes in the African construction material palette have many disadvantages.

The following section gives a comprehensive review of construction materials available in Africa, including traditional materials, mainstream industrial materials and emerging circular materials. This includes a review of the environmental, social and economic impacts and the possible uses of these materials and whether the production of the materials can be upscaled to respond to the rapidly growing demand for construction materials.

After the section on materials, the focus shifts to the urban context and presents a proposal for mid-rise construction. A concept of flexible high-density construction is presented – which is suitable for sustainable mixed-use neighbourhoods and simultaneously supports the use of local sustainable materials. The flexible and scalable approach we propose promotes the use of local materials and labour. Hence, the utilisation of existing industry and competence set the framework in which to introduce ways local circular materials can replace conventional non-circular materials that often need to be imported.

Finally, we discuss how our proposed concept could be mainstreamed and the obstacles that need to be tackled and by whom. This section outlines how to support the rapid and efficient adoption of circular economy principles in the built environment and how factors such as cross-disciplinary cooperation, business models, roadmaps, legislation, standards and increased awareness can work together to integrate circularity into building practices.

INTRODUCTION

Globally, the buildings and construction sector (BCS) uses 36% of the total energy and produces 39% of emissions and 40% of all solid waste (UNEP, 2009; UNEP et al., 2019). The sector also uses 50% of all the extracted materials in the world (GlobalABC et al., 2019). Global raw material extraction and processing are estimated to cause 90% of biodiversity loss (IRP, 2019). Today, only 9% of the extracted resources are circular. In other words, 91% of the total material inputs into the global economy are currently virgin materials (Circle Economy, 2019). Besides having a significant environmental impact, the BCS employs 7,7% of the global workforce and contributes to 13% of the global gross domestic product (Oxford Economics, 2021; UNEP, 2009). Human wellbeing is also significantly affected by the built environment, since many people spend the majority of the time inside buildings (European Commission, 2003; Klepeis et al., 2001).

There is an urgent need for change as human activity has led to climate emergency, resource depletion and biodiversity crisis. Our planetary boundaries – the thresholds within which humankind can thrive for generations to come – have been breached and changes that return our activities within these boundaries are required.

The BCS, with its wide-ranging impacts, needs to play a key role in tackling climate change, reducing biodiversity loss and using existing resources more efficiently. The now dominant linear economy, in which materials are extracted, used and then discarded as waste, is having significant negative environmental impacts. A transition from this linear economic model to a circular economic model could significantly reduce the negative environmental impacts of construction. Circularity represents a holistic approach that enables the BCS to replace the take-make-waste practices with more sustainable practices that better utilise the resources at hand. In a circular economy, materials are not removed from circulation but are utilised efficiently for as long as possible. The recycling of materials and products is optimised and emissions are eliminated (or minimised). In a circular society, all human activity adheres to planetary boundaries. Besides its positive environmental benefits, circularity also increases employment and disposable income because of the reduced cost of products and services in the long run (Horbach and Rennings, 2015). Additionally, it results in a better user experience since circular products are of higher quality. Thus, the BCS has a significant environmental, economic and social impact as well as strong potential to promote circularity.

The need for action is global. However, such change is particularly important and urgent in Africa – the fastest-growing region in the world. While the region's contribution to climate change has been marginal to date, emissions are projected to grow exponentially in the coming decades. This growth is being caused by rapid population growth as well as increasing urbanisation and wealth. Because of the fast population growth, especially in cities, there are large affordable housing backlogs since construction has failed to meet the rising demand for housing. Tackling these backlogs will require immense amounts of new construction and resources.

Addressing the housing deficit more sustainably requires different urban settlement patterns and zoning, increased densification, mixed-use neighbourhoods, multi-functional and adaptable buildings, enhanced planning, increased design and construction capacity, and locally produced circular materials and products. Cognisant of the rich diversity of cultures, economies and societies in Africa, this publication presents the key factors that will affect future construction in African countries. It is largely focused on nine countries – Burkina Faso, Ghana, Kenya, Morocco, Nigeria, Rwanda, Senegal, South Africa and Uganda. Based on identified needs and available resources, this publication presents new technical concepts for circular urban multi-storey construction that utilise local circular resources more efficiently than do current mainstream solutions. The focus is on the materials economy and how the use of circular building materials could strengthen local economies. The publication also outlines policies and other measures that can be used to promote the mainstreaming of alternative circular solutions.

1.

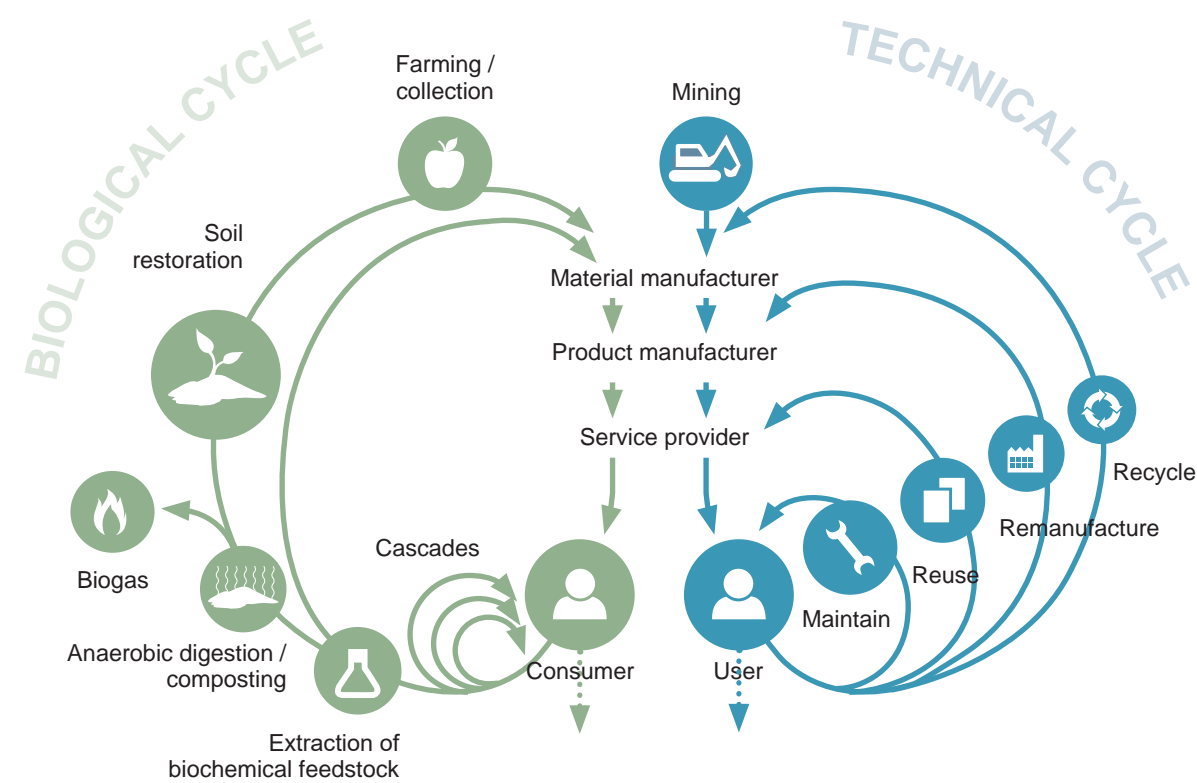


Figure 1: Circular economy – the biological and technical cycle

Source: Ellen MacArthur Foundation (2019), redrawn by the author

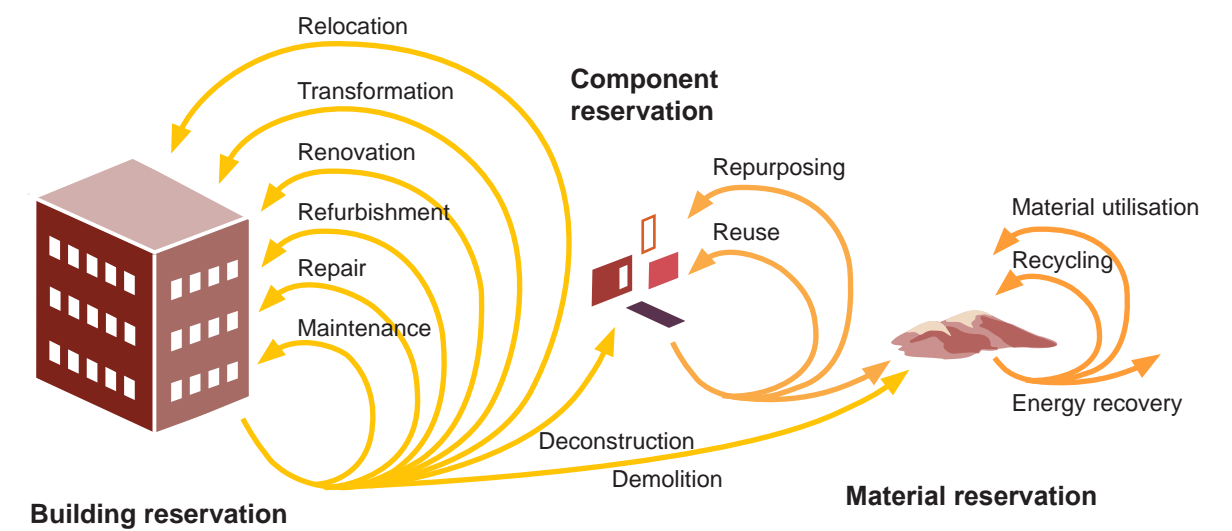


Figure 2: Circular economy in construction

Source: (Huuhka and Vestergaard, 2020), redrawn by the author

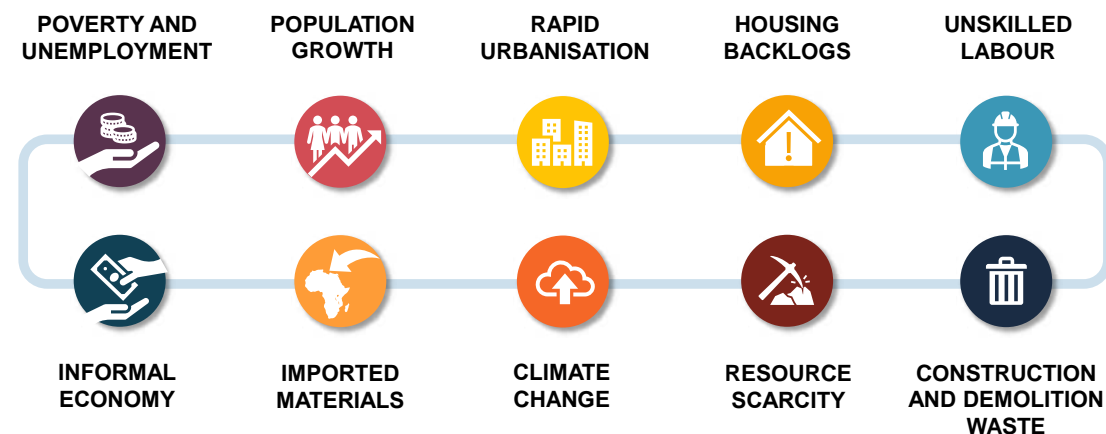
AFRICAN CONTEXT

Africa's share of global greenhouse gas emissions is only 2–3% (UNEP, n.d.) but the region's emissions are expected to increase exponentially in line with rapid population growth and urbanisation and an increase in wealth. With the growing need for cooling brought on by the heating climate, the importance of developing and mainstreaming passive heating and cooling systems for buildings also grows.

It is crucial to develop and mainstream solutions that meet the needs of the population without contributing to climate change, resource scarcity and biodiversity loss. Circular approaches are beneficial as they not only reduce environmental impacts, but they also produce beneficial social and economic impacts such as the creation of local enterprises and jobs, which are particularly important in developing African countries.

2.

Key points



Circular construction contributes to the SDGs

The United Nations has introduced 17 Sustainable Development Goals (SDGs) that contribute to a sustainable future by addressing poverty, inequality, climate change, environmental degradation, peace and justice. Circularity is not an SDG but it is embedded in many of the goals that contribute to sustainability. The One Planet Network (OPN) Sustainable Buildings and Construction (SBC) Programme has been mapping through a survey which of the SDGs are most interlinked with circularity in the built environment. According to the survey results, SDG11 (Sustainable Cities and Communities), SDG12 (Responsible Consumption and Production) and SDG13 (Climate Action) are primary goals, and SDG6 (Clean Water and Sanitation), SDG7 (Affordable and Clean Energy), SDG9 (Industry, Innovation and Infrastructure) and SDG8 (Decent Work and Economic Growth) are secondary goals. These conclusions are based on the responses of 185 respondents, of whom 39 are from Africa. There are no significant differences between the African and global results, as seen in Figure 3.

Poverty and unemployment

Out of the world's 28 poorest countries, 27 are found in Sub-Saharan Africa. There, the average poverty rate is 41% (The World Bank, 2018a). Among the Sub-Saharan countries, Nigeria has the largest poor population, with 87 million people falling under the extreme poverty limit. Approximately one-fifth of the African poor live in Nigeria, making it one of the poorest economies in the world (ibid). The severity of poverty in Africa is represented in Figure 4.

Besides struggling with extreme poverty, many African countries face high unemployment rates. South Africa has an unemployment rate of 33,9% and an unemployed youth rate of 61,4%, while these rates for Nigeria are 33,3% and 53,40%, respectively (Trading Economics, n.d.). Hence, the sustainable solutions tailored for Africa need to be affordable and to strengthen local economies, in addition to reducing the negative environmental impacts.

Even though Africa's share of emissions is small, it is the most vulnerable region in the world because of its weak socioeconomic status (UNEP, n.d.). The poor cannot buy services and goods that can shelter them from the effects of climate change or other drastic changes. Hence, it is crucial to focus not only on climate change mitigation but also on resilience and adaptation. In other words, African countries need to mitigate climate change to support socioeconomic priorities and strengthen local communities, create local jobs and healthy and pleasant environments, increase local knowledge, strengthen food security, boost the local economy, and reduce the dependence on imported goods and services.



Figure 3: The interlinkages of SDGs and circularity in the built environment

The orange web shows the results for Africa and the red web shows the global results

Source: (Cheong et al., 2021a), redrawn by the author, photographs by Pekka Huovila

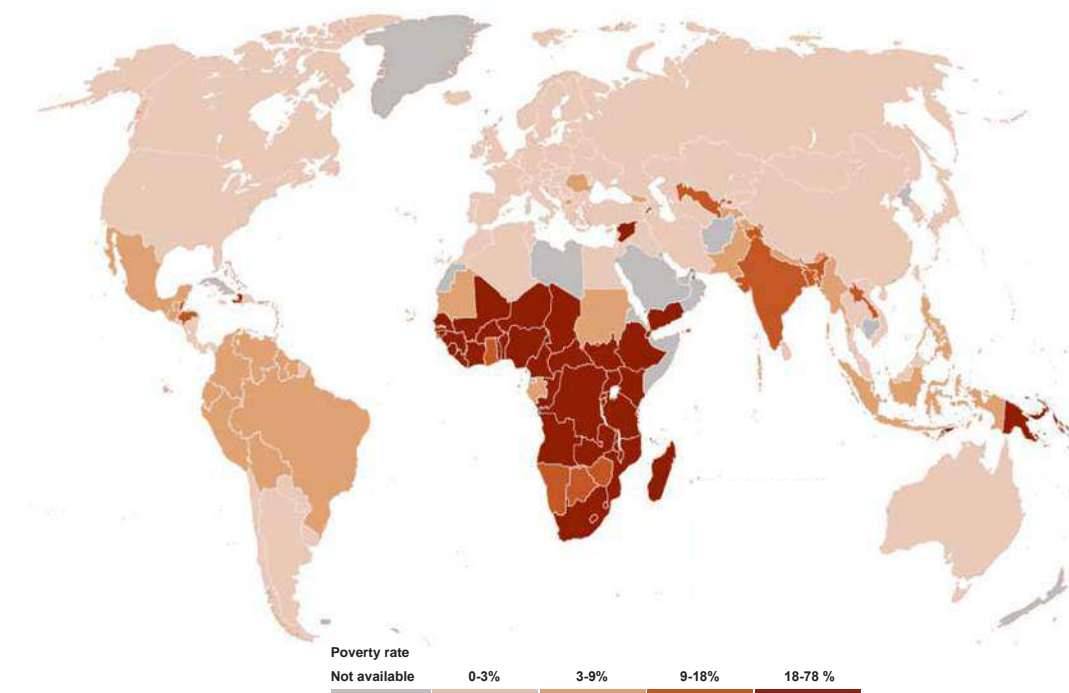


Figure 4: Extreme poverty rate by country

Source: The World Bank (2018b), redrawn by the author

High population growth

The world population is expected to grow by 40% by 2100, from 7,8 billion people in 2020 to 10,9 billion people in 2100. Most of this population growth will happen in the less-developed regions, among which Africa currently has the fastest-growing population (see Table 1). Out of the projected global population growth, 40% is projected to happen in Africa. In Africa, the population is expected to grow by 220% between 2020 and 2100, from 1,3 billion to 4,3 billion people. The fastest-growing geographic regions in Africa are Western, Eastern and Central Africa, as presented in Table 2 (UN, 2019).

Rapid urbanisation

Concurrent with massive population growth, the population is shifting from rural to urban areas (see Table 3). The African urban share is projected to change from today's 44% to 60% by 2050. As shown in Table 6, Africa is not evenly urban – Rwanda has an urban share of 17% while the share for Burkina Faso is 30%, for Nigeria is 51% and for South Africa is 67%. The population is expected to grow by 78% in Rwanda, 107% in Burkina Faso, 95% in Nigeria and 27% in South Africa (see Figure 5). Most of this growth will be in urban areas. Rapid urbanisation leads to massive formal and informal growth in cities. Informal settlements are further discussed in the following section.

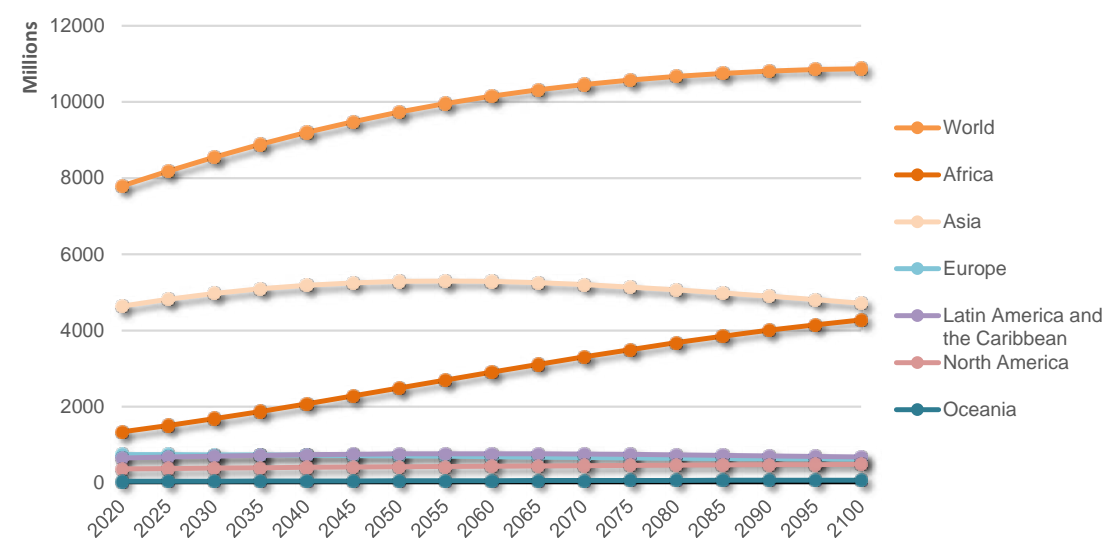


Table 1: Projected population growth in the world (2020-2100)

Source: UN (2019), illustrated by the author

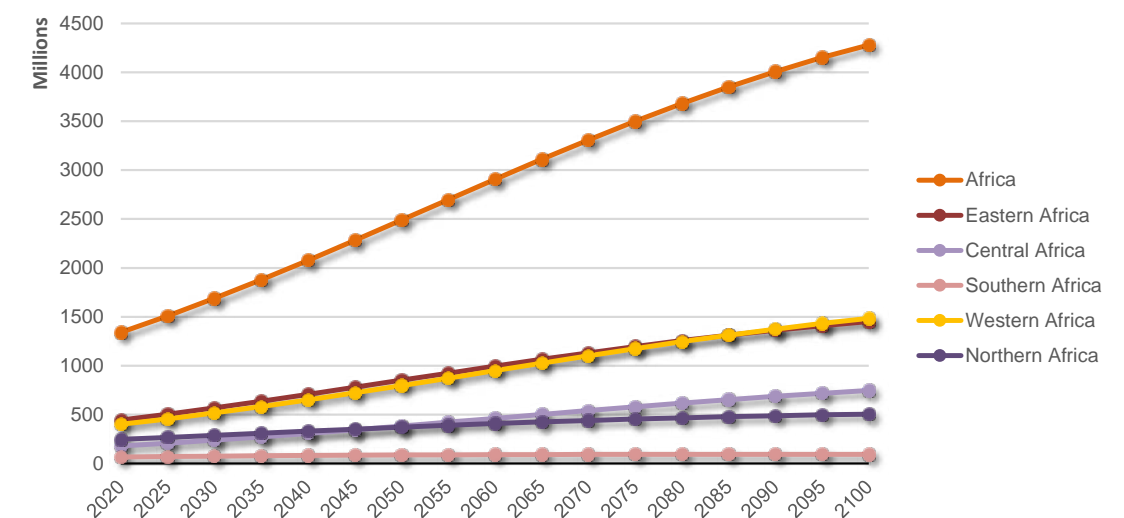


Table 2: Projected population growth in Africa (2020-2100)

Source: UN (2019), illustrated by the author

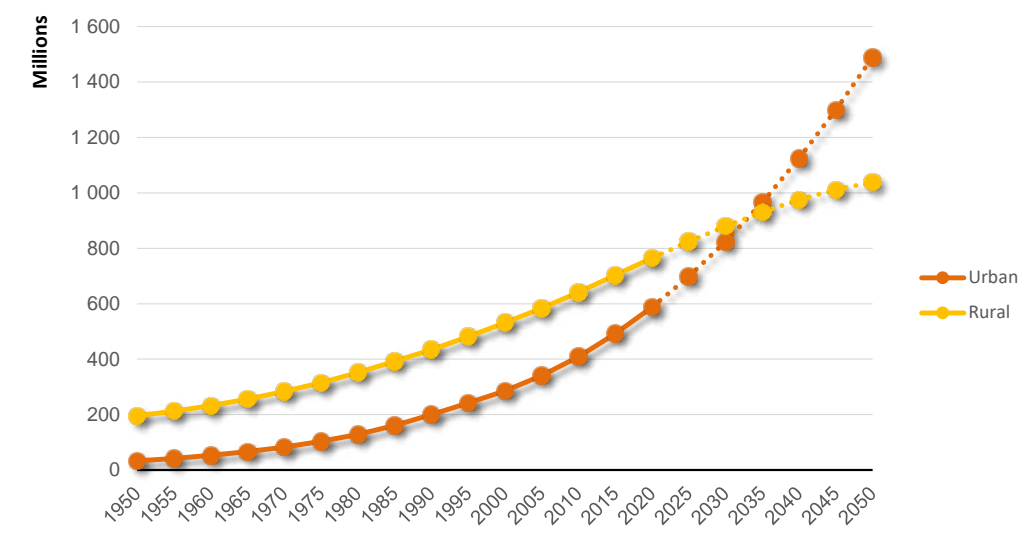


Table 3: Actual and projected urban and rural population growth (1950-2050)

Source: UN (2018a, 2018b), illustrated by the author

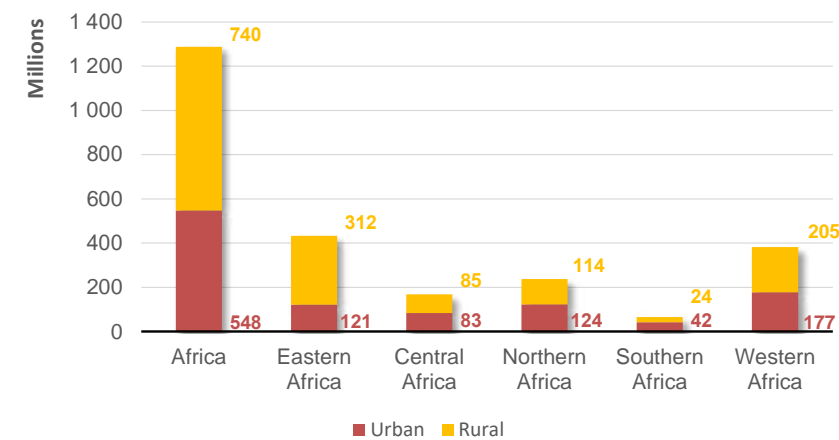


Table 4: Urban and rural populations in Africa
Source: UN (2018a, 2018b), illustrated by the author

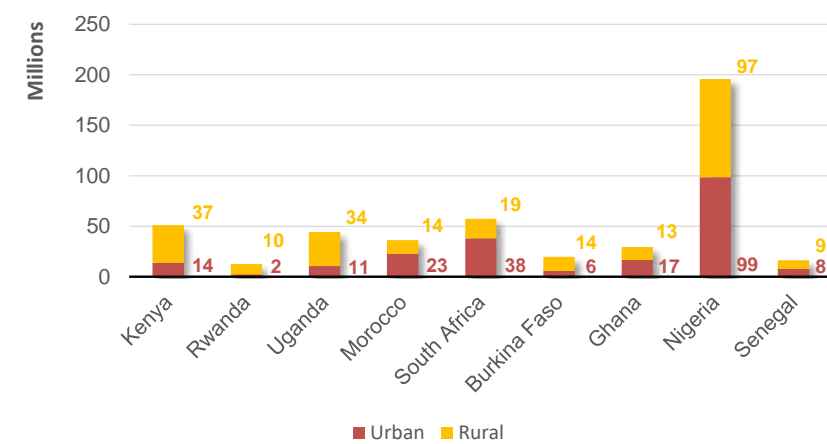


Table 5: Urban and rural populations in selected African countries
Source: UN (2018a, 2018b), illustrated by the author

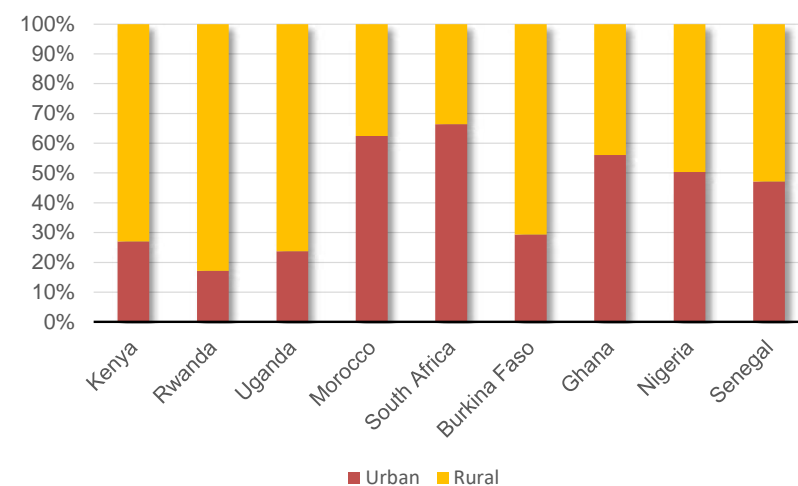


Table 6: Urban-rural population divide in selected African countries
Source: UN (2018a, 2018b), illustrated by the author

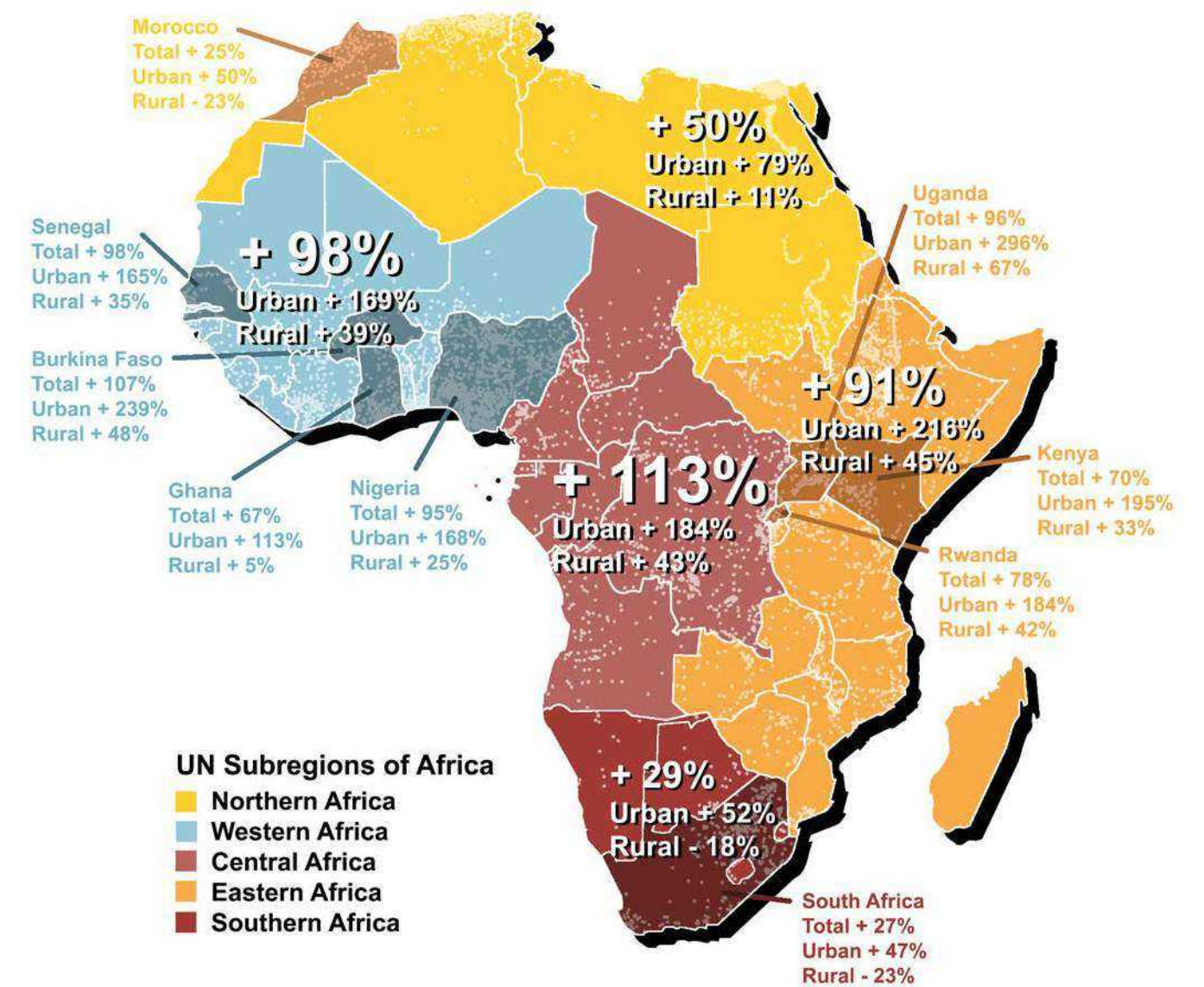


Figure 5: Total, urban and rural population growth in African subregions and selected countries (2020-2050)

Population centres are highlighted with light dots

Source: Population growth data (UN, 2018a, 2018b), population centres (Heinrigs, 2020), illustrated by the author

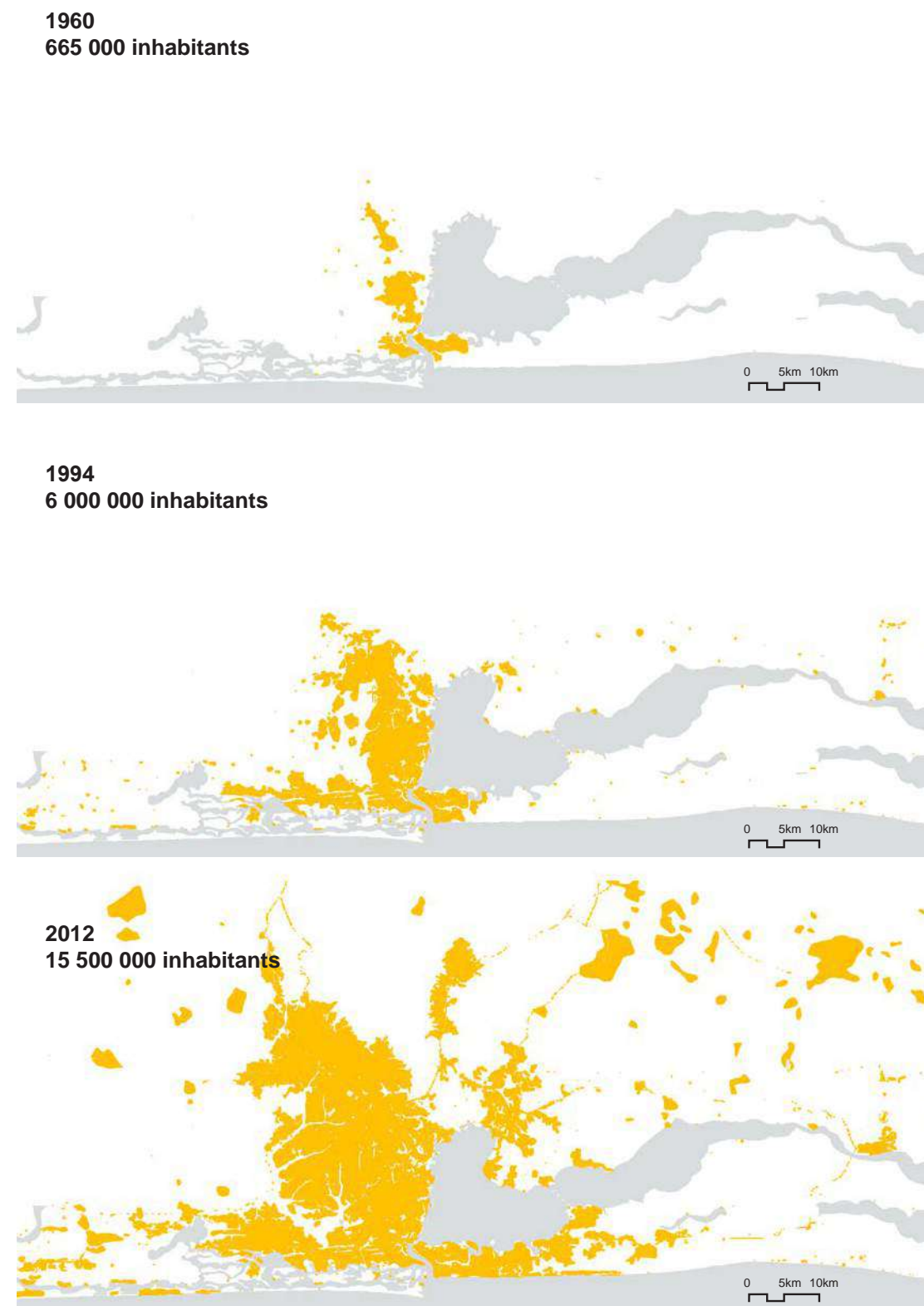


Figure 6: Maps depicting the growth of the city of Lagos in Nigeria (1960-2012)

Source: Sawyer (n.d.), redrawn by the author

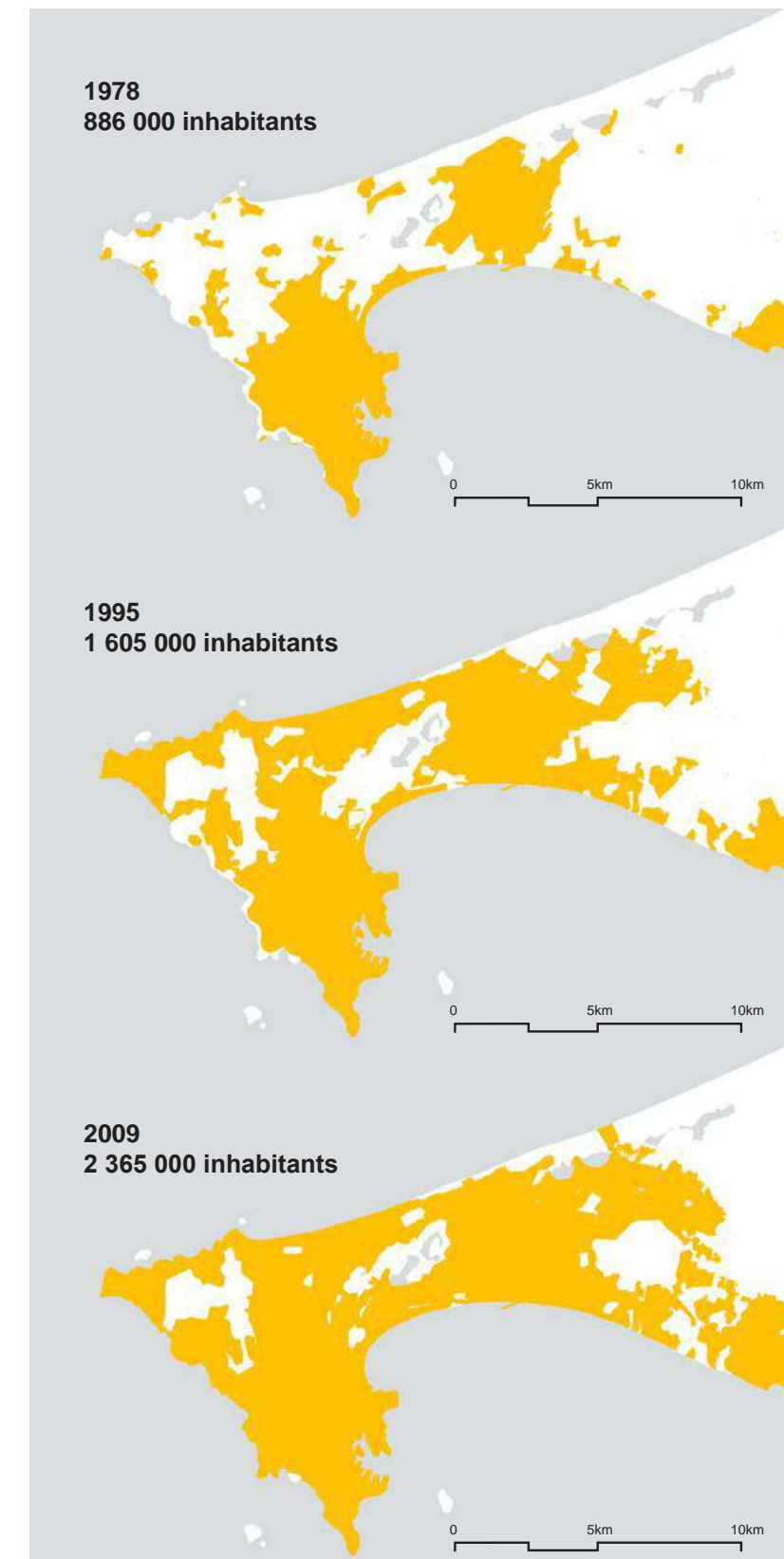


Figure 7: Maps depicting the growth of the city of Dakar in Senegal (1978-2009)

Source: Macrotrends (2022); Ndiaye (2022), redrawn by the author

Housing backlog is leading to informal growth

As a result of rapid population growth and the associated rising urbanisation, Africa is struggling with a housing backlog of more than 50,6 million housing units (Faye and Geh, 2018a). Nigeria alone has a housing deficit of 17 million housing units. The housing backlogs in the selected countries are illustrated in Table 7.

The enormous housing backlog and the lack of affordable housing in Africa has led to growth in informal housing. According to UN-Habitat's estimation, 56% of the African population resides in informal settlements (UN-Habitat, undated). In cities, the situation is worse, where approximately 70% of the urban population live in informal settlements (The World Bank, 2013). With only a minority living in formal housing, there is both pressure and opportunity to enhance the quality of housing by adopting a circular approach to buildings and construction.

Construction creates work and economic value

The BCS in Africa is worth 5,2 billion euros and its worth is projected to continue growing at an annual rate of 6,4% by 2024 (ReportLinker, 2020). The sector is an important employer, although it is highly dependent on an informal and unskilled workforce. There is no exact data available on how many people are employed by the BCS in Africa since the sector is highly informal and many of its activities are included in the manufacturing sector (see Table 8).

The sector that employs the most people in low-income countries is the agriculture sector. In African countries, where the BCS is often reliant on unskilled labour, a shift away from mined construction materials towards more sustainable bio-based materials would benefit from and be able to utilise existing agricultural know-how.

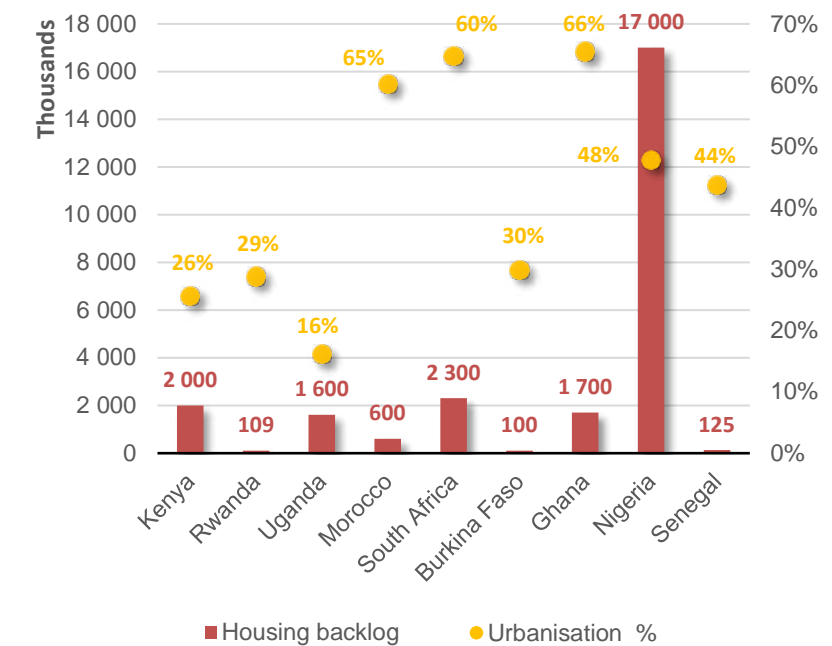


Table 7: Housing backlog and urbanisation rate in selected African countries (2015)

Source: Faye and Geh (2018a), redrawn by the author

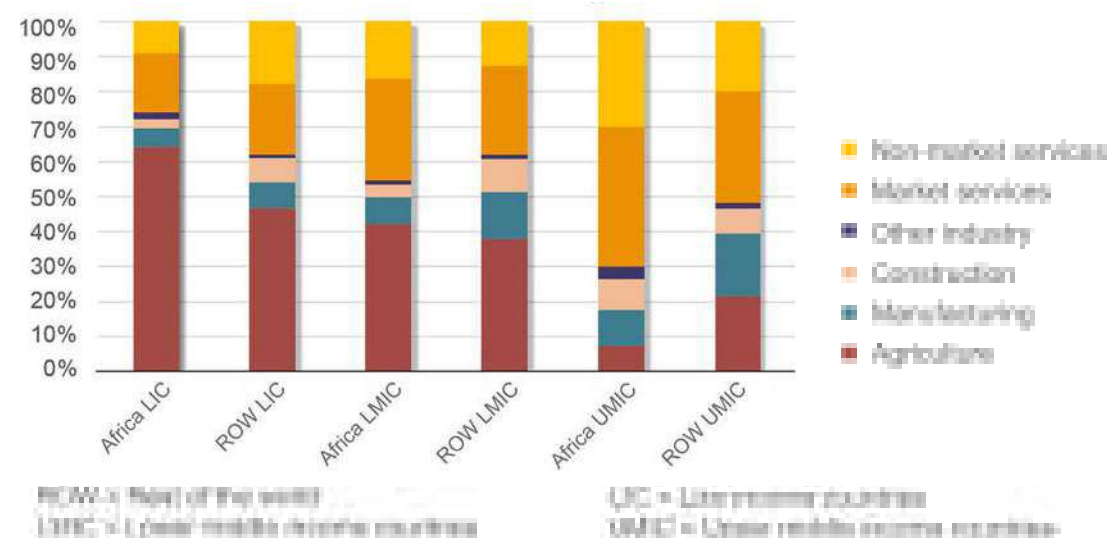


Table 8: Employment by sector and income group, Sub-Saharan Africa and the rest of the world

Source: Our World in Data and UN-Habitat (2018), redrawn by the author

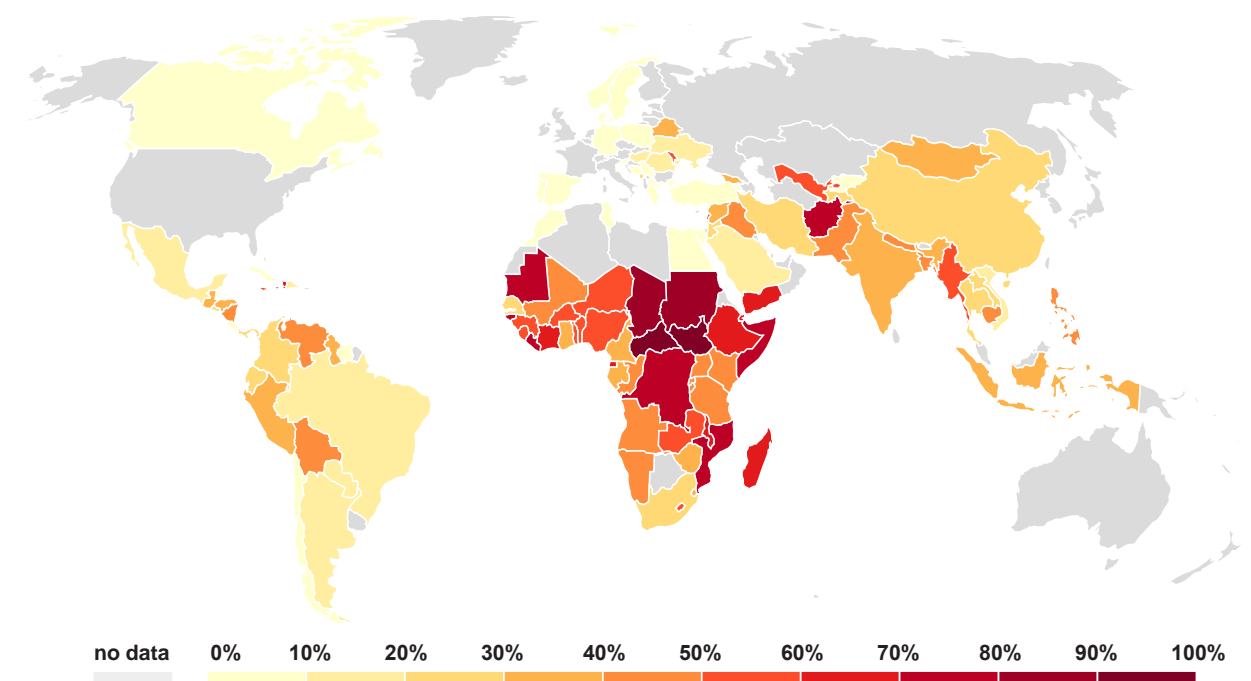


Figure 8: Share of urban population living in informal settlements (2018)

Source: Our World in Data and UN-Habitat (2018), redrawn by the author

Dependence on informal and unskilled workforce

In many African countries, the majority of the workforce in construction is informal but the informal construction sector's share of the total output is relatively low. Characteristic of informal contractors is a lack of productive assets, a small number of employees, a lack of formal education, learning-by-doing and deficient commercial skills. Small informal and formal contractors dominate the market in terms of their number, but they have difficulties accessing clients with large-scale formal projects unless they work as subcontractors for larger contractors.

The formal and informal construction sectors are strongly linked, with the former depending on the cheap labour provided by the latter. This relationship can be beneficial for informal contractors since they can become acquainted with and learn from the formal construction systems and thereby increase their competence.

Because cheap labour is available throughout Africa, mainstream practices that have been developed in more developed regions under completely different circumstances (such as contexts where materials are cheap in comparison to labour) are not well suited to the developing countries of Africa. The sustainable development of the construction sector in Africa must therefore consider the local context, including the reliance on the informal economy (Msinjili, Makunza and Akindahunsi, 2013).

Dependence on imported construction materials

Today, significant amounts of construction materials in Africa are imported, as shown in Table 9. Sub-Saharan Africa produces only 2% of all globally produced cement and aluminium and less than 1% of the world's steel (IEA, 2019a). This level of production is small considering that 15% of the world's population resides in Sub-Saharan Africa. As a result, African countries import a big share of these carbon-intensive materials. This is something that ought to change to strengthen local economies and reduce the vulnerability of the region. Transitioning from using imported materials to locally available and produced materials creates local jobs, which is a key to socioeconomic growth.

Buildings contribute to climate change

The BCS is the biggest emitter of greenhouse gases in the world. In Africa, most of the emissions from the BCS come from either the importation of materials or the production of carbon-intensive materials such as cement, steel and fired bricks (Pouzaint, 2020). In 2018, buildings used 61% of the total energy and caused 32% of the total process-related CO₂ (embodied) emissions in Africa – data that does not include the impacts of the construction industry (IEA, 2019a) – as shown in Figures 9 and 10.

Modern construction in Africa is highly dependent on cement. Cement production causes around 8% of global emissions and is projected to grow by 12–23% by 2050 (IEA, 2018a). In this same period, the share of African cement in global output is expected to increase from 26% to 37% (Djobo, 2021). Cement production is expected to at least triple in Africa by 2050 (IEA, 2018b). Additionally, primary steel production in Sub-Saharan Africa (excluding South Africa) is projected to increase 20-fold by 2040 (IEA, 2019a). There is an urgent need to cut emissions arising from the production of carbon-intensive materials, reduce the use of these materials in construction, and develop alternative ways to meet the growing need for new buildings. Reducing the use of virgin resources, especially non-bio-based ones, and cutting down emissions must apply to all building materials. Today, Africa's use of construction materials per capita is minimal in comparison to the global average, but the region's resource use is projected to grow exponentially as a result of population growth and rising urbanisation.

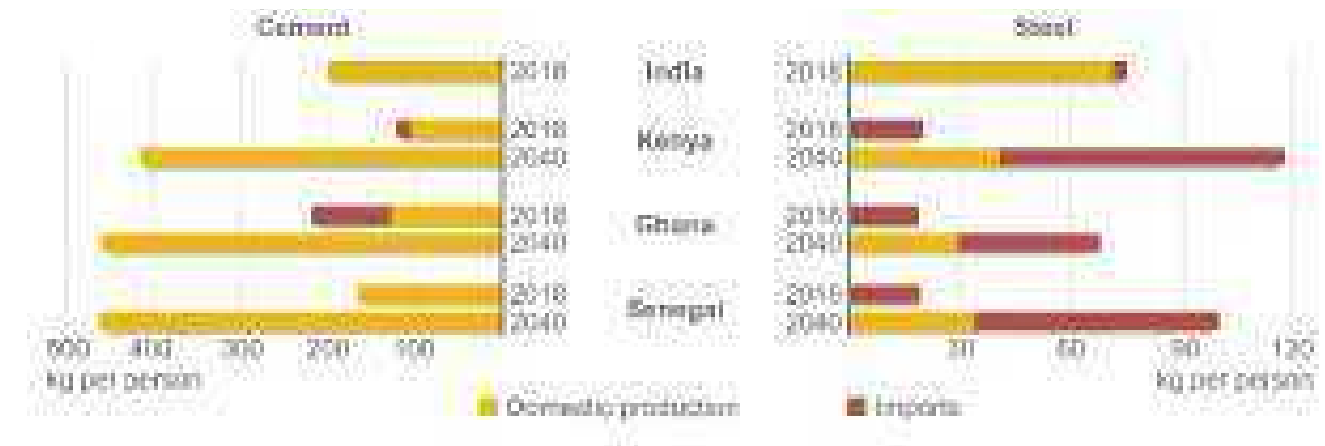


Table 9: Steel and cement demand per capita in selected African countries compared with the levels in India

Source: IEA (2019a), redrawn by the author

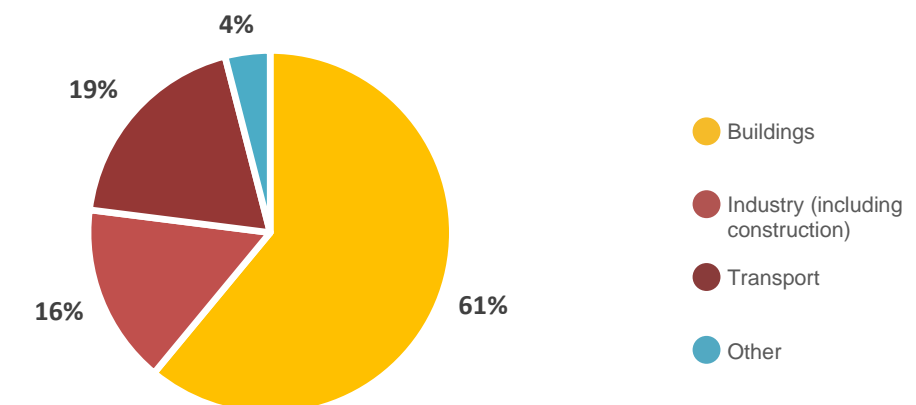


Figure 9: Final energy consumption in Africa (2018)

Source: Global ABC et al. (2019), redrawn by the author

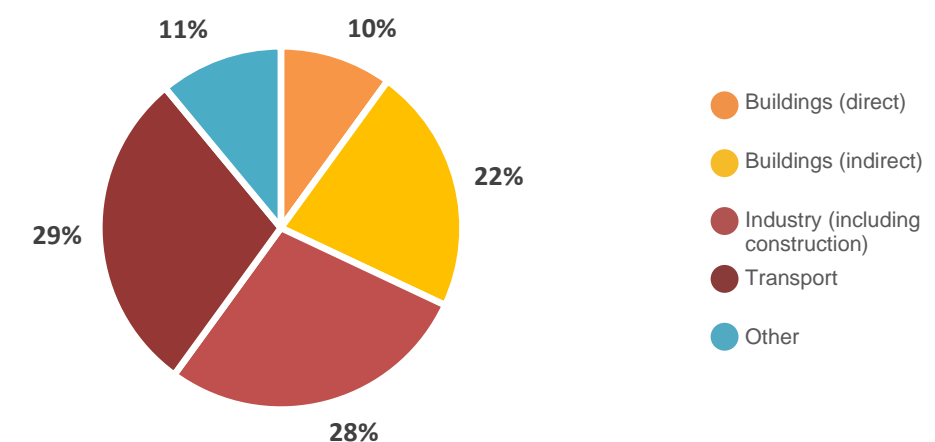


Figure 10: Total CO₂ emissions in Africa (2018)

Source: Global ABC et al. (2019), redrawn by the author

Significant decarbonisation potential

According to the World Energy Outlook, the use of decarbonisation measures in buildings and construction in Africa could reduce buildings' overall energy demand by 40% by 2040 while at the same time electricity demand triples (IEA, 2019b). The switch from gas and other non-renewables to energy-efficient electric heat pumps reduces total energy consumption but increases the use of electricity. In this sustainable development scenario, the embodied emissions of buildings could be reduced by 24% from their level in 2018. (GlobalABC et al., 2020). The decarbonisation measures would result in a reduction of over 330 MtCO₂ in annual emissions by 2040, compared to the current course of action.

It is estimated that by 2050 in Africa, 80% of the buildings will have been built after 2015. Within the same period, the increase in the demand for cooling in the region is projected to be more than 10-fold because of both the heating climate and population growth. As a result of the latter, the demand for heating is also expected to rise. Because of the projected enormous amount of new construction in Africa, the impact of adopting energy-efficient building methods could reduce the final energy consumption for heating and cooling in 2050 by 64% (Edelenbosch et al., 2021). In this regard, climate change and population growth are both driving the need to design and renovate buildings with thermal comfort in mind. In Senegal, 33% of electricity usage is due to air-conditioning in buildings (ABC21, 2022), which further underlines the importance of energy-efficient construction and passive heating and cooling solutions. In Africa, the embodied emissions of local earth- and bio-based construction materials are much lower than that of mainstream industrial materials, meaning that the production of the former causes significantly fewer emissions in comparison to the latter. At the same time, these low-carbon materials show great potential in reducing the energy needed to reach thermal comfort (Ávila et al., 2021; Hema et al., 2020; Jami et al., 2019; UNIDO, 2015).

Buildings contribute to resource scarcity

The BCS is the biggest resource user in the world. Sand and gravel together are the most extracted and traded resources after water, and yet their extraction is among the least regulated activities in the world. These resources are used to make concrete, asphalt and glass – making them vital for the BCS. UNEP has identified sand and gravel extraction as among the most pressing sustainability challenges of the 21st century. The need for sand and gravel keeps growing since the demand is directly linked to construction – at least as long as concrete remains the most used material in urban construction. To respond to this need, vast quantities of sand and gravel are extracted and traded illegally, in some cases by criminal organisations, or so-called sand mafias. This is the case in Morocco, where half of the sand (10 billion m³) is extracted illegally, with severe consequences for the local environment and economy. Hence, it is crucial to reduce sand extraction, use recycled aggregates to replace natural sand and find alternative solutions that reduce the need to use sand. For the BCS, this means that making concrete more circular, and replacing concrete with sustainable local materials where appropriate, must be prioritised (UNEP, 2019)

Construction and deconstruction produce waste

The BCS has a long way to go before becoming circular in Africa. Alongside its high levels of emissions and use of resources, the volume of construction and demolition waste (CDW) it produces is also generally high. This is partly the result of poorly planned construction and deconstruction, a lack of skills (Aiyetan and Smallwood, 2013) and limited legislation that requires

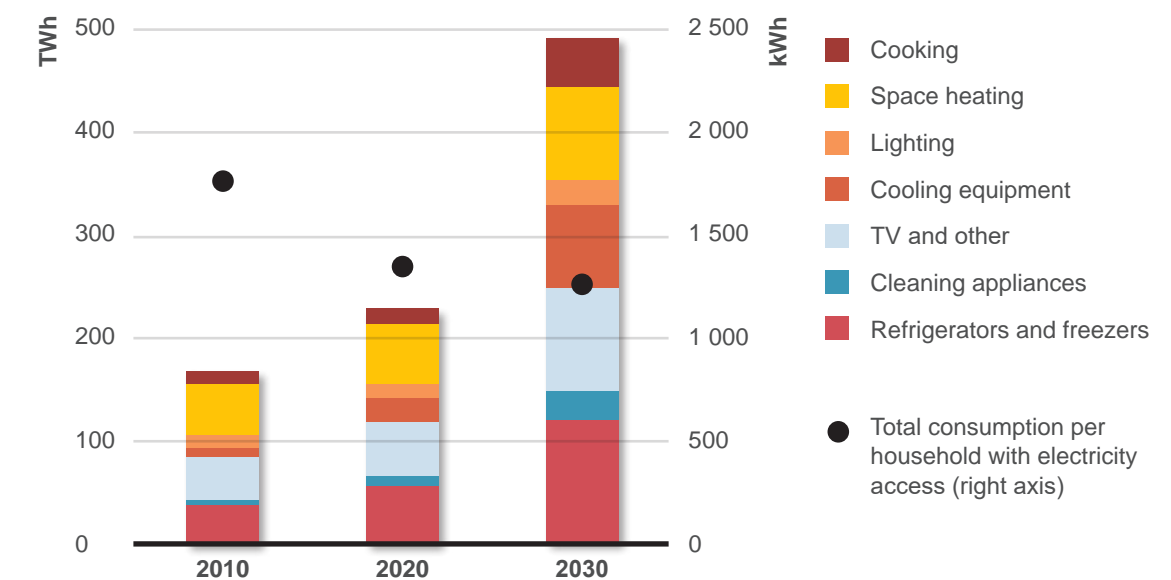


Table 10: Household electricity consumption in the sustainable development scenario in which Africa is to achieve all energy-related development goals on time and in full

Source: IEA (2022), redrawn by the author

circularity (Gibberd, 2020). Most of this waste is directed to landfills because the region lacks facilities that can reuse materials such as concrete; although some more valuable materials, such as metals, are more likely to be recycled (ibid). The mindset in relation to materials should change such that CDW would be regarded as a resource rather than something to get rid of. This would lower the negative environmental impacts of construction and help tackle resource scarcity, a problem that will only worsen with population growth.

Regional housing trends

Not all construction in Africa is linear and waste-intensive. Most of the traditional construction methods are highly circular in nature. Even though traditional materials are still widely used in rural areas, they are generally replaced with imported carbon-intensive materials in an urban context.

Traditional houses

Traditional African buildings are built of local low-carbon materials: earth, timber, bamboo and thatch. These buildings are vernacular, meaning that they represent local building techniques and traditions and their construction uses local resources. Consequently, vernacular architecture is connected to its geographic and cultural context and is often strongly linked to cultural identity. The traditional African construction methods are simple and the houses are often built by their owners with the help of neighbours; and very little waste is produced. Vernacular buildings are still common in rural areas across the African continent. Typically, these buildings are small and found in villages, small settlements and farms. Since vernacular buildings use locally sourced materials, the materials used vary depending on location and available resources. Imported materials are rarely used in traditional dwellings. Additionally, the materials used are of such character that they can easily be returned to nature if the buildings are no longer needed. Africa is a diverse region, and this is visible in the large variety of traditional African architecture. A few traditional housing types are described below to present the traditional material palette.

Yomata is a traditional housing type that has a cylinder-shaped layout and is constructed with mud and bamboo. Another traditional housing type is *Mdindo*. Typically, this type has a rectangular floor plan, and the structure uses wood, bamboo and compressed earth. *Zidina* is a third housing type. It has a rectangular floor plan and one or two floors. Zidina houses are built with sun-dried earth blocks and timber (Sá Ribeiro et al., 2016)

Semi-urban dwellings in low-density areas

Suburban houses are a housing type commonly built today. These dwellings are typically built on the outskirts of cities and towns. Old suburban houses typically have brick walls, timber and corrugated iron roofs, and timber windows and doors. Modern suburban houses are usually built of concrete block walls, timber, corrugated iron roofs, and steel or aluminium windows and doors.

Multi-storey buildings in high-density areas

Modern multi-storey buildings are found in central urban areas. These buildings are typically residential, economic or administrative buildings, or they have a mix of functions. They often have a reinforced concrete frame (posts, beams and floors) that is built on site. Additionally, they have corrugated steel roofs and brick, concrete block or glass façade walls. The concrete is sometimes locally sourced, while the glass and aluminium facades, tiles and lift systems are imported.

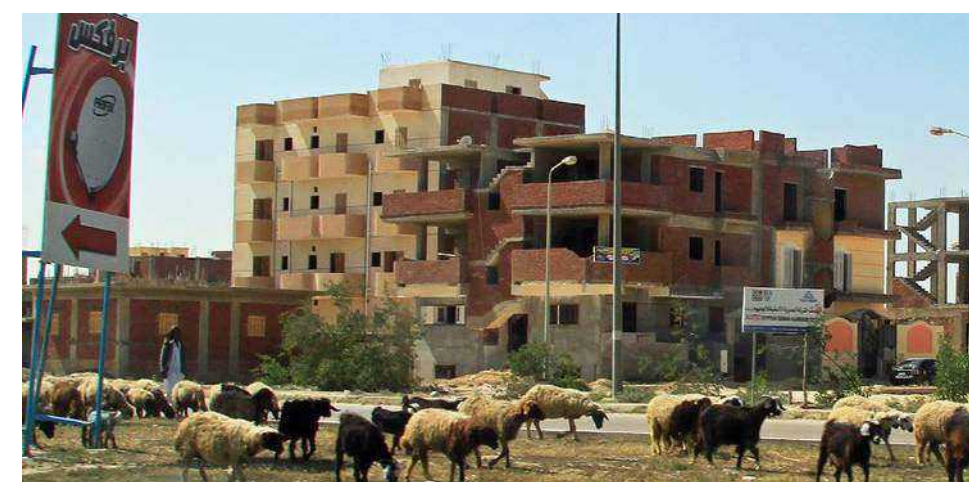


Figure 11: Images representing housing trends

Above: traditional housing, middle: suburban houses, below: multi-storey construction

Credit: Pekka Huovila

MATERIAL PALETTE

The construction material palette used in Africa is rich in diversity – traditional little-processed materials co-exist with industrially produced materials, and new materials are constantly being developed. Bio-based materials are gaining popularity in Europe, because of increased environmental awareness. In Africa, such materials are widely used in rural areas but they have been excluded from urban construction mainly because of their artisanal character and vernacular image (ABC21, 2022). However, the production of bio-based and traditional materials is being professionalised in Africa at a rapid pace, which gives these materials much greater potential for use in urban contexts.

Today, urban construction in Africa is highly dependent on imported, non-circular, carbon-intensive materials. This reliance on imported materials increases construction costs and slows the economic development of the continent. In contrast, a higher utilisation rate of locally sourced and processed materials would create more local jobs, boost the economy and help to combat the region's vulnerability and poverty. Additionally, keeping the materials in the loop and lowering emissions are necessary to meet the needs of the growing population in the region while also ensuring that resource use respects the planetary boundaries.

This section presents the region's traditional materials and industrial mainstream materials and considers the emerging circular materials that may be used in the region. Emerging circular materials include materials produced mainly out of waste or side streams and traditional or mainstream materials that have been modified to be more circular. Finally, the potential of different construction materials is evaluated and presented in the form of Table 17. The table considers the environmental, social and economic impacts of using different materials, how they can be used, and whether manufacturing can be quickly upscaled to respond to the rapidly growing need for construction materials in the region.

3.

Key points

TRADITIONAL MATERIALS



EARTH



STONE



STRAW



BAMBOO



WOOD

*local
low-tech
low-carbon
circular
(affordable)*

INDUSTRIAL MAINSTREAM MATERIALS



CONCRETE



BRICKS &
BLOCKS



AIRCREE



INORGANIC
INSULATION



METALS

*imported
industrial
carbon-intensive
(expensive)*

EMERGING CIRCULAR MATERIALS



HEMPCRETE



BIO-BASED
CONCRETE



STRAW PANELS
& BALES



BIO-BASED
INSULATION



BIO-
COMPOSITES



RECYCLED
PLASTIC

*local
industrial
low-carbon
circular*

WINDOWS & DOORS



PVC & METALS



WOOD

*imported
industrial
carbon-intensive
(expensive)*

*local
low-carbon
circular
bio-based*

FURNITURE & FITTINGS



PLASTICS, METALS, ETC.



NATURAL MATERIALS

*imported
industrial
carbon-intensive
(expensive)*

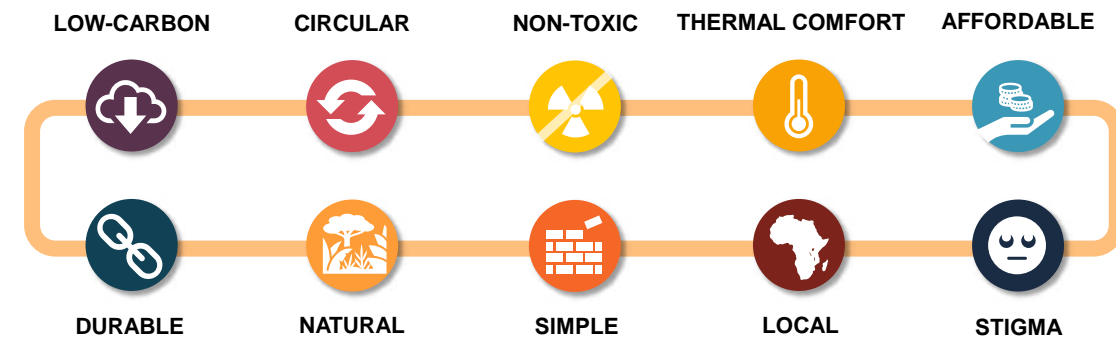
*local
low-carbon
circular
bio-based*



Traditional materials

Bio-climatic construction materials are materials found and fit to be used locally – they are non-destructive for the user and the environment, and they blend into their natural surroundings. Traditional African construction materials are intrinsically bio-climatic. They are locally manufactured out of locally sourced raw materials. Most of these materials are low-carbon and highly circular in nature. Bio-climatic construction materials are often produced by small- and medium-sized enterprises (SMEs) since they do not need high initial investment costs. However, many African countries lack proper standardisation of traditional materials, which often limits the use of these materials in large-scale formal projects. The traditional materials presented in this report are earth, including different bricks and blocks, rock, wood, bamboo and straw.

Earth



Raw earth has been used in different ways for construction worldwide for thousands of years. Thus, there is an accumulated experience from centuries of using earth in construction. Typically, earth is used to construct walls, vaults and domes. The oldest still-standing earth building is the Ramesseum in Egypt, with an age of about 3 300 years. Nonetheless, there has been a noticeable global shift away from earth-based materials towards concrete in the last century. This change has led to a loss of expertise and local jobs, a decrease in energy efficiency, and an increase in greenhouse gas emissions and waste.

At the present time, approximately 40% of the global population lives in earthen buildings. Additionally, 17% of the world's cultural heritage sites are constructed out of earth. Raw earth is rarely used in modern construction, and it is often seen as a material of the past and associated with poverty and a low level of development. Raw earth construction is, however, starting to receive more interest in recent years. Today, the material is best known for its low embodied energy, easy recyclability and exceptional thermal behaviour, all of which make it well suited to hot and arid climates. Earthen dwellings can naturally preserve the indoor climate within the thermal comfort limits most of the time, without consuming any energy.

When building out of earth, the identification of the soil is crucial. Not all types of soil are suitable for construction and different types of construction require a different type of soil. Nevertheless, if the builder has enough knowledge of earth as a building material, most soils can be used for construction. CRATerre (1991) has identified 18 different types of earth construction and divided them into three categories: load-bearing monolithic structures, load-bearing masonry, and construction in which earth is used in conjunction with some other load-bearing structure. The construction types are presented in Figure 13. The simplest way to earth-construct is to mix water with earth, shape the mixture to the desired form and let it dry in the open air. Sometimes moulds are used, as is the case in *traditional non-fired bricks and blocks*. *Modern non-fired bricks* can be manufactured with precision and the material's properties can be improved with the help of appropriate machinery. Thus, the production of non-fired bricks is like that used for fired bricks, except that no energy is needed for firing and therefore potentially provides high reductions in emissions (Heath et al., 2009).

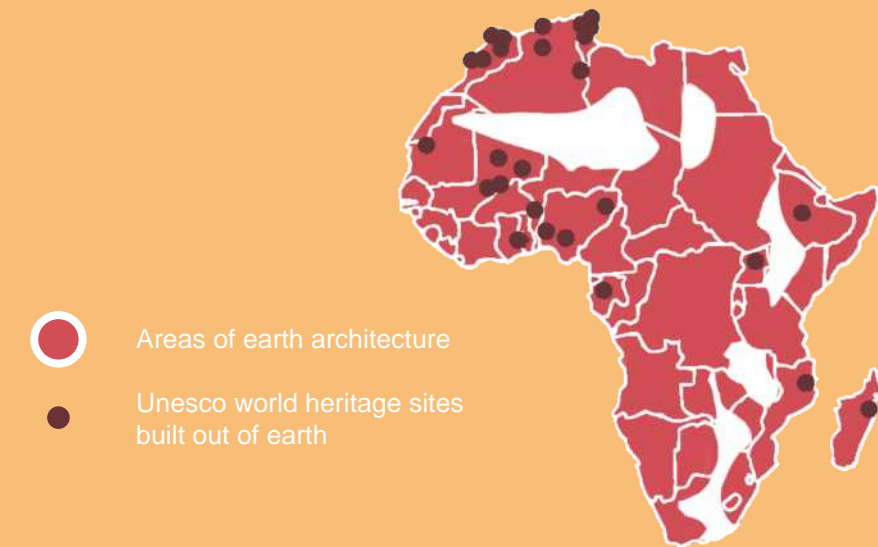


Figure 12: Map illustrating areas with the tradition of earth construction

Source: Guillaud et al. (n.d.)

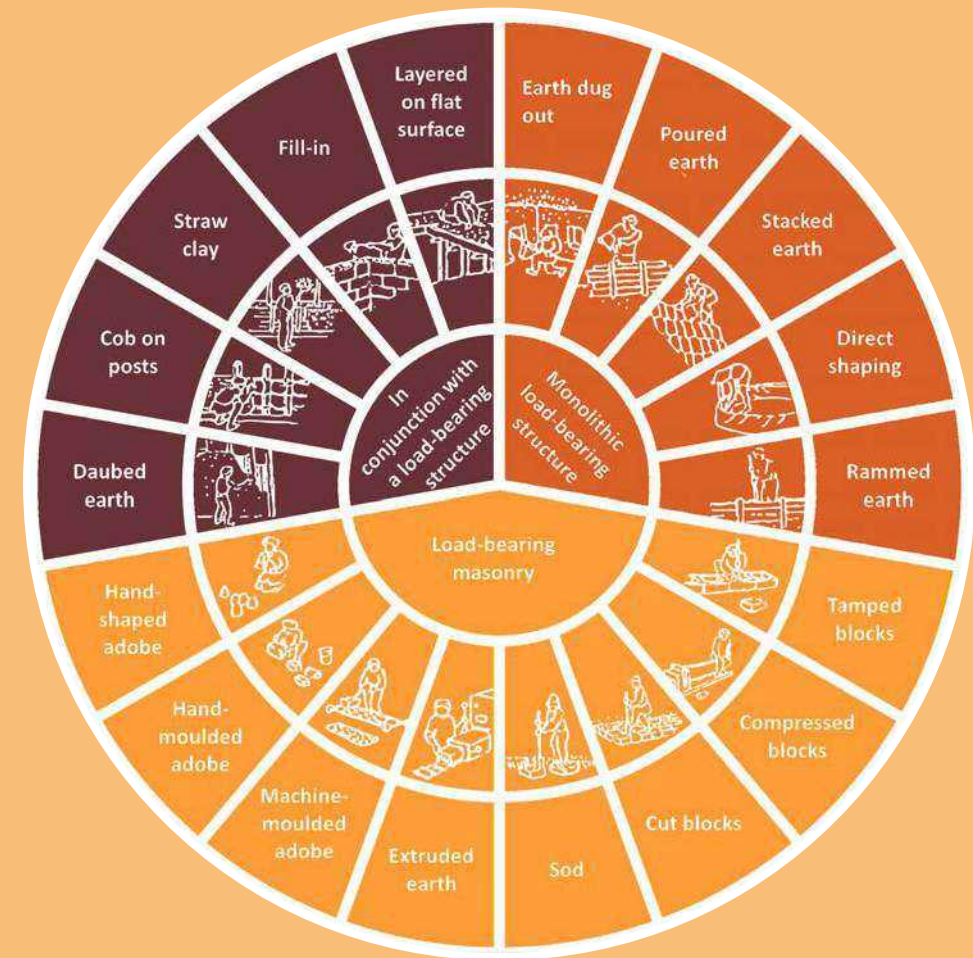


Figure 13: 18 types of earth construction divided in three main categories: monolithic load-bearing structures, load-bearing masonry, and earth used in conjunction with load-bearing structures

Source: CRATerre (1991)

Compression can be used to strengthen raw earth, as is the case in *rammed earth* construction and the manufacture of *compressed earth bricks and blocks (CEB)*. Additives may be used to enhance specific properties of the material. If the additive is a chemical binder the material is stabilised (CsEB). For example, earth can be stabilised with lime, natural pozzolans, cement or fly-ash. The mechanical properties of CEB can be improved by using additives such as banana fibres (Mostafa and Uddin, 2016). Unfired clay bricks can be strengthened by mixing in seaweed biopolymer (Dove et al., 2016). The thermal conductivity of clay bricks can be significantly improved by using barley as a bio-aggregate additive (Giroudon et al., 2019). Findings like these underline the great potential of using recycled agricultural waste and by-products in construction to contribute to a more circular built environment.

Some of the earth materials, such as bricks and blocks, can easily be prefabricated, making them easy to use in dense urban environments. Construction with rammed earth, one of the simplest monolithic earth construction methods, is traditionally carried out on site. Rammed earth can, however, be prefabricated for different uses. For example, Austrian company Lehm ton Erde is among the first to produce prefabricated load-bearing rammed earth elements; while American company Rammed Earth Works has specialised in prefabricated rammed earth panels for interior and exterior surfaces. Industrial rammed earth products have much wider market possibilities than traditional on-site rammed earth.

No material has lower embodied energy than locally sourced and produced unstabilised earth materials. However, the use of additives such as cement, and excessive transport or energy-intensive firing processes, can increase their embodied energy and emissions (Dabaieh et al., 2020). Table 11 compares the global warming potential of 1 m³ of rammed earth, CEB, CsEB, adobe, reinforced concrete, concrete blocks, modern kiln-fired bricks and country-fired bricks. Rammed earth has 97% lower (ABC21, 2021; Ávila et al., 2021), CEB has 94% lower (Pouzaint et al., 2020) and CsEB has 84% lower emissions than concrete (UNIDO, 2015).

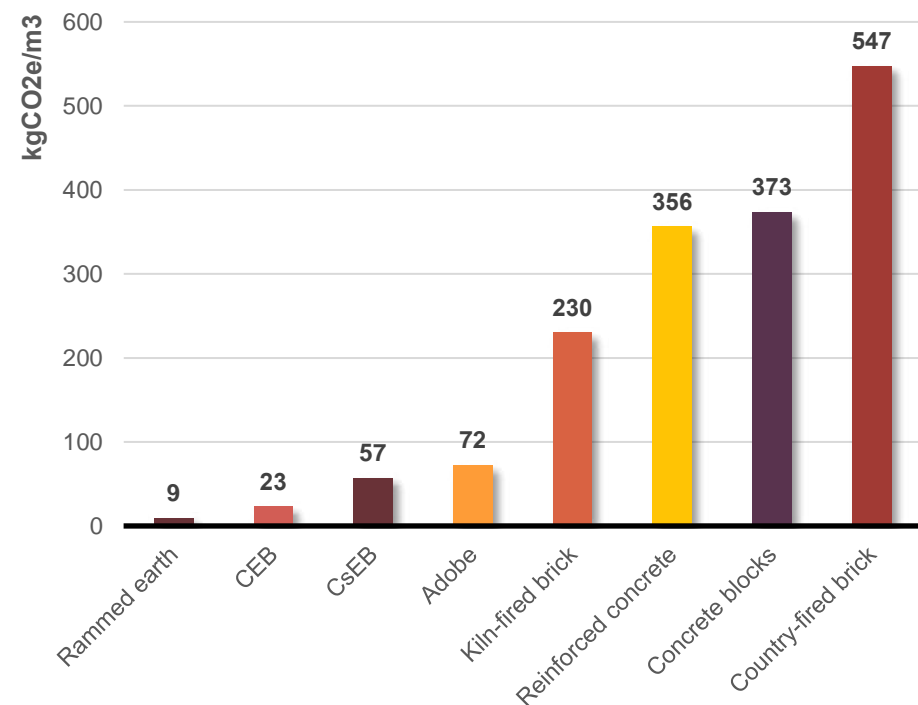


Table 11: Embodied emissions caused by 1 m³ of different earth construction techniques in comparison to conventional materials

Sources: ABC21 (2021) [rammed earth]; Ávila et al. (2021) [adobe]; Dabaieh et al. (2020) [bricks]; InEnergy (2010) [concrete]; Pouzaint et al. (2020) [CEB, concrete blocks]; UNIDO (2015) [CsEB], table created by the author



Figure 14: CEB blocks
Credit: Pekka Huovila



Figure 15: Drying of adobe blocks
Credit: 102553295 © Oleg07871 | Dreamstime.com



Figure 16: Modern interlocking CEB
Credit: DSF Africa

Besides its environmental benefits, local earth construction has significant social benefits. The price of a CEB wall might be slightly higher than that of concrete blocks (approximately 2%) because of the higher associated ‘labour costs’ (approximately 25%). Yet this comparison does not include the social or environmental costs. Poverty and unemployment burden national economies and increase social injustice, making job creation crucial in supporting sustainable development in Africa. In one case study, the cost of creating a job in CEB construction was 3% lower than that for concrete block construction. CEB production can create more green jobs than can the concrete or concrete block industry while also having much lower negative environmental impacts, as presented in Table 12 (Pouzaint et al., 2020).

Regular earth-based materials do not possess the same mechanical strength as concrete or fired brick. Hence, earth buildings are typically low-rise buildings. However, earth is not excluded in taller structures; and there are successful examples of mid-rise and even high-rise buildings constructed of earth. Additionally, hybrid solutions are gaining popularity in construction, which is widening the possibilities for using earth. Some of the earth materials perform very well as on-load-bearing materials, such as infill within a frame structure (ABC21, 2021).

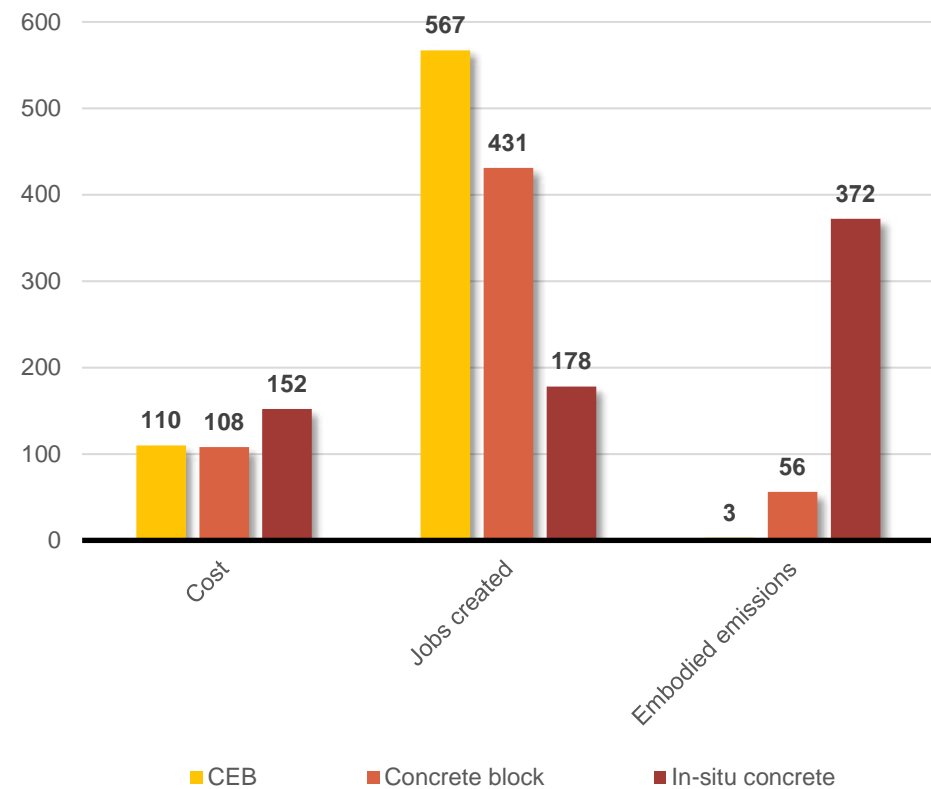


Table 12: Cost, jobs created, and embodied emissions of CEB, concrete blocks and in-situ concrete

Cost in euros per 1 m² of wall in each material. Jobs as the number of jobs generated by the sector. Embodied emissions in kgCO₂e caused by the construction of 1 m² of wall in each material

Sources: Ndiaye et al. (2005) and Pouzaint et al. (2020), table created by the author

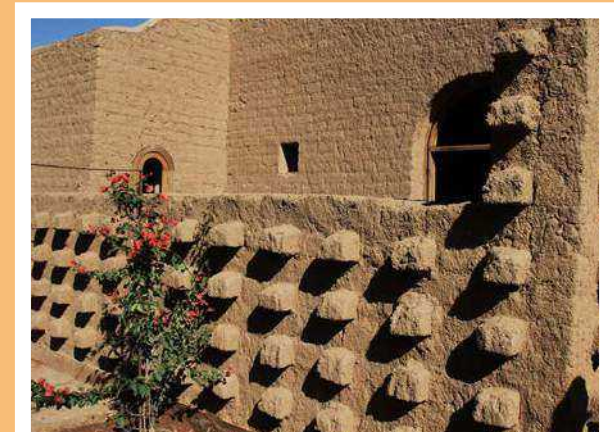


Figure 17: Adobe wall
Credit: Pekka Huovila

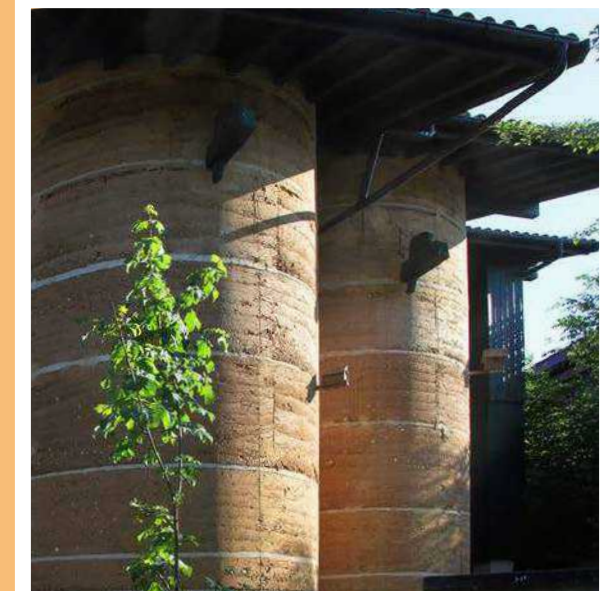
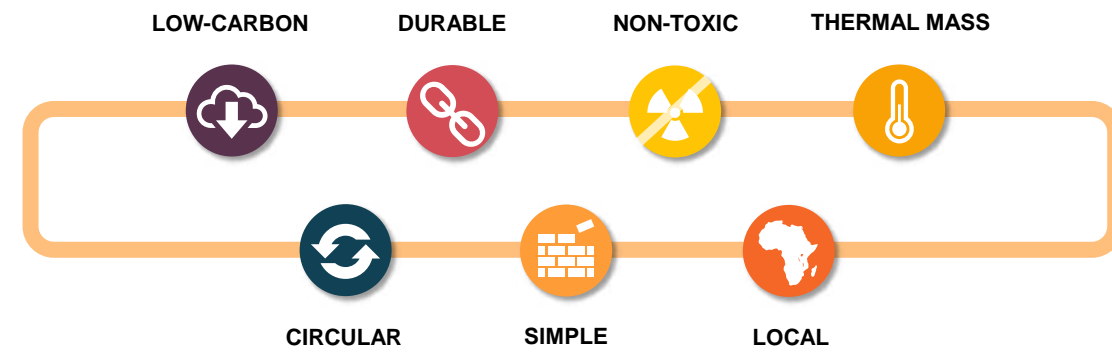


Figure 18: Rammed earth
Credit: Pekka Huovila



Figure 19: Decoratively painted and plastered adobe wall

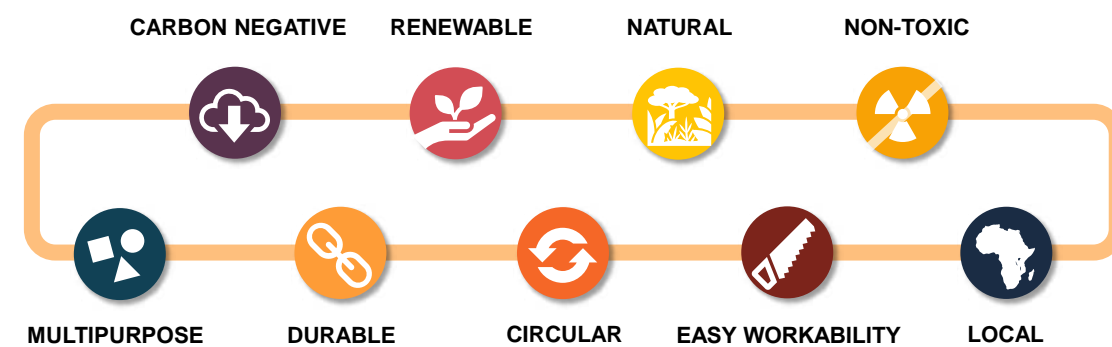
Stone



Stone is an extremely durable construction material – stone structures built hundreds of years ago are still used today. Stone is a natural material that needs neither maintenance nor manufacturing. Stones are easily dismantled from one structure for reuse in another, which makes stone a circular material. Natural stones have a lower carbon footprint than many mainstream materials. The embodied emissions depend on the stone type, but average emissions are 16–18 kgCO₂e/m³ (ABC21, 2021), in comparison to concrete, at 228 kgCO₂e/m³ (InEnergy, 2010) and modern kiln-fired bricks, at 230 kgCO₂e/m³ (Dabaieh et al., 2020). Long distance transportation of stone is to be avoided since it can significantly increase the emissions because of the high density of stone. Additionally, stones have low water absorption capacity and low insulation properties. Yet they possess high thermal capacity, which makes stone structures well suited to hot climates because they keep indoor spaces cool during the day and warm during the night, thereby reducing energy use (Ehrlich, 2013).

Stones can be used in various applications, such as load-bearing masonry structures, roofing, flooring, facades, aggregates and landscaping (ABC21, 2021). Most stones have high mechanical performance but assessing the strength performance of masonry structures is much more complex than for single stone types. The strength and stiffness of a stone structure depend on the strength of the stones and mortar used, the shape of the components, the stone–mortar ratio, and the shape and texture of the entire structure. Stone masonry buildings perform well under vertical loads. However, when subjected to a horizontal load (such as an earthquake), their strength performance is weak due to the low tensile strength of the structure (Dipasquale et al., 2020).

Wood



Wood is a widely used natural and renewable construction material. It is characterised overall by high strength and stiffness, although these properties can vary significantly dependent on species and growth conditions (ABC21, 2021). Wood species grown and used in construction in Africa include iroko, doussie, sapele, bubinga, azobe, padouk, tali, pachyloba, ayous, teak, cedar, pine and oak (Cameroon Timber Export, 2019). Wood has traditionally been used in the

Figure 20: Vernacular African rondavels made from stones and straw in Lesotho

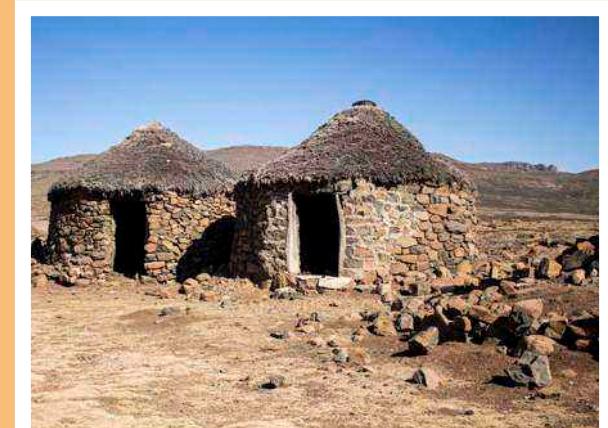


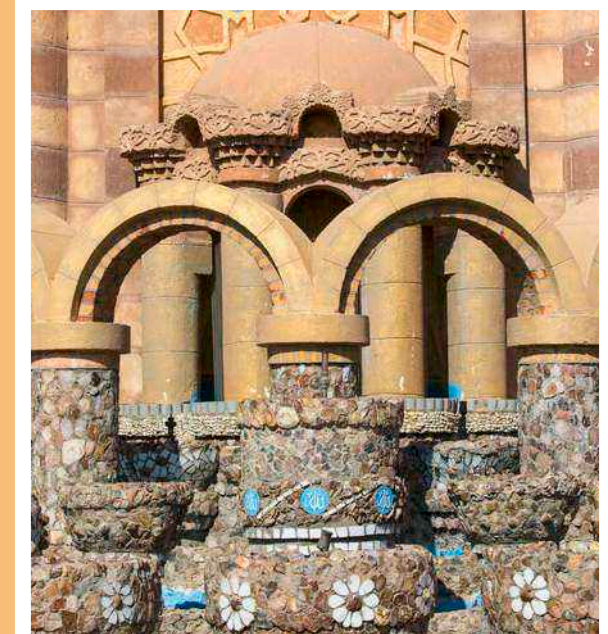
Figure 21: Stone masonry wall in Morocco

Credit: 61686816 © Lkpro555 | Dreamstime.com



Figure 22: Stone details in Al Mustafa mosque, a large Islamic temple in Egypt

Credit: mychadre77 / Depositphotos.com



region for load-bearing structures, interior and exterior surfaces, windows, doors and furniture. Modern engineered timber products widen the possibilities for the use of wood in construction in the African context, particularly as these products are already mainstreamed in many industrial countries.

Trees, and other plants, absorb carbon from the atmosphere when growing. Replacing conventional non-renewable carbon-intensive construction materials with wood can significantly lower the greenhouse gas emissions of construction because wood products produce generally much lower emissions during their life cycles. Additionally, the carbon-storing capacity of timber makes it a carbon-negative material – a material that stores more carbon than its production and processing releases. For example, 1 m³ of wood stores approximately 1 000 kgCO₂e, while the production of 1 m³ of concrete emits around 350 kgCO₂e (ABC21, 2022; InEnergy, 2010). On average, for every 1 kg of carbon stored in wood products that substitute other products in buildings, there is an emission reduction of 0,9 kgCO₂e (FAO, 2022).

In low-income countries, especially in Africa, the reliance on woodfuel is high. More than 90% of the cut wood is used as fuel (FAO, n.d.). Using wood in products with long lifespans utilises wood's carbon-storing capacity, whereas using wood for fuel quickly releases the carbon into the atmosphere. Therefore, replacing woodfuel with more sustainable energy sources and using wood for construction would be climate-smart (FAO, 2022).

Increasing the use of wood in construction in Africa would also contribute to green job creation. Wood production and processing to meet the expected demand for housing in the region by 2050 could create 25 million jobs and contribute 80 billion euros to local economies. Unlocking this potential sustainably requires a significant increase in the supply of wood through restoration, reforestation and afforestation of degraded lands. The current trend of net losses of forests in Africa needs to be stopped and preferably reversed (FAO, 2022).

The BCS also needs greater investment to scale up production. It is crucial to use sustainably grown wood to make long-lasting products and avoid extensive use of raw materials and waste creation through efficient production and processing and the cascading use of materials. The sustainable production and use of wood would support the transition to a circular economy (FAO, 2022).

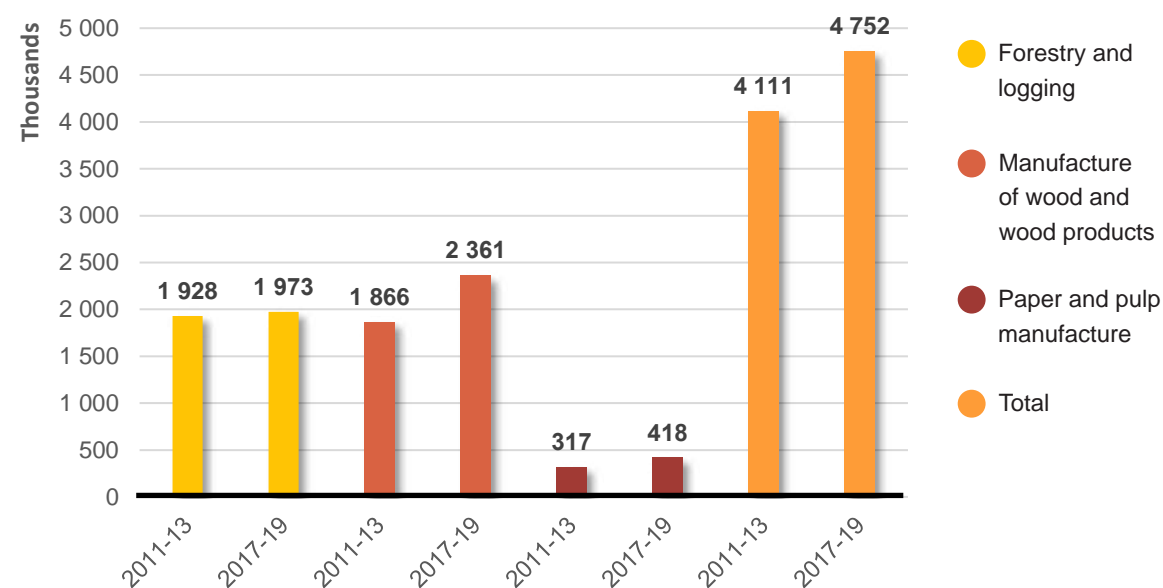


Table 13: Total direct formal and informal employment in the forest sector, 2011-2013 and 2017-2019

Source: Li et al. (2022), illustrated by author

Figure 23: Wooden huts in the Kalahari Desert, Botswana



Figure 24: Traditional wooden roof structure

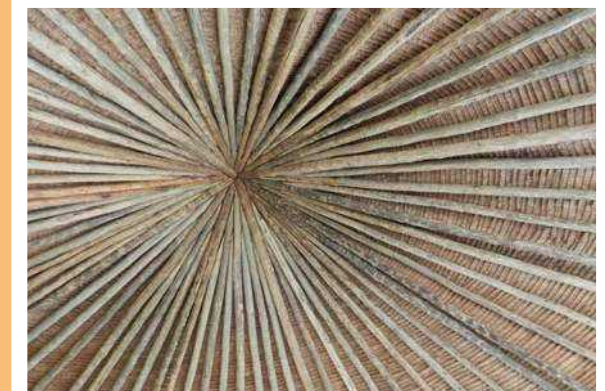
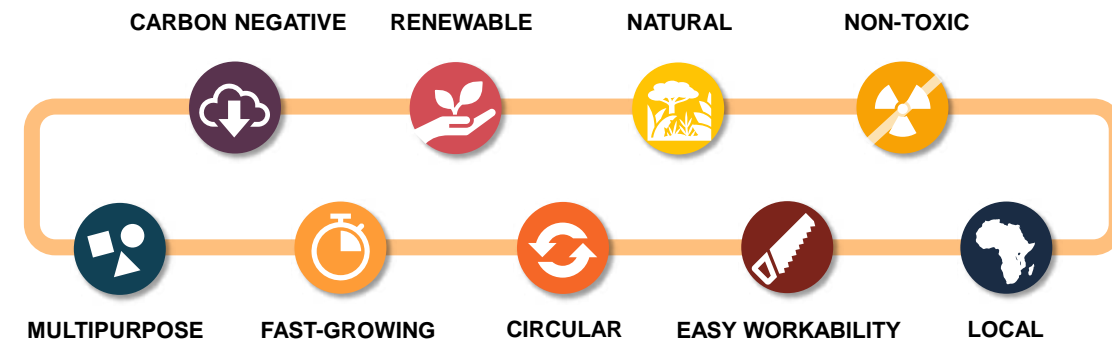


Figure 25: Modern wooden trusses

Credit: 01622574 © Lucian Coman | Dreamstime.com



Bamboo



Bamboo is among the oldest construction materials. It is often compared to or even considered to be wood, even though it is scientifically classified as grass. Bamboo and wood have many characteristics in common: renewability; bendability; high flexural, compressive and tensile strength; low embodied emissions; and big carbon-storing capacity (ABC21, 2021). Bamboo forests have the potential to be excellent carbon sinks since the giant grass absorbs twice the amount of carbon dioxide than does a regular tree (Zipporah, 2016).

Bamboo is a lightweight material with excellent strength in relation to density. It is also circular in that even if bamboo products are not reused, the lifespan can be prolonged by turning the bamboo fibres into pulp (ABC21, 2021). Because of its structural and environmental properties, bamboo and bamboo-based materials are well suited to construction. Untreated bamboo is vulnerable to insects and fungus so special treatments are needed to protect it.

Unlike wood, bamboo is the fastest-growing plant on earth – it is possible to harvest it for use 4–5 years after planting (ABC21, 2021). Bamboo can thrive in very poor soil and in almost all climates. Additionally, it needs no fertilisers or pesticides – making it a very easy plant to grow (Zipporah, 2016).

Bamboo is a traditional construction material in Africa, but it has never been utilised as efficiently as it has in Asia. Nevertheless, East African countries have abundant bamboo resources, representing significant unrealised socioeconomic and environmental potential (Mekonnen et al., 2014a). Ethiopia has the biggest bamboo reserves in Africa, with an estimated bamboo forest area of 1 million hectares, which is 67% of the African total and 7% of the global total of bamboo forests. Yet the country has not yet managed to capitalise on bamboo (Embaye et al., 2003; Mekonnen et al., 2014b; Wang, 2006).



Figure 26: Map showing the distribution of bamboo in existing forests

Source: adapted from Zhao et al. (2017)

Figure 27: Cut and dried bamboo for construction in Ghana

Credit: 26002766 © Dianearbis | Dreamstime.com



Figure 28: Vernacular construction with bamboo and earth

Credit: 52702017 © Inge Hogenbijn | Dreamstime.com



Figure 29: Bamboo in modern construction

Credit: 24789881 © Project1photography | Dreamstime.com

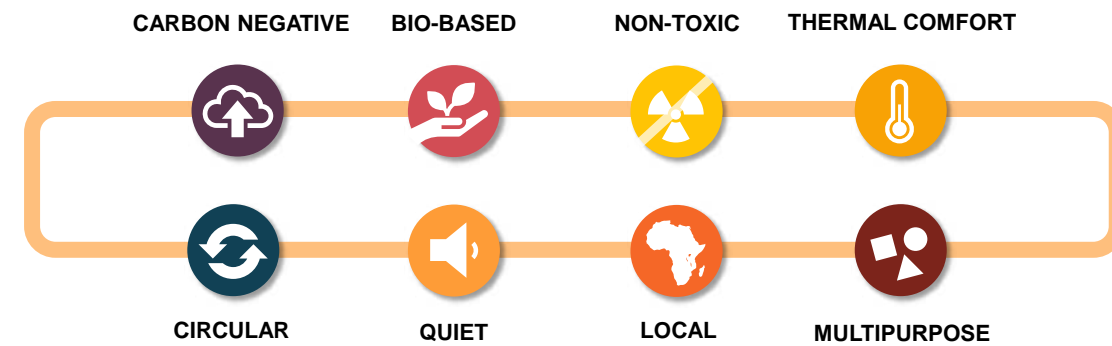


Upscaling the use of bamboo in Africa could alleviate poverty, create local green jobs and SMEs, and reduce the negative environmental impact of construction by replacing more harmful materials with bamboo (INBAR, n.d.).

The International Bamboo and Rattan Organization (INBAR) is a UN programme that promotes the growth of bamboo and rattan for economic and environmental profit. Today, 18 African countries with naturally growing bamboo have joined INBAR: Benin, Burundi, Cameroon, Eritrea, Ethiopia, Ghana, Liberia, Kenya, Malawi, Madagascar, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo and Uganda. Angola, Gabon and Zambia are expected to join the organisation in the near future (Zipporah, 2016).

Today, bamboo has many uses in construction, including structural use, roofing materials, fencing, veneer, flooring, panels for walls and ceilings, scaffoldings, door and window frames, window blinds and furniture (Zipporah, 2016). Additionally, as with wood, engineered bamboo products are being developed, creating new possibilities for the use of bamboo. An example of such is cross-laminated bamboo (CLB), which is yet to be commercialised. CLB is the bamboo alternative to the cross-laminated timber (CLT) that is already mainstreamed in many industrialised countries.

Straw



In Africa, straw has historically been used for thatching in roofs, lining for internal plasters and reinforcement for traditional earth structures. Thatching is a traditional and very affordable way to construct roofs by using dry vegetation such as straw. The structure typically consists of either stacked layers or bundles of dry vegetation. Straw is the part of a cereal plant that remains after the grains have been harvested. Straws can originate from plants such as barley, maize, wheat, oats, rye, rice and sorghum. Using straw in construction comes with many environmental benefits; it is renewable and local, it has low embodied carbon and it originates from the upcycling of agricultural waste.

Straws catch fire easily and thus fire is a risk that needs to be considered in straw construction. The material's fire resistance can be increased through mechanical compression. Compressed straw structures have high resistance to flame spread and temperature increase. Industrially produced compressed straw-based materials are further discussed in the section 'Emerging circular materials'.

Figure 30: Traditional African houses with thatched roofs

Credit: Jeremy Gibberd

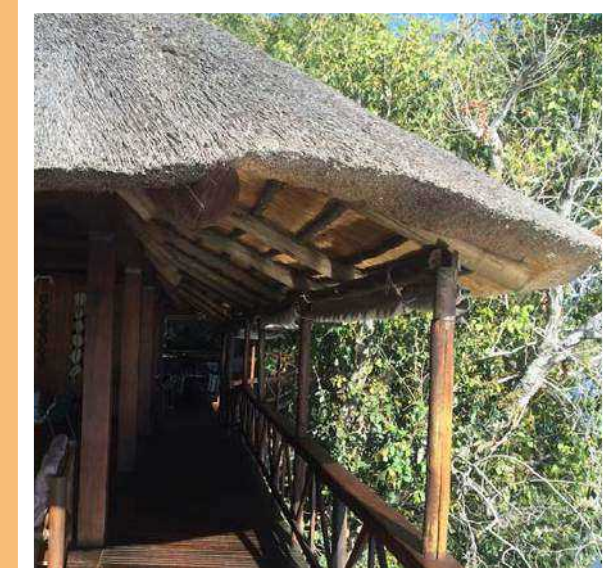


Figure 31: The making of a thatched roof

Credit: 119375274 © Amnat Buakeaw | Dreamstime.com



Figure 32: Reinforcing earth blocks with straw

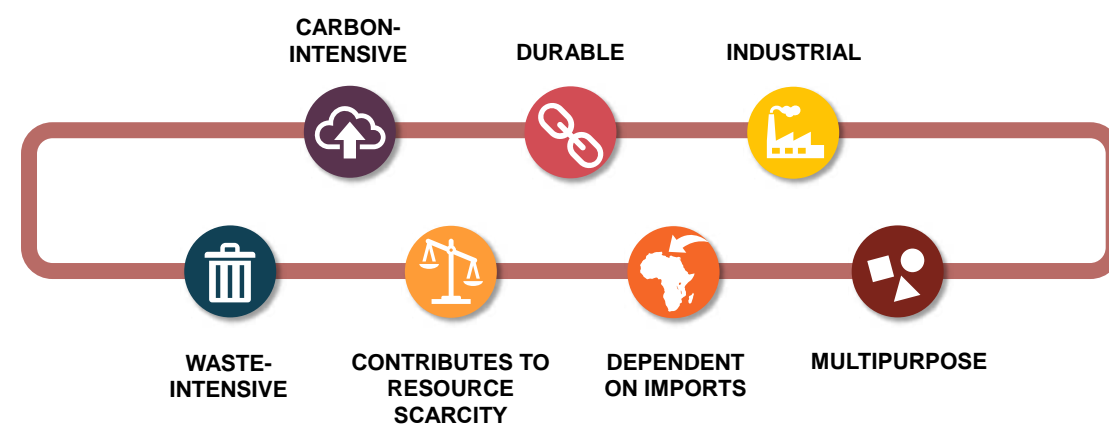
Credit: Pekka Huovila



Industrial mainstream materials

Conventional industrial materials have replaced traditional materials in African cities. Characteristic of these mainstream materials is industrial production, generally high emissions, problematic waste (with the exception of metals), their origin in non-renewable resources, and high levels of importation to Africa. Additionally, these materials are often produced by large enterprises because high initial investments are needed. The production of and construction with these materials require generally higher levels of competence than is needed for traditional construction materials. Conventional materials are highly standardised, which makes their use simple in large-scale formal construction projects. The industrial mainstream materials presented in this section are concrete, concrete blocks, aircrete, modern bricks, metals and inorganic insulation materials.

Concrete



Most of Africa (except South Africa) does not have a long history of using concrete in construction. Concrete was for a long time a material of the northern hemisphere and has thus mainly been optimised for use in Europe, Asia and North America. Most African countries did not start producing cement until as late as the middle of the 20th century. Because of the European colonisation of Africa at the time, most of Africa adopted European standards for concrete. Yet, these standards have been optimised for a completely different geographical region and culture and very little effort has been made to establish national or regional standards in Africa (Schmidt et al., 2013).

Generally, concrete consists of cement, water, sand and aggregates (such as gravel). The price of cement is high in Africa because there are very few cement plants. Senegal is an exception, since the country has domestic cement production (Cheong et al., 2021b); whereas Ghana, for example, has to import around 40–45% of its cement (IEA, 2019a).

The high price of cement motivates the African concrete industry to use as little of the material as possible (Schmidt et al., 2012). In the northern hemisphere, in contrast, the cost of labour is high and the price of cement is generally low. This has optimised the industry to use more cement but minimise the need for labour. Similar optimisation is not favourable for Africa, where the ideal would be a concrete industry that benefits more from labour while minimising the use of cement (Schmidt et al., 2013). Both the price and the environmental impact of cement could be reduced by utilising waste streams or the region's big reserves of natural pozzolans much more efficiently, and more research is needed in this area. Africa has large reserves of limestone, natural pozzolans and gypsum, all of which can be used as binders in concrete. Most of these binder reserves are found in eastern and western rift valleys in Central Africa (Msinjili et



Figure 33: Prefabricated hollowcore concrete slabs
Credit: 115165995 © Oleksandr Shpak | Dreamstime.com



Figure 34: Pouring of concrete
Credit: 50442038 © Bogdan Hoda | Dreamstime.com

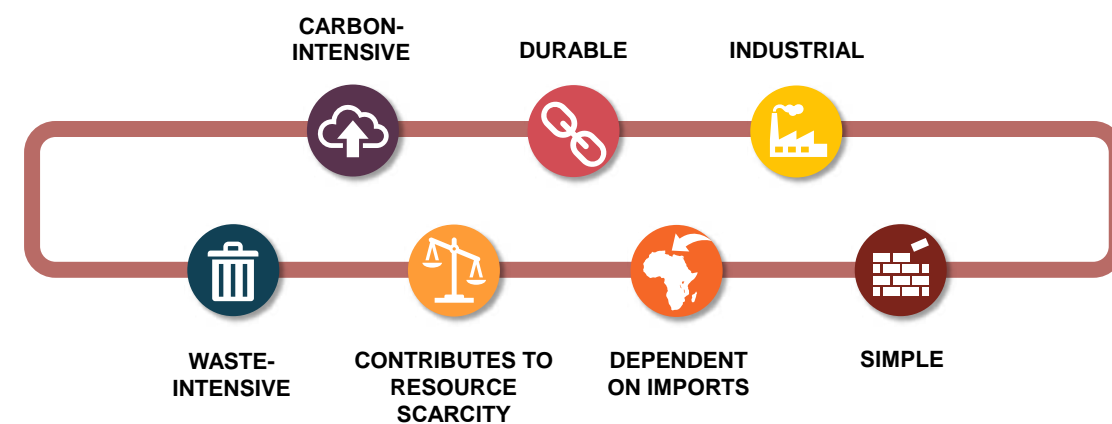


Figure 35: Construction of a concrete framed building
Credit: Pekka Huovila

al., 2013). Using waste streams in concrete would contribute to a more circular built environment; this is further discussed in the section 'Emerging circular materials'.

Much has been written about the negative environmental impacts of concrete, which is the most used construction material in the world. The production of cement, a crucial ingredient in concrete, is carbon-intensive. Cement production causes around 8% of global greenhouse gas emissions (IEA, 2018b). The embodied emissions of African concrete are 195–483 kgCO₂e/m³ (InEnergy, 2010), making them significantly higher than the emissions of most traditional materials. However, in the context of the Global South, at the present time it seems impossible to meet the extremely high need for affordable housing without using concrete (Wray, 2012). Thus, the focus must be on making concrete more environmentally friendly while also reducing its use by combining it with more sustainable materials. It is crucial to rationalise its use and reserve cement and sand for where it is necessary to use them. The aim should be to replace as much of the conventional concrete as possible, where appropriate, with local sustainably and responsibly sourced materials. Such materials include earth, stone, plant fibres and sustainably managed wood. The advantages of these materials are that they are low-carbon; they require no or very little processing; they are locally available, which reduces the need for transport; and they are either renewable or easily accessed and available through recycling. Additionally, they are biodegradable or easily reused or recycled and thus they support the transition from a linear to a circular economy (Pouzaint, 2020).

Concrete blocks



Concrete blocks are among the most common materials used in urban construction in Africa. They can be either solid or hollow. Since concrete blocks are cement-based they have high embodied emissions. These blocks are generally non-load-bearing, meaning that they need to be combined with a separate load-bearing structure. Typically, this structure is made of concrete and steel, which increases the emissions of the structures. Concrete blocks provide neither thermal mass nor insulation, making them poorly suited to hot climates. Thus, buildings constructed with these blocks require either proper insulation or lots of energy for air-conditioning to maintain good thermal comfort. Earth-based alternatives, such as CEB, are locally available materials that can provide better thermal comfort (Hema et al., 2020) with 85-94 % lower emissions (Pouzaint et al., 2020).

Figure 36: Worker on construction site of a building with concrete frame and concrete block infill on the Mauritius coast

Credit: vladvitek / Depositphotos.com



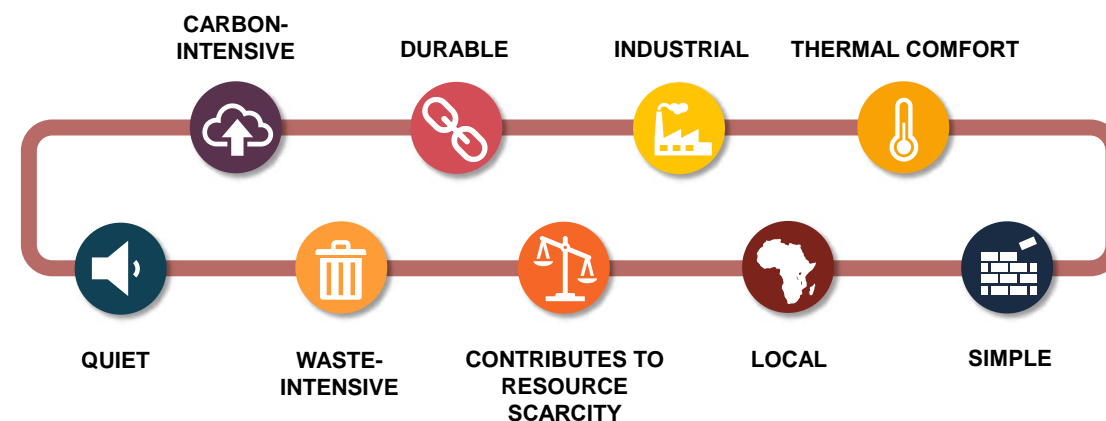
Figure 37: Aircrete block masonry



Figure 38: Installation of wooden roof trusses on an aircrete structure



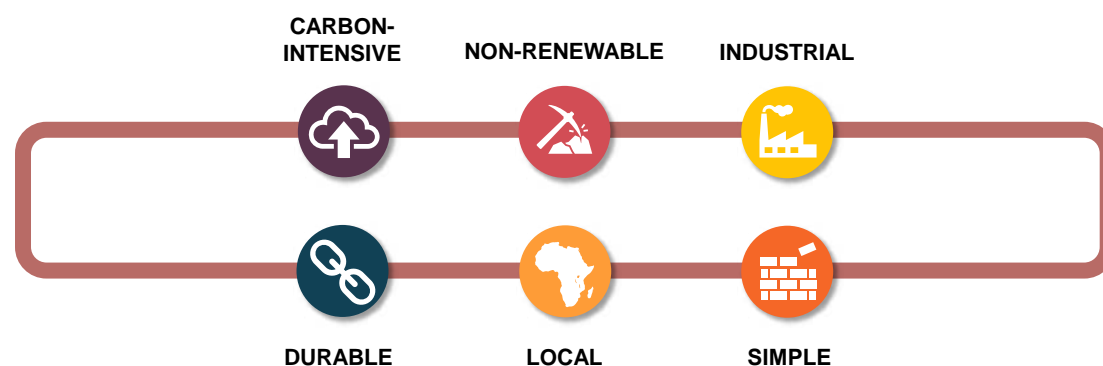
Aircrete



Aircrete, also known as Autoclaved Aerated Concrete (AAC) or cellular concrete, is a light-weight cement-based construction material, usually available as blocks (suitable for vertical structures) or reinforced elements (suitable for vertical and horizontal structures). The production of ordinary non-reinforced aircrete blocks is not dependent on exclusive know-how and the blocks are widely available across Africa (DMI, 2022). Yet the manufacture of reinforced aircrete elements remains a challenge for most producers in Africa (van Boggelen, 2014).

Aircrete contains air pores, which explains its good sound absorption and thermal insulation capabilities. Aircrete is also strong, cost-effective and pest- and fire-resistant. Additionally, the installation of aircrete is fast and easy – the material is easily cut and sanded on site. Aircrete is available in a variety of recipes and densities, and its strength and insulation capabilities are closely linked to the density and recipe used (DMI, 2022). Generally, aircrete consists of cement, lime, gypsum, fine sand and aluminium powder (van Boggelen, 2014). In contrast to concrete, coarse aggregates are not needed in aircrete, resulting in a smaller negative environmental impact.

Modern bricks



Clay is a term generally applied to any very fine-grained plastic mineral raw material and it is the main material in modern fired bricks. There is a big variety of clays used in brick-making and the technical performance and aesthetic of the bricks depend on which type is used. Suitable clays are shapable or mouldable when mixed with water and react and turn into durable ceramic products when fired in a kiln at appropriate temperatures. Modern bricks are moulded, dry-pressed or extruded. Bricks can be joined using mortar or adhesives or by interlocking. The main mortars used today are either cement- or lime-based, while a traditional mortar consisted



Figure 39: Making of modern bricks

Credit: SKAT Rwanda

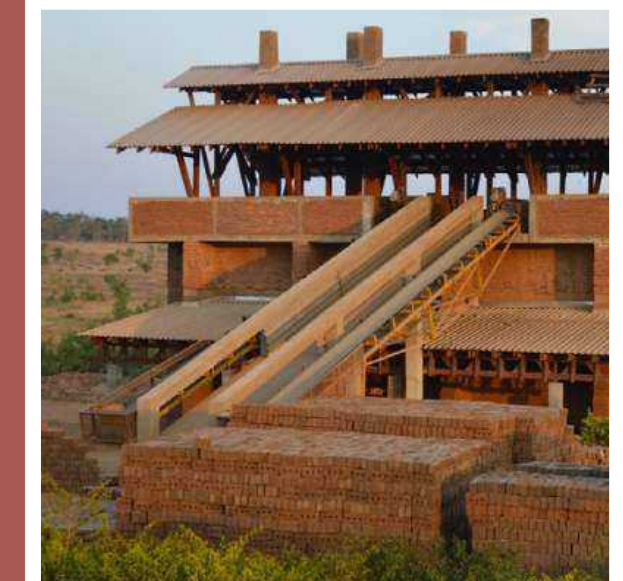


Figure 40: Brick firing kiln

Credit: Dr. Soumen Maity
(Development Alternatives, TARA)

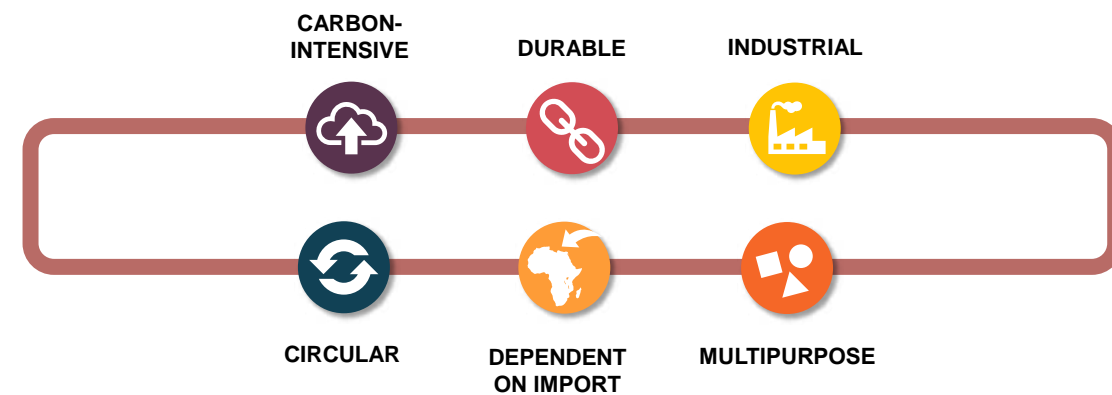


Figure 41: Typical construction with concrete frame and modern brick infill in North Africa

of mud and clay. Lime mortar is softer than cement mortar and allows for more flexibility and easier disassembly, which facilitates reuse.

Fired brick is an old material but the modern kiln-fired brick differs significantly from more traditional country-fired bricks, especially in terms of environmental impacts. The embodied emissions of kiln-fired bricks are around 230 kgCO₂e/m³, whereas the emissions of country-fired bricks are significantly higher, at around 547 kgCO₂e/m³, as a result of inefficient firing. These two fired brick types have in common the raw material used and firing in kilns at hot temperatures. Modern bricks, however, are produced in efficient plants and are generally of higher quality. Improvements in kiln designs and the mechanisation of production have contributed to the mainstreaming of fired bricks. Traditional non-fired bricks generally have much lower emissions since the burning of modern bricks is energy-intensive and often highly polluting, as shown in Table 11.

Metals



Steel and iron play a big role in modern construction. Thus, the demand for these metals has increased threefold since 1970 and today they account for about 95% of the metal produced annually in the world. Demand for these materials is expected to continue growing, especially in developing nations, due to population and GDP growth and increased industrialisation (Kim et al., 2022). The steel industry is underdeveloped in Africa, except South Africa (Globe Newswire, 2021). Therefore, most of the steel in Africa is imported (IEA, 2019b) and the steel industry that does exist in Africa is highly dependent on imported raw materials (Africon, n.d.).

Steel production is energy-intensive – the steel and iron industry consumes approximately 7% of the global energy supply. Additionally, this industry emits 7–9% of global greenhouse gas emissions (Kim et al., 2022). Lowering the environmental impact of this industry is vital for climate change mitigation and for achieving the sustainable use of these materials in the future. Even though the emissions and energy use for steel and iron production are high, in terms of circularity one benefit of most metals is that they are easy to recycle and reuse.



Figure 42: Steel reinforcing bars

Credit: 50442020 © Bogdan Hoda |
Dreamstime.com



Figure 43: Painted steel roof

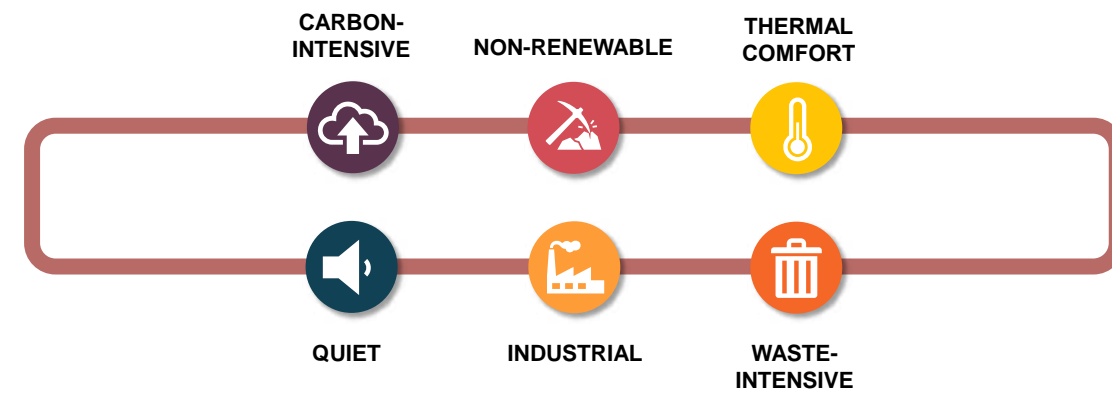
Credit: 173169884 © Jj Van Ginkel
| Dreamstime.com



Figure 44: Steel frame structure
of a house in South Africa

Credit: 54901791 © Falang15555 |
Dreamstime.com

Inorganic insulation materials



Insulation made of mineral wool or synthetic materials has excellent thermal and acoustic performance and is very cost-effective. Therefore, these products account for more than 90% of the building insulation market in Africa (Schiavoni et al., 2016). However, the production of these insulation materials causes high emissions and is highly dependent on the use of non-renewable resources (Asdrubali et al., 2015). Additionally, many of the industrially produced inorganic insulation materials are difficult to recycle or reuse, and therefore end up in landfill (ibid).



Figure 45: Cutting of mineral wool

Credit: 16586782 © Arne9001 |
Dreamstime.com

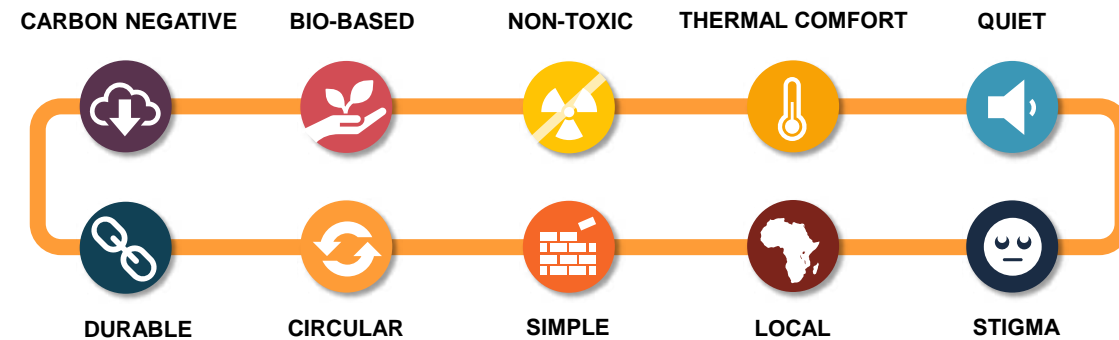


Figure 46: Mineral wool installed
between roof trusses

Emerging circular materials

This section presents new circular materials and more-circular variations of previously discussed industrial materials. The construction materials considered here are either renewable natural materials that can easily be returned to nature or materials that utilise waste or side streams from construction or other industries. The industrial mainstream materials presented in this section are hempcrete, waste-based concrete, straw panels and bales, products utilising recycled plastic, and bio-based insulation materials.

Hempcrete



Hempcrete, also called hemp-lime, is a relatively new material but its use is growing exponentially, especially in Europe. Hempcrete is made by mixing hemp, lime and water and the mixture results in a concrete-like material that weighs a lot less and has much lower embodied emissions than concrete. Hempcrete utilises the hurd, the wood-like part of the hemp plant, which is a by-product of the hemp fibre industry that is typically considered waste. Hempcrete is a circular material because it utilises waste streams, is bio-based and has low emissions, and crushed hempcrete can easily be used to make new hempcrete.

Hempcrete can be used to make different kinds of blocks, panels and elements. It can also be used as stucco to protect outdoor walls. The properties of hempcrete vary depending on the ratios of the ingredients used in the mixture and many recipes are in use today. Some hempcrete mixtures perform well as roof, wall or slab insulation. The thermal properties of hempcrete are extraordinary. It provides thermal mass and works well as insulation. It is a good insulator because of the air trapped inside the material, both in spaces between hemp shiv pieces and in microscopic pores within the hemp. Hempcrete is also completely toxin-free and breathable.

Moreover, a clear benefit of using hempcrete is that it is considered carbon-negative. It is both a carbon sink and a carbon storage – hempcrete carbonates because of the lime and carbon is stored in the hemp (Arrigoni et al., 2017). The emissions and storage capacity depend on the mixture used for the hempcrete, but the average emission is 194 kgCO₂e/m³ and average storage capacity is -301 kgCO₂e/m³ (Arrigoni et al., 2017). In other words, in general it stores much more carbon than it emits.

Its low negative environmental impact, together with its good ability to regulate moisture, relative humidity and heat (Jami et al., 2019), makes hempcrete a material well suited to massive structures. Hempcrete blocks are easy to install, making them ideal infill in frame-structured walls. Traditional hempcrete is not load-bearing and thus needs to be combined with a supporting structure, of wood, concrete or steel, for example.

The mainstreaming of hempcrete is being hindered by the stigma and legislation that prohibits or complicates hemp cultivation or the marketing of hempcrete. The industrial cultivation of hemp was prohibited in South Africa until 2021, when it was declared to be an agricultural crop (South African Government, 2021). Prior to that, South African law did not differentiate between



Figure 47: Hemp hurd

Credit: 97940121 © Notwishinganymore | Dreamstime.com



Figure 48: Spray-applied hempcrete in timber frame wall

Credit: 83442825 © Leonardo Briganti | Dreamstime.com



Figure 49: Hempcrete construction

Credit: 125403095 © Notwishinganymore | Dreamstime.com

hemp and marijuana, which is still classified as a narcotic (Goliath, 2021). Today, besides South Africa, only 11 African countries permit the industrial cultivation of hemp, including Ethiopia, Ghana, Malawi, Morocco and Rwanda (Kasuto, 2022). Legislative changes are needed to scale up the production of hempcrete. Mainstreaming hempcrete would create local jobs and hempcrete could be used to replace materials that contribute to a linear economy.

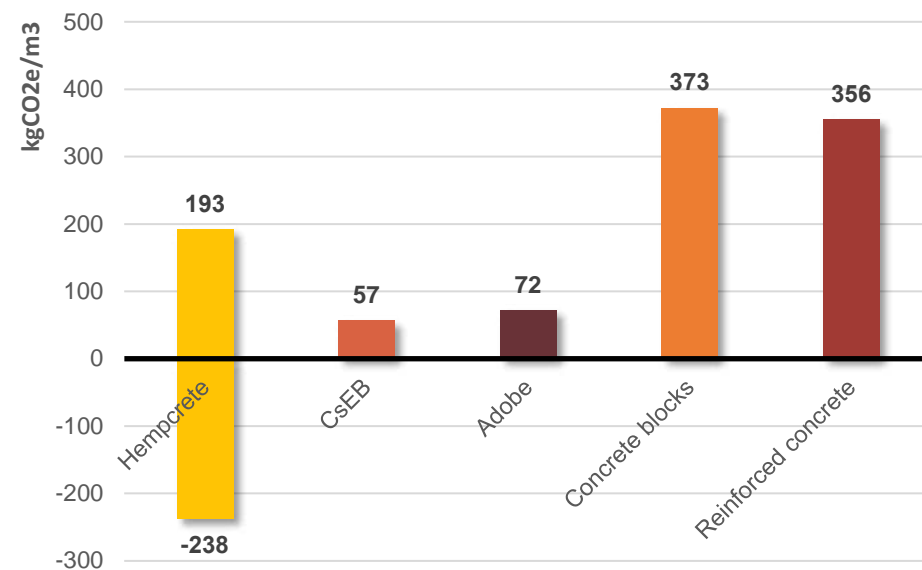
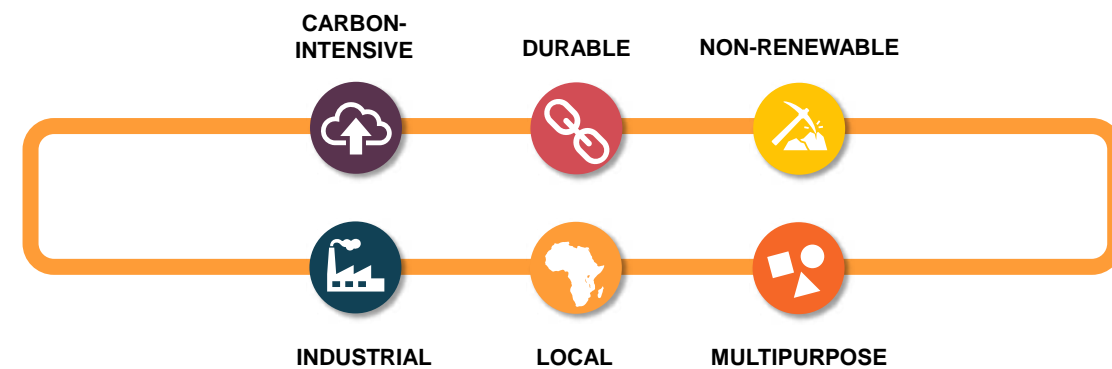


Table 14: Embodied emissions and carbon storage of 1 m³ hempcrete, CsEB, adobe, concrete blocks and reinforced concrete

Source: Arrigoni et al. (2017) [hempcrete]; Ávila et al., 2021 [adobe]; Dabaieh et al., 2020 [bricks]; InEnergy, 2010 [concrete]; Pouzaint et al., 2020 [CEB, concrete blocks] and UNIDO (2015) [CsEB]

Waste-based concrete



Conventional concrete is problematic from a sustainability point of view because it is carbon-intensive and linear. Today, there are more circular concrete options on the market and in the research and development stage and replacing conventional concrete with these or even more sustainable options is highly recommended.

A study in Tanzania concluded that a significant amount of the nation's CDW could be used to make new concrete blocks (Sabai et al., 2016). South Africa has seen the big potential of using waste streams such as fly-ash and slag as aggregates in construction and their use is on the rise (Department of Environmental Affairs, 2012).

Research shows promising results with regard to bio-based concrete that uses agricultural waste commonly found in Africa, namely cassava husks (BAM, n.d.; Oladipo et al., 2013).



Figure 50: Cassava, cassava peel, cassava peel ash and cassava concrete

Credit: Illustration by author



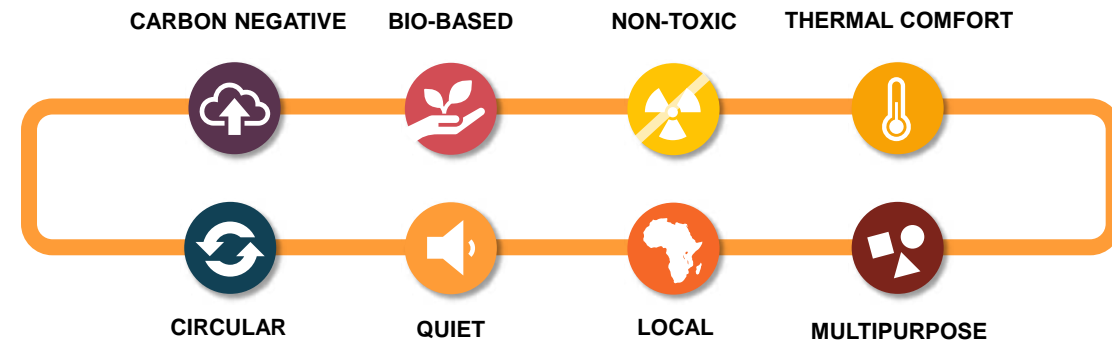
Figure 51: Recycling concrete waste



Figure 52: Blast furnace slag aggregates, a by-product from the iron and steel industry that can be used to replace cement

The cassava plant is one of the most popular food crops grown in Africa and thus there is a local and constant supply of cassava husks. Cassava husks contain both silica and alumina, which makes *cassava peel ash* an affordable, sustainable and circular substitute for cement in concrete. The demand caused by this use of cassava husks is benefiting local farmers and is expected to exceed the supply in the future (Oladipo et al., 2013).

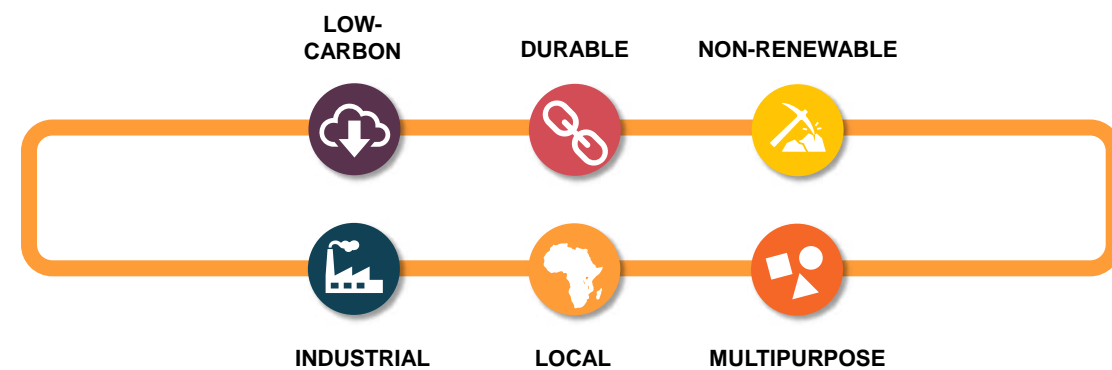
Straw panels and bales



Straw has traditionally been used in construction in Africa. However, newly developed straw panels increase the opportunities to use straw in the built environment. These prefabricated panels consist of renewable low-carbon materials, namely, compressed and thermally combusted straw wrapped in recycled paper. No chemical additives are needed to produce these panels. The final product has a carbon footprint that is nearly zero. Additionally, these panels allow for fast and easy assembly, which leads to time and cost savings. Straw panels also work well as both sound and thermal insulation.

In addition to the uses mentioned above, straw is the main material used in strawbale construction – a construction technique where individual strawbales are stacked to form walls. This technique is old in many parts of the world but new to Africa. Strawbales can be used as load-bearing structures in vertical loads or as infill in frame structures (both vertical and horizontal). Frame structures with strawbale infill can easily be prefabricated off site, which reduces the risk of fire on site caused by loose straw. Strawbales are not left exposed – they are either coated or covered. No binders are necessary for strawbale construction. Besides these benefits, strawbale walls have good sound and temperature insulation properties. Out of the insulation materials available in Africa, straw has the lowest environmental impact. However, the insulation qualities and physical strength of strawbales are highly dependent on their density.

Products utilising recycled plastic



Plastic waste is a big problem in Africa. New enterprises utilising plastic waste streams have started turning plastic waste into building products in Africa. Recycled plastic is turned into bricks, blocks, tiles and boards, among other building materials. Kenyan company Ecopost, which produces a plastic-based alternative to wood, has created more than 300 local jobs and



Figure 53: Compressed straw panel

Credit: Strawtec Building Solutions



Figure 54: Strawbale construction

Credit: 258007758 © Pojoslaw | Dreamstime.com

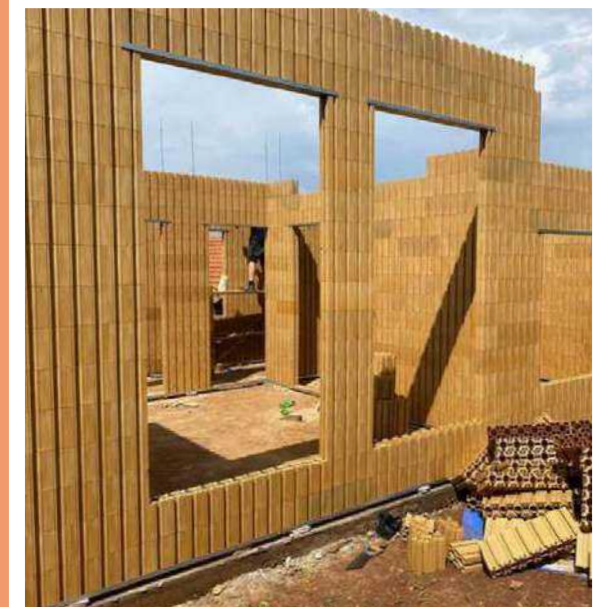
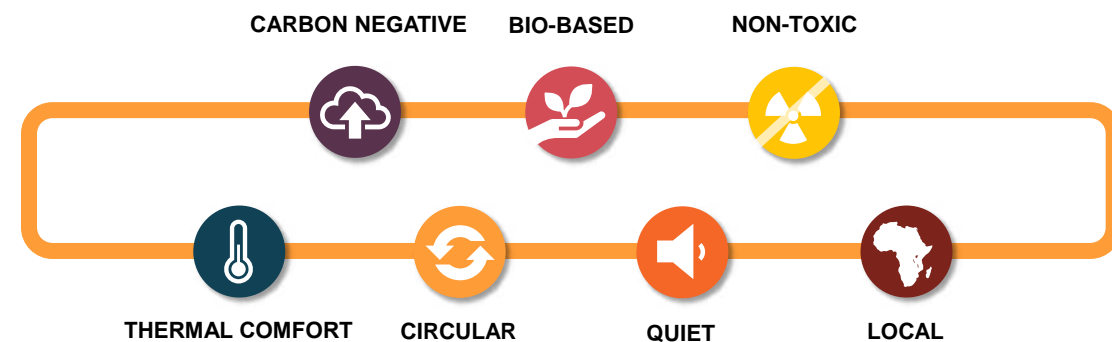


Figure 55: Construction with Block Solutions

Credit: Block Solutions

avoided the deforestation of around 100 hectares of forest, while using more than 1 million kg of waste plastic (Lionesses of Africa, 2019). Plastic waste can also be combined with natural fibres and turned into bio-composites. Lightweight bio-composite blocks can be used as load-bearing structures for construction in a way that allows for easy assembly, disassembly and reassembly (Block Solutions n.d.).

Bio-based insulation materials



Even though the most commonly used insulation material in Africa is mineral wool, there are other more sustainable bio-based options on the market. Conventional bio-based insulation materials are cellulose and wood fibre. Besides these, cork, straw, hemp, sheep wool and the fibres of flax, kenaf, coir, jute and many others, can be used for insulation (Schiavoni et al., 2016). What all of these have in common, if they are locally harvested, is low embodied emissions. Generally, these materials have a small carbon footprint while they also store carbon, which makes most of them carbon-negative, as presented in Table 15 (Magwood et al., 2022). They are also all renewable and circular. They are generally easily reused, recycled or composted (although the composting depends on the chemicals used). Additionally, the production of some of these materials, such as wood fibre and coir, typically utilises waste streams (Schiavoni et al., 2016). As shown in Table 16, many of the bio-based insulation materials are competitive with mainstream insulation materials when it comes to their insulation properties. However, most of the bio-based materials need additional fireproofing, especially in densely populated areas.

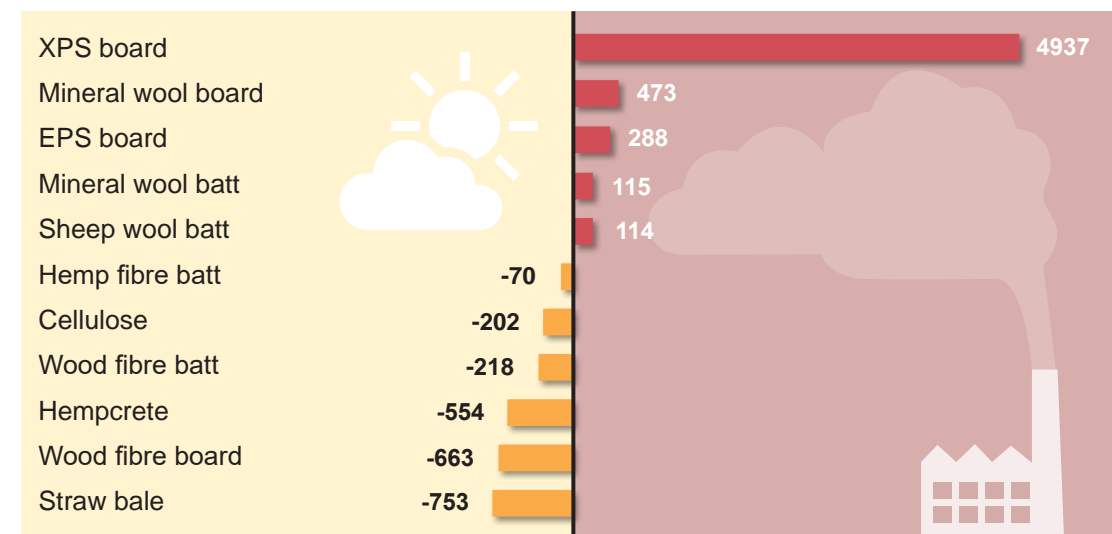


Table 15: Range of net emissions (kgCO₂e) for 100 m² (R-value = 5) of different insulation materials

Source: Magwood et al. (2022)



Figure 56: Compressed thermal hemp fibre insulation

bio-based

Material	Density (kg/m ³)	Thermal conductivity (W/m K)	Specific heat (kJ/kg K)	Fire classification	Water vapour diffusion resistance factor, μ-value
Cellulose	30-80	0,037-0,042	1,3-1,6	B-C-E	1,7-3
Cork	110-170	0,037-0,050	1,5-1,7	E	5-30
Wood fibre	50-270	0,038-0,050	1,9-2,1	E	1-5
Hemp fibre	20-90	0,038-0,060	1,6-1,7	E	1-2
Kenaf fibre	30-180	0,034-0,043	1,6-1,7	D-E	1,2-2
Flax fibre	20-100	0,038-0,075	1,4-1,6	E	1-2
Sheep wool	10-25	0,038-0,054	1,3-1,7	E	1-3
Coir fibre	75-125	0,040-0,045	1,3-1,6	D-E	5-30
Jute fibre	35-100	0,038-0,055	2,3	E	1-3
Stone wool	40-200	0,033-0,040	0,8-1	A1-A2-B	1-1,3
Glass wool	15-75	0,031-0,037	0,9-1	A1-A2	1-1,1
EPS	15-35	0,031-0,040	1,25	E	20-70

Table 16: Properties of different insulation materials

Source: Schiavoni et al. (2016)

Windows and doors

Windows and doors that are available in African countries may be made of aluminium, PVC, timber, glass or steel. Where there is limited local manufacturing capability, these components may be imported. However, in most African countries some local small-scale manufacturers produce timber windows and doors. Wooden windows and doors generally have lower embodied emissions than other options on the market. These timber products can support circularity if they are sourced from local sustainably managed forests. As well as being managed and manufactured locally, these components can also be repaired and maintained locally, creating jobs and supporting small businesses. Careful product design and architectural detailing can ensure that timber doors and windows achieve appropriate performance standards and have a long service life. They can also be readily reused in other buildings where this is necessary.

Furniture and fittings

Furniture and fittings made of aluminium and steel, timber, textile and plastic-based materials are generally available in African countries, although a limited local manufacturing base often means that many of these products are imported. However, there are local manufacturers who produce furniture and fittings made from local materials such as timber, bamboo, rattan, natural fibres and leather. Circularity can be supported if locally manufactured furniture and fittings based on sustainably grown or extracted raw materials are specified and used. Local manufacture increases the potential for products to be maintained, repaired and kept in use for longer. It also has direct social and economic benefits through the creation of local jobs and SMEs. These benefits can be enhanced by business models in which the manufacturer remains the owner and generates revenue from providing a 'furniture and fittings service'. Components can be designed as modular and easy to fit, remove and upgrade. This allows components such as kitchen units, and elements within them like handles and doors, to be easily replaced, thereby avoiding waste. Having the manufacturer responsible for repairs and maintenance, as well as for changing and upgrading furniture and fittings, avoids waste and helps extend the service life of products (Stijn et al., 2020).



Figure 57: Timber window and door with a wooden structure to provide shading

Credit: 101713369 © Glenn Nagel | Dreamstime.com

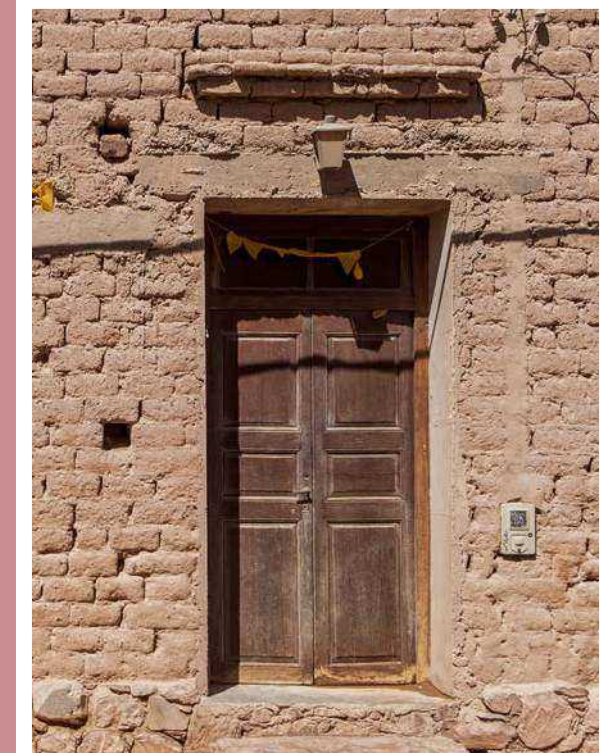


Figure 58: Adobe brick wall with timber door

Credit: 139161981 © Marcelmaaktfotoos | Dreamstime.com

Table 17: Evaluating the potential of construction materials

Evaluating the environmental, social and economic impacts of different construction materials, how they can be used and whether the manufacture of them can be quickly upscaled to respond to the rapidly growing need of construction materials

Material	Efficient use of resources	Low embodied emissions	Regenerating natural systems	Renewable	Long service life	Affordability	Locally produced	New local jobs created	New SMEs created	Fast scalability	Positive impact
Rammed earth	●	●	-	-	●	●	●	●	●	○	7
Adobe	●	●	-	-	●	●	●	●	●	●	8
CEB	●	●	-	-	●	●	●	●	●	●	8
CsEB	●	●	-	-	●	●	●	●	●	●	8
Full sun-dried bricks	●	●	-	-	●	●	●	●	●	●	8
Hollow sun-dried bricks	●	●	-	-	●	●	●	●	●	●	8
Country-fired bricks	○	-	-	-	●	●	●	●	●	●	6
Stone	●	●	-	-	●	-	●	●	●	-	6
Wood	●	●	●	●	○	●	●	●	●	●	8
Bamboo	●	●	●	●	○	●	○	●	●	-	6
Straw	●	●	●	●	○	●	●	●	●	○	7
Concrete	-	-	-	-	●	○	○	○	-	●	2
Concrete blocks	-	-	-	-	●	○	○	○	●	●	3
Aircrete	-	○	-	-	●	○	○	●	-	●	3
Modern fired bricks	○	-	-	-	●	●	●	●	●	●	6
Steel	●	-	-	-	●	-	○	○	○	●	3
Aluminium	●	-	-	-	●	-	-	-	-	-	2
Glass	●	○	-	-	●	●	●	●	○	●	6
Hempcrete	●	●	○	○	●	●	○	●	●	●	7
Waste-based concrete	○	○	-	○	●	○	○	●	-	○	4
Straw panels	●	●	●	●	○	●	○	●	○	○	5
Recycled plastic products	○	○	-	-	○	○	○	●	●	○	2
Wood windows/doors	●	●	●	○	○	●	●	●	●	●	8
PVC windows/doors	-	-	-	-	○	○	○	○	-	○	0
Aluminium windows/doors	●	-	-	-	●	○	○	○	●	●	4

Foundations	Floors	Load-bearing walls	Intermediate walls	Infill	Insulation	Facade	Roof	Windows	Doors
		●	●	●		●			
		●	●	●		●			
		●	●	●		●			
		●	●	●		●			
		●	●	●		●			
●	●	●	●	●		●			
	●	●		●	●	●	●	●	●
	●	●	●	●		●		●	●
		●	●	●		●			
●	●	●	●	●		●			
		●	●	●		●			
●	●	●	●	●		●			
			●	●	●	●			
				●	●				
	●	●	●	●		●			
				●	●				
		●	●	●		●	●		
								●	●
								●	●
								●	●

Evaluation explained

Icons -, ○, and ● stand for ‘not at all’, ‘to some extent’, and ‘definitely’

These are explained in greater detail below:

Efficient use of resources

- Easy to recycle and does not create problematic waste
- Possible to recycle under some circumstances
- Difficult to recycle or dispose of at the end of life

Low embodied emissions

- Production of the material produces very little emissions
- Production of the material produces moderate amount of emissions
- Production of the material produces very high emissions

Regenerating natural systems

- Consists mainly of renewable resources that enhance natural systems
- Consists partly of renewable resources that enhance natural systems
- Not renewable

Long service life

- Lasts long when used in the right way and requires very little or no maintenance
- Needs regular maintenance to last long
- Short lifespan and difficult to repair/replace

Affordability

- Cheaper than mainstream solution
- Cost of mainstream solution
- More expensive than mainstream solution

Locally produced

- Locally produced
- Contains locally produced materials
- Imported

Local jobs created

- Majority of work related to production is local
- Some of the work related to production is local
- None of the work related to production is local

Local SMEs created

- Easily produced by small local enterprise, does not require much capital, expertise or equipment
- Possible to produce by small local enterprise, does not require much capital, expertise or equipment
- Cannot be produced locally or requires much capital, expertise or equipment

Scalability

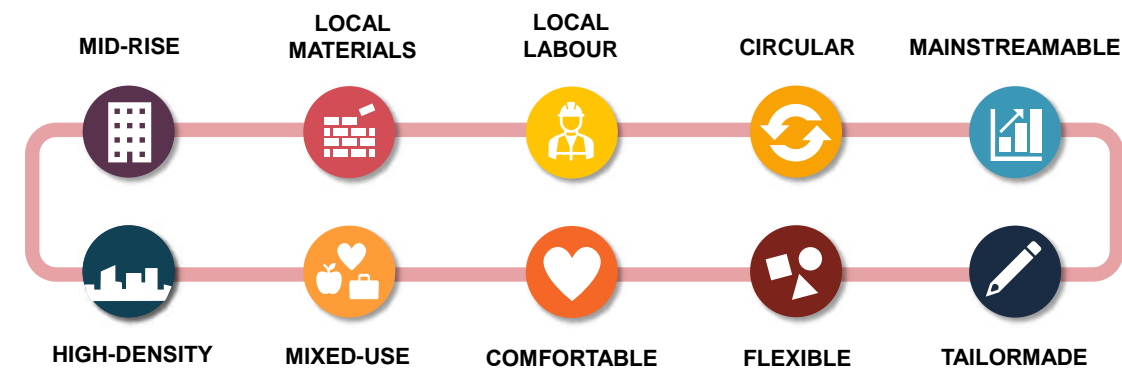
- Fast to scale up local production. Needed industry and expertise already exists or can be easily attained
- Possible to scale up production locally but requires new expertise and significant investment capital
- Cannot be scaled up locally to volumes that significantly impact local market

SCALABLE CONCEPT FOR CITIES

Circular construction can play a key role in advancing economic growth in Africa. For the transition from a linear to a circular economy to be successful, it must be tailored to fit the African context. Most of the population growth happens in urban areas because of the high urbanisation rate in many African countries. The rapid growth of its cities provides Africa with the potential to leapfrog mainstream linear practices and move directly to the adaptation of sustainable circular solutions. This could lead to substantial positive environmental impacts through reduced waste, pollution and emissions while providing beneficial social and economic impacts such as increased innovation and the creation of new jobs.

4.

Key points



Urban form matters

Urban form is defined 'as the physical structure and organisation of cities' (Yenice and Ciftci, 2018). Urban density (including residential, commercial, industrial and institutional) is an essential part of the urban form. Much research has been carried out on the sustainability impacts of urban form. The predominant conclusion of this research is that compactness is the key to sustainable urban development. High density and diversity, a mix of uses, and avoidance of urban sprawl are characteristics of a sustainable city (UN-Habitat, 2015; Yenice and Ciftci, 2018). Compact mixed-use neighbourhoods reduce the need to travel by designing buildings with a range of functions.

The same densities can be achieved with different building heights and typologies, as presented in Figure 59. Especially interesting is the comparison between Macao and Paris, two cities with almost the same density but completely different urban forms. Macao has an average of 28 high-rise buildings per km² while Paris only has 4 per km² (Emporis, n.d.). The urban forms of African cities are not well documented. However, Africa is the region in the world that is experiencing the fastest rates of urban sprawl – something often linked to dysfunctional urban form because of low-density and single-use development.

How tall is sustainable?

Although dense urban construction is desirable from a sustainability point of view, this density should not be achieved with excessively tall buildings. No optimal height has been set for sustainable buildings, but research shows that high-rise buildings in general use more energy and materials per built square metre than mid-rise buildings (Ronald, 2008).

The urban form of downtown Paris, which is dense, mixed-use and mainly consists of mid-rise buildings, is often seen as the ideal. It is an example of efficient land use but also of a highly socially integrating environment (Ronald, 2008). An African city that somewhat resembles the urban form of Paris is downtown Cairo. Some districts in Cairo, formal and informal ones, reach densities that are even higher than that found in Paris. Additionally, the old districts of downtown Cairo are mainly mid-rise and mixed-use.

Sustainable high-density urban living

Going forward, with enormous population and consumption growth, resource depletion, climate change and biodiversity loss, it is clear that energy consumption and materials efficiency will have a significant effect on the kinds of buildings we should or can build. Considering the research drawn on in this publication, there is an urgent need to develop sustainable ways to

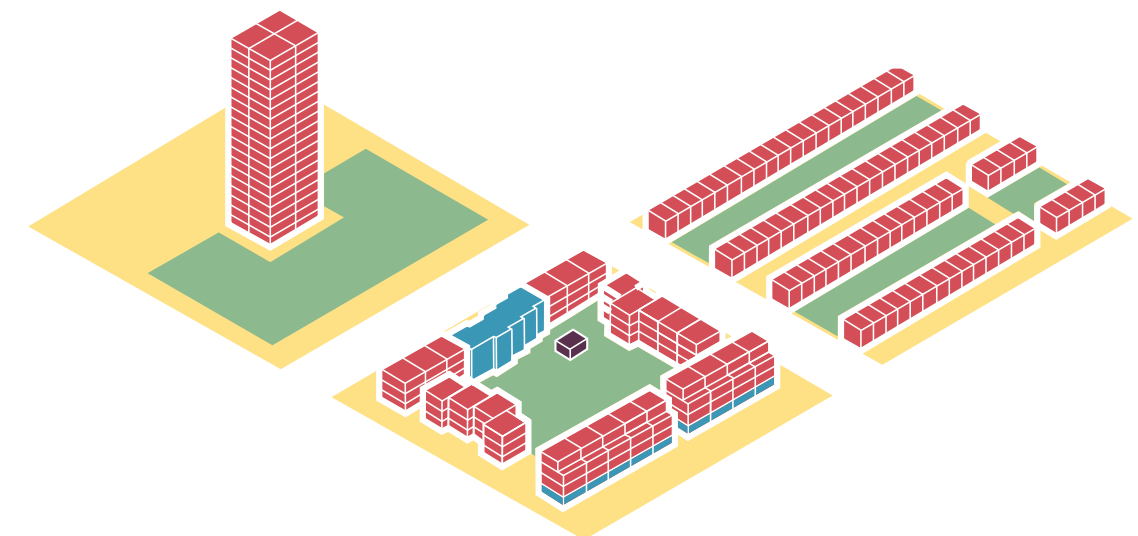


Figure 59: Same population density can be achieved with different building typologies but mid-rise construction easily fits more than just housing

Credit: Andrew Wright Associates, edited by the author



Figure 60: Paris, Macao and Downtown Cairo

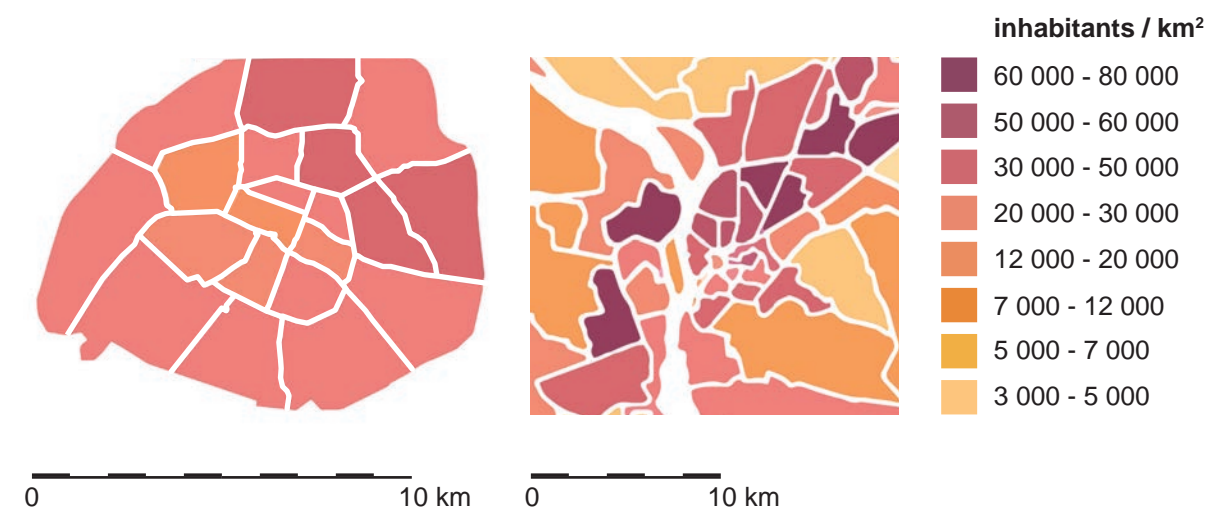


Figure 61: Densities of districts in Paris and Cairo

Source: (Recherche et al., 2017; Wikimedia Commons, n.d.)

build mixed-use mid-rise buildings that are suitable for rapidly urbanising Africa. Planning the scale and adaptability of buildings is also crucial since the positive effects this has on sustainability extends further than individual buildings alone. Hence, this section presents a concept that outlines how to utilise local sustainable materials in adaptable mid-rise construction in a way that brings environmental, economic and social benefits simultaneously.

Reintroducing local materials

This new concept presented here for a multi-storey building utilises existing modern technology and knowledge as a basis since the aim is to develop a concept that can be mainstreamed as quickly as possible. The need for change in Africa is urgent because of the vast environmental impacts of construction together with the rapid population growth in cities.

In the proposed concept, all materials that are typically imported or have high emissions are replaced by local sustainable materials wherever appropriate – meaning that structural integrity or comfort are not compromised. The materials that have been chosen are those that were found to perform well in the impact analysis in the previous chapter. The concept developed for multi-storey construction is flexible – the size and division may vary, as may the functions within the building. This concept represents an alternative way to construct buildings that has a much better impact on the environment and the local economy and society than conventional modern construction. In the selection of the material palette for the concept, priority is given to fast scalability, circularity, energy and material efficiency, low-carbon impacts, affordability, and location of materials and labour.

Promoting local materials and labour

A large number of people in African cities live in informal settlements because of the lack of affordable formal alternatives. The variety of construction found in informal neighbourhoods is high. In Cairo, the most commonly found informal neighbourhood is high-density and mainly mid-rise but even tall buildings occur. The main materials used are reinforced concrete and burned bricks. A problem with these buildings is that the construction quality might be poor because it is not regulated or checked, which makes some of these buildings unsafe. From time to time, these buildings collapse and lives are lost (Howeidy et al., 2009).

To address the issues around safety and alleviate the pressure for housing, the framework we suggest consists of a formal industrial lightweight load-bearing structure that is built according to minimum safety standards. Building services like plumbing, drainage, hygiene and sanitation systems, wiring, and sustainable energy supply are delivered by skilled labour of established building companies to ensure safety and adequate access to water and energy. These building services are located so that they are easily accessed and maintained, as presented in Figure 63.

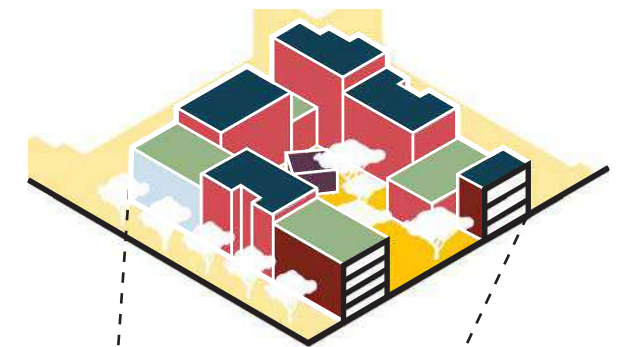


Figure 62: Dense pedestrian-friendly diverse mixed-use city with active ground floors and cozy courtyards

Credit: Illustrations by author

Once the framework and essential services have been completed, the building can be finalised in different ways. The remaining work can be divided into smaller packages. Dividing the work makes it easier to use sustainable materials produced by local small manufacturers and helps small contractors access work. In this case, units are finalised before being handed over to end users. Alternatively, the end users could be allowed to finalise the building. In both cases, the builders are provided with guidance on how to finalise the units using sustainable local materials. These materials are not necessarily standardised, available in high quality in terms of strength or available in large enough quantities to interest big developers. These three qualities typically limit the formal use of such materials in large projects.

The building material guidelines and main architectural principles included in the proposed concept can also be adopted by big building contractors in a way that they provide completed buildings. However, in this case, economic sustainability needs to be considered with extra care – the built spaces, regardless of their purpose, need to be affordable to poor people.

Thermal comfort

The importance of energy efficiency in buildings is increasing in line with the growing need for cooling in Africa. Because of the region's high poverty rate, it is not sustainable to design buildings the operation of which is energy- and emission-intensive or reliant on investment in expensive air-conditioning to maintain thermal comfort. Thus, passive and biomimetic solutions are preferred. Furthermore, the demand for insulation is expected to grow in the region, as the insulation level of new construction is currently low. However, focusing only on well-insulated structures is not the answer. The addition of insulation without attention to thermal mass often causes extra costs and reduces thermal comfort. Therefore, the combination of thermal mass and insulation is often required for cost, comfort and energy efficiency (Hema et al., 2020; Kumirai and Conradie, 2012).

The concept in greater detail

1. Structural frame: Other than the site, the structural frame is usually the most permanent aspect of a building and is unlikely to be altered unless the building is demolished (Velenturf and Purnell, 2021). It is therefore important that the vertical dimensions, such as floor-to-ceiling heights, and the horizontal dimensions between structural elements, such as columns, provide high levels of flexibility and adaptability and enable a wide range of functions to be accommodated, including potential changes from residential to commercial activities, and vice-versa. The load-bearing structure should be constructed of circular materials, such as timber from local sustainably managed forests; but where this is not available or suitable, the structural frame may be made of concrete or steel. If concrete or steel is used, the structure should be resource and energy efficient, the embodied emissions should be as small as possible and the use of secondary raw materials as high as possible. The structure should also be designed so that it can be disassembled, and elements reused, in case the building reaches the end of its useful life.

2. Infill – exterior walls: Walls play an important role in environmental control and should be specified and designed to respond to the activities undertaken in the building and local climatic conditions. Passive environmental control strategies such as cross-ventilation, night-time cooling and control of direct solar gain create comfort without requiring energy and can be supported through the design of suitable openings and the specification of wall materials with appropriate thermal performance. Research shows that thermal comfort can be improved by replacing conventionally used concrete blocks with low-carbon materials such as CEB (Hema et al., 2020). Massive earth-based walls can without insulation perform better than conven-

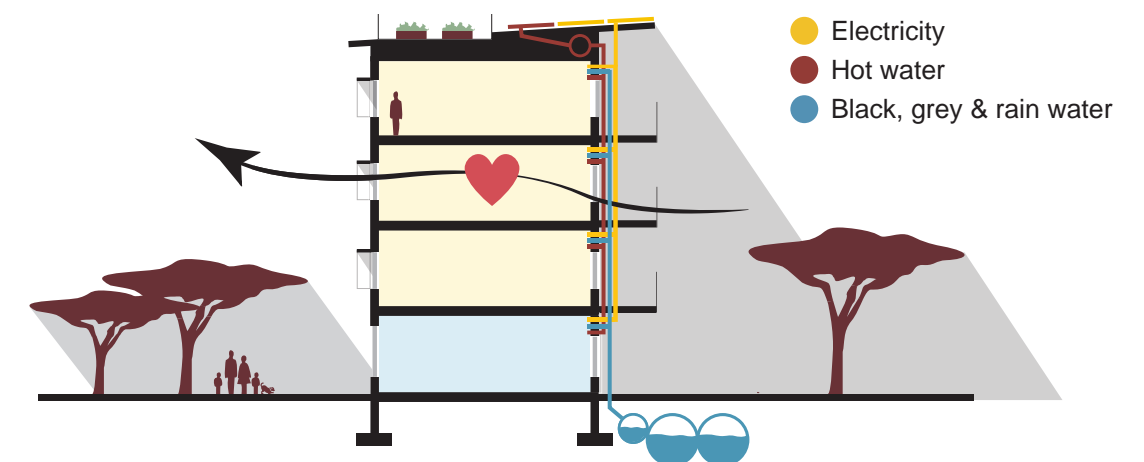


Figure 63: Section showing the solutions for solar control, natural ventilation, electricity, hot water and black, grey and rain water system. Vertical pipes and wires are placed in shafts along the facade so that they can be easily accessed and maintained from the passageways

Credit: Adapted from Gibberd (2019), illustration by the author

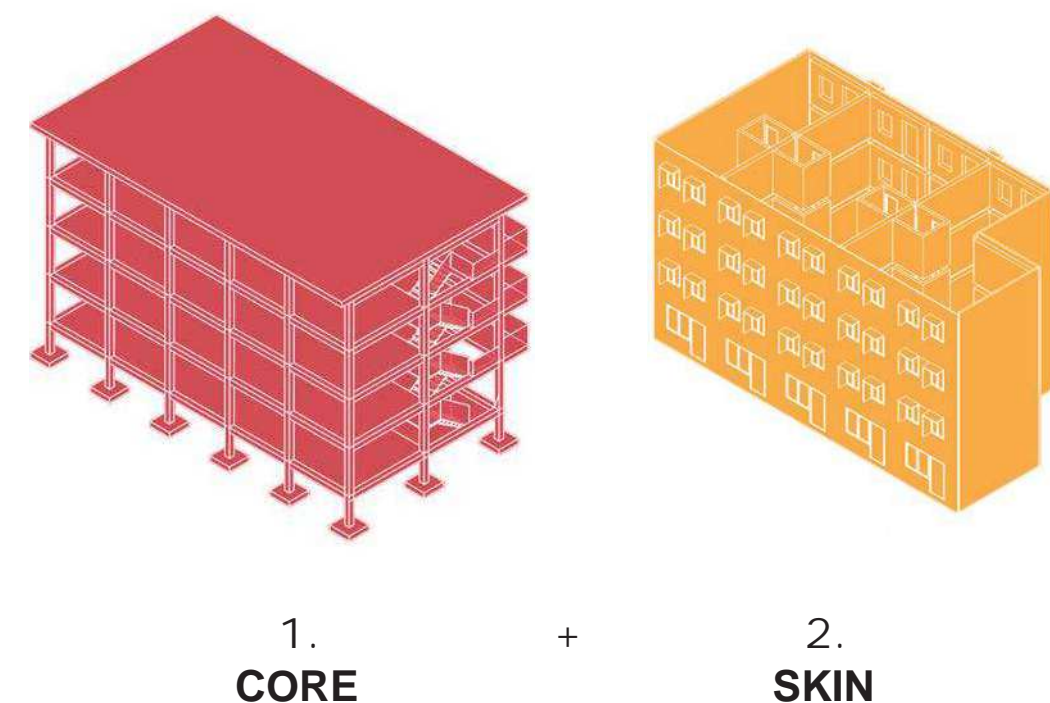


Figure 64: The conceptual building consists of an industrial core and a less formal skin. The load-bearing core is built according to standards by skilled workers, making it easier to build the skin with local circular materials with unskilled labour

Credit: Illustration by the author

tional concrete blocks in terms of thermal properties because of their thermal mass. CEB and adobe are local and affordable low-tech materials that are well suited for use as infill in exterior walls. If these materials are unstabilised but reinforced with natural fibres, they are also completely circular.

Thermal comfort can be increased by an additional insulation layer. The appropriate location of the insulation is highly dependent on the climate and occupancy period of the rooms. In hot climates, the insulation layer should be placed on the exterior side if spaces are in use during the day and on the interior side if spaces are used at night (Hema et al., 2020). If using insulation, lightweight bio-based alternatives should be favoured because of their low negative environmental impact.

Sustainably achieving high thermal comfort is even easier with hempcrete than CEB or adobe, since hempcrete has good thermal insulation properties and provides thermal mass. Hempcrete works well as a massive structure and does not need additional insulation. In African countries, hempcrete is not as accessible or widely available in comparison to earth-based solutions, but where it is available, it is a good choice of material.

Exterior surfaces can be exposed if the quality of the infill material is good enough to withstand local weather conditions. If applying internal finishes, they should be done with the following in mind: they generally receive considerable wear and tear and may need to be modified for changes in use or to access services such as electricity, water and ICT. Therefore, this element should be designed and built to minimise maintenance requirements and accommodate change without waste. Where the infill material is not left exposed, potential internal finishes include plasters, non-toxic paints, straw panels, plasterboard and timber panelling.

3. Façade: If the bricks or blocks used as infill are not left untreated on the exterior side, non-toxic paints, plasters or wooden planks are affordable options for the façade that can be locally produced from local raw materials. Regardless of the façade material, the façade should be designed to minimise maintenance requirements and accommodate change without waste. When the users of the building finalise their units on their own or in small clusters, they can bring liveliness and personality to a building's façades since façade materials, treatments and openings can vary between units, as seen in Figure 67.

4. Windows and doors: Glazing can be one of the most expensive elements of a building envelope. It is therefore important that glazing is chosen that can achieve a long service life. Glazing and windows should be carefully designed to enable users to manage their thermal comfort by, for instance, opening windows to support cooling and allowing the adjustment of shading devices to reduce solar gain. Sustainably farmed timber is a suitable circular material for window, glazing and door frames in many situations, but designers should ensure that any exposed timber elements can be accessed for maintenance and repair. Windows and doors can also be reused and such second-hand items can be accessed fairly easily in some African countries.

5. Solar control: Solar controls and shading devices can play an important role in mediating between harsh external weather and comfortable internal conditions. These devices should therefore be designed with an understanding of local conditions and so that they respond dynamically as the conditions change. For instance, shutters may be closed during dust storm conditions and shading may be engaged in the late afternoon to shield the interior from a hot, low-angled sun. Timber or other renewable local materials can be used for these devices and will often enhance the aesthetic appearance of buildings as they age naturally. However, access should be provided to ensure that maintenance, repairs and eventual replacement of these elements are supported.

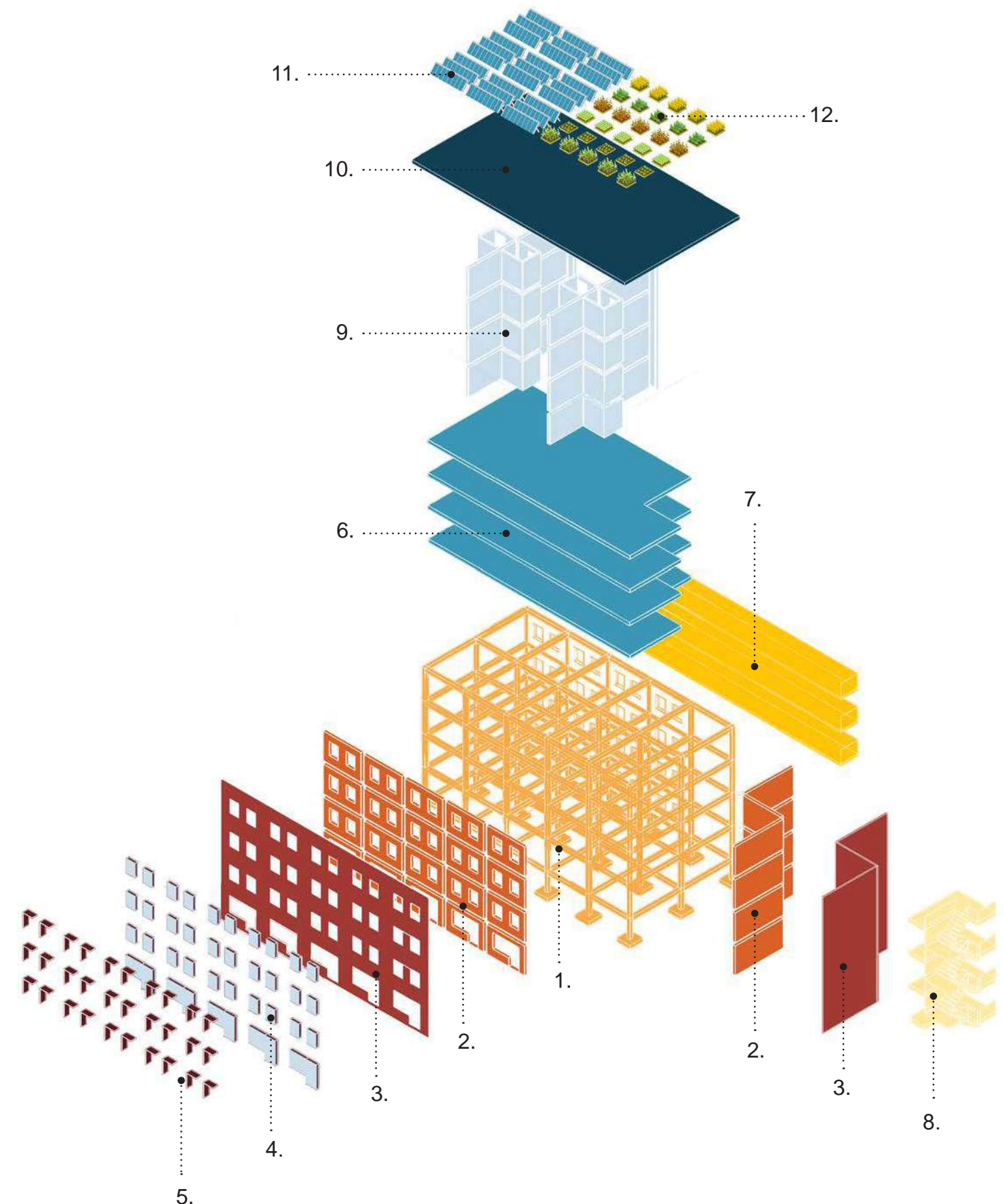


Figure 65: Exploded axonometric presentation of the building parts
The numbered layers are explained in the section 'The concept in greater detail'

Credit: Illustration by the author

6. Floors: Flooring receives heavy wear and tear in many buildings, so it is important to specify materials that can accommodate this and achieve a long service life. Floors are among the building components with the highest environmental impact, thus materials should be chosen with care. In situ concrete floors are common in Africa but their emissions are high in comparison to hollow-core concrete or timber floors and should therefore be avoided when possible. Out of the mentioned materials, timber is the most circular option if it is harvested sustainably. If timber is not available or affordable, prefabricated hollow-core concrete elements are a good option. If concrete is used, the concrete may be exposed to benefit from its thermal mass.

7. Balconies and access passageways: Locating balconies and access passageways on the periphery of buildings can be used to improve the internal adaptability and flexibility of buildings. These elements may also be used as part of passive design strategies by creating environmental buffer zones and solar control elements. Balconies and access passageways should be made with ample dimensions to enable a variety of social encounters that strengthen the feeling of togetherness, safety and wellbeing. Material suggestions and design strategies are the same as for the staircases below.

8. Staircases: Locating staircases on the periphery of buildings frees up internal space while also improving a building's flexibility. Stairs and access passageways should be generously proportioned to enable the easy movement of people and goods in and out of the building. Many components of stairs, balconies and access passageways can be made from circular materials such as sustainably grown and recovered local timber. However, if this timber is used and exposed to weather, designs should be developed that enable easy maintenance and repair. If concrete or steel is used for staircases and passageways, their modularity and disassembly potential should be considered.

9. Internal walls: Internal walls can easily be self-built as they do not require much skill or competence. This also means that users can fit out their units to their own needs and build them at their own pace. Suitable local materials for internal walls are different earth-based bricks and blocks, timber, compressed straw panels, hempcrete or reclaimed secondary non-hazardous materials.

10. Roofs: Roofs play an important role in protecting internal space against precipitation and the sun. They can also provide valuable additional external space, in the form of roof gardens, as well as an additional water supply, through rainwater harvesting. Roof materials therefore must be able to accommodate direct exposure to the elements such as sunlight and precipitation and, as roofs may also be difficult to access, materials should have a long service life and require little maintenance. Suitable materials include modular roof sheeting that can be easily repaired or reused.

11. Solar collectors and panels: Roofs should be used to produce local renewable energy since African countries get lots of sunlight. Solar collectors may be installed to generate heating energy and solar panels installed to produce electricity. Together they lower a building's emissions and operational costs and ensure that the users of the building are less affected by external factors such as power outages or rising energy and electricity costs.

12. Roof gardens: Roofs can be made into green roofs or gardenlike areas, or they can be used for sustainable urban farming. Increasing the amount of greenery in urban environments has a positive effect on air quality but roof vegetation can also be used to increase the thermal performance of roofs. Plants can utilise and neutralise wastewater produced on site and use the nutrients to produce healthy edibles. Gardening also has beneficial impacts on physical and mental health and provides meaningful activities for urban inhabitants, in a shared space where they can meet and bond.

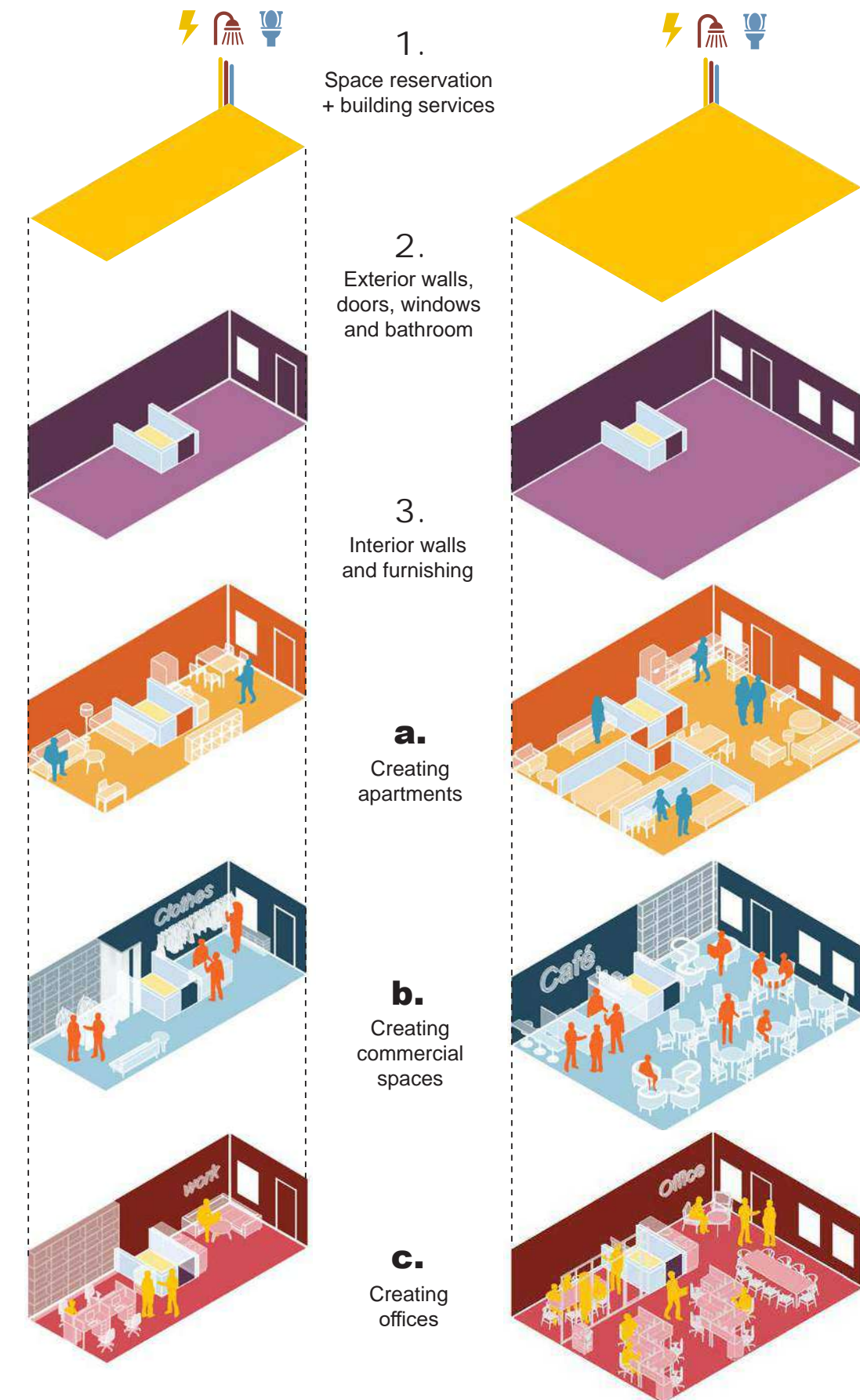


Figure 66: Adapting spaces into tailored, personalised and fully functioning units for different uses

Credit: Illustration by the author

Figure 67: Illustration showing how the concept can be used to create lively mixed-use neighbourhoods. Local materials dominate the material palette and the freedom to personalise the facades results in lively, unique and easily recognisable buildings

Credit: Illustration by the author and Pekka Huovila



Great decarbonisation potential

The suggested changes made above in the material palette would create local jobs, increase the use of local materials and lower the environmental impact of construction significantly. The embodied emissions according to the life cycle assessment (LCA) of the concept house presented in Figure 65 show great decarbonisation potential when using local circular materials compared to conventional materials, as shown in Tables 18 and 19. LCA was done on the concept building using four different material palettes, of which one represents the base scenario. Only main structures have been included in the LCA: posts, beams, slabs (including passageways), roof structure, infill, intermediate walls, windows, doors (exterior) and stairs. Foundations, insulation, surface materials, furniture, interior walls that are not separating two units, and building services were excluded from the LCA. These four scenarios are presented briefly below and in greater detail in Appendix 1. The dimensions of the load-bearing structures have been estimated according to Eurocodes 1, 2 and 5 (EN 1991-1-1; EN 1992-1-1; EN 1995-1-1). Bracing has not been accounted for but can be solved on a case-by-case basis through a more detailed design.

Base Scenario

Concrete frame + in-situ slab + concrete blocks

- In-situ concrete posts and beams
- In-situ concrete slabs and roof
- Concrete blocks as infill and interior walls
- Aluminium windows
- Wooden doors with steel frame
- Concrete stairs

Option 1

Concrete frame + hollow-core elements + CsEB

- In-situ concrete posts and beams
- Hollow-core concrete slabs
- Timber roof structure
- CsEB as infill and interior walls
- Wooden windows
- Wooden doors
- Wooden stairs

Option 2

Concrete frame + hollow-core elements + hempcrete

- In-situ concrete posts and beams
- Hollow-core concrete slabs
- Timber roof structure
- Hempcrete as infill and interior walls
- Wooden windows
- Wooden doors
- Wooden stairs

Option 3

Wooden frame + CEB

- Glulam posts and beams
- Timber floor structure
- Timber roof structure
- CEB as infill and interior walls
- Wooden windows
- Wooden doors
- Wooden stairs

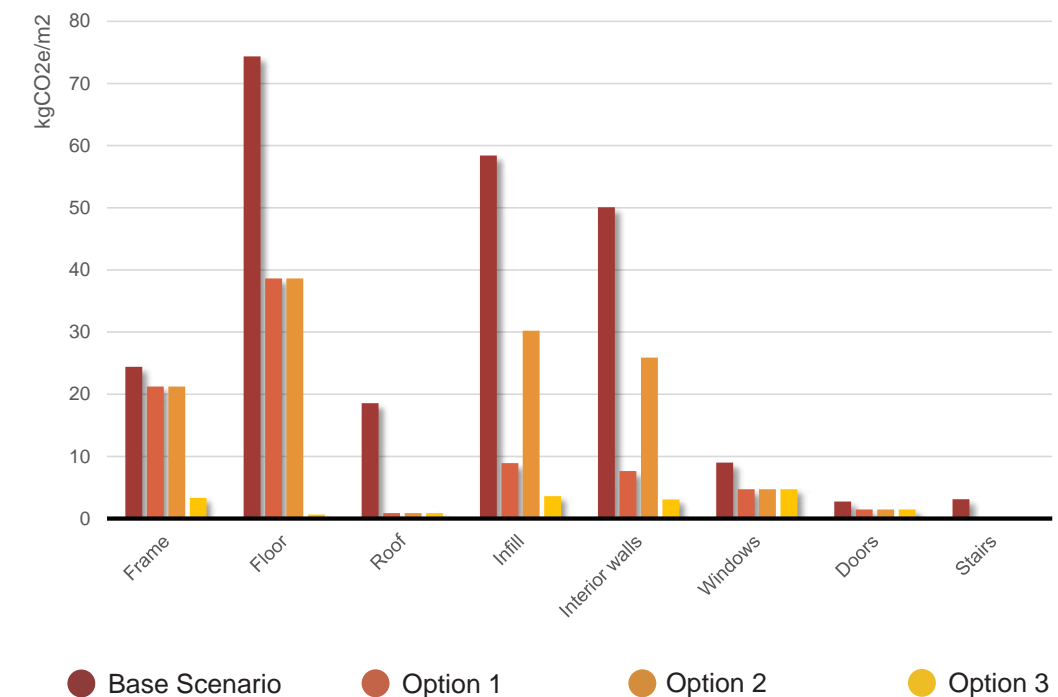


Table 18: Embodied emissions of the different construction parts of the concept house (per m² of gross floor area) when constructed with three different material palettes and comparing the results to the base scenario

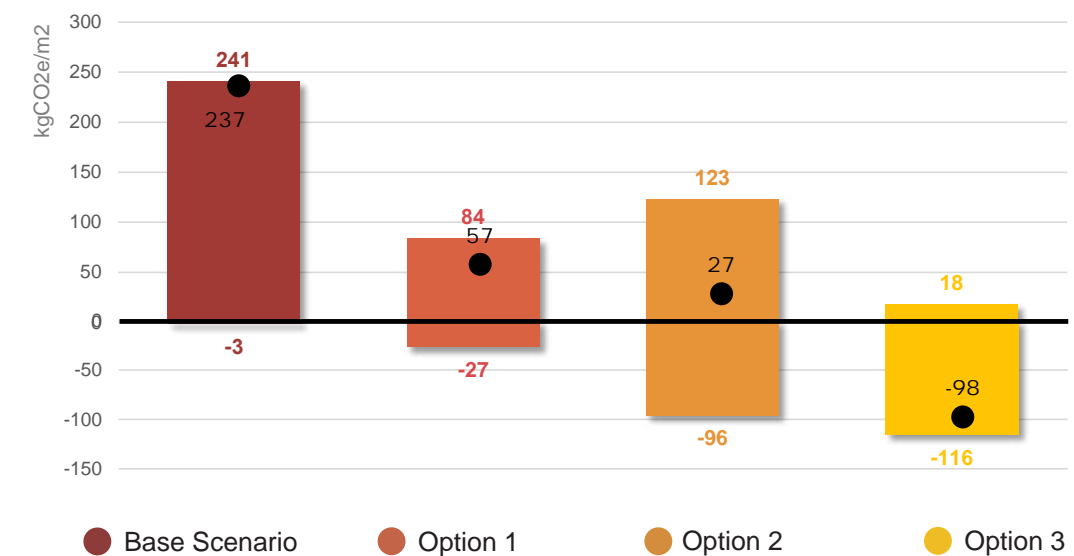


Table 19: Embodied emissions (positive value above horizontal axis), carbon storage (negative value below horizontal axis) and carbon balance, which is the sum of the former two (black dot), of the concept house (per m² of gross floor area) when constructed with three different material palettes and comparing them to the base scenario

When comparing to the base scenario, the carbon footprint per square metre is 65% lower for Option 1, 49% lower for Option 2 and 93 % lower for Option 3. Out of the options that are based on a sustainable local material palette, Options 2 and 3 are carbon negative, meaning that they store more carbon than their construction emits. The most significant carbon reductions can be achieved in the floor and roof structures, the infill in the exterior walls, and the interior walls, as seen in Table 18. Replacing the in situ reinforced concrete slab with prefabricated hollow-core concrete slabs can result in around 47 % lower embodied emissions per square metre of slab. Similarly, replacing the concrete blocks with CsEB can result in 84 % lower embodied emissions per square metre of wall. Even higher emission savings, up to 95%, can be achieved with the use of unstabilised CEB, as seen in Table 18.

If assuming that the demand is for housing units with an average size of 40 m², eliminating Africa's entire housing backlog by adopting to the suggested options could result in a carbon footprint reduction of 237–450 billion kgCO₂e. This reduction is comparable to 1,6–2,2 years of the entire African region's emissions (Faye and Geh, 2018b; Friedlingstein et al., 2022).

The material palettes that are based on local materials and labour result in much lower carbon footprints. Additionally, the use of bio-based materials in Options 2 and 3 turns these buildings into effective carbon storages. The carbon storage capacity of Option 3 is higher than the option's carbon footprint, which results in a negative carbon balance. This means that the entire demand for housing according to this option could store (taking into account the carbon footprint) up to 1,4 times the region's annual emissions.

Contribution to the SDGs

The new concept promotes the upscaling of local circular materials, something which has wide-ranging positive environmental, social and economic impacts. Therefore, it is not surprising that the proposed concept contributes to all the SDGs that the SBC programme has claimed are relevant for circularity in the built environment; SDG11 (Sustainable Cities and Communities), SDG12 (Responsible Consumption and Production), SDG13 (Climate Action), SDG6 (Clean Water and Sanitation), SDG7 (Affordable and Clean Energy), SDG9 (Industry, Innovation and Infrastructure) and SDG8 (Decent Work and Economic Growth), as seen in Figure 68.

The conceptual proposal supports SDG11 by creating affordable housing and lowering the negative environmental impact of cities. It promotes SDG12 by increasing the use of locally manufactured products, lowering emissions per capita and reducing the amount of waste and pollution. And it supports also SDG13 through the lowering of emissions.

The proposed concept supports SDG6 since it uses less water than conventional solutions because of the material palette and the suggested building services. The building reduces the need for operational energy by being naturally ventilated and utilising thermal mass. Additionally, it produces solar energy. Therefore it also contributes to SDG7.

Increasing the use of local construction materials and scaling up their production will create local jobs and SMEs thus boosting economic growth. The growing pressure to cost-efficiently decrease emissions, waste and pollution caused by material production boosts innovation. Because of these factors, the new concept also supports SDGs 8 and 9.

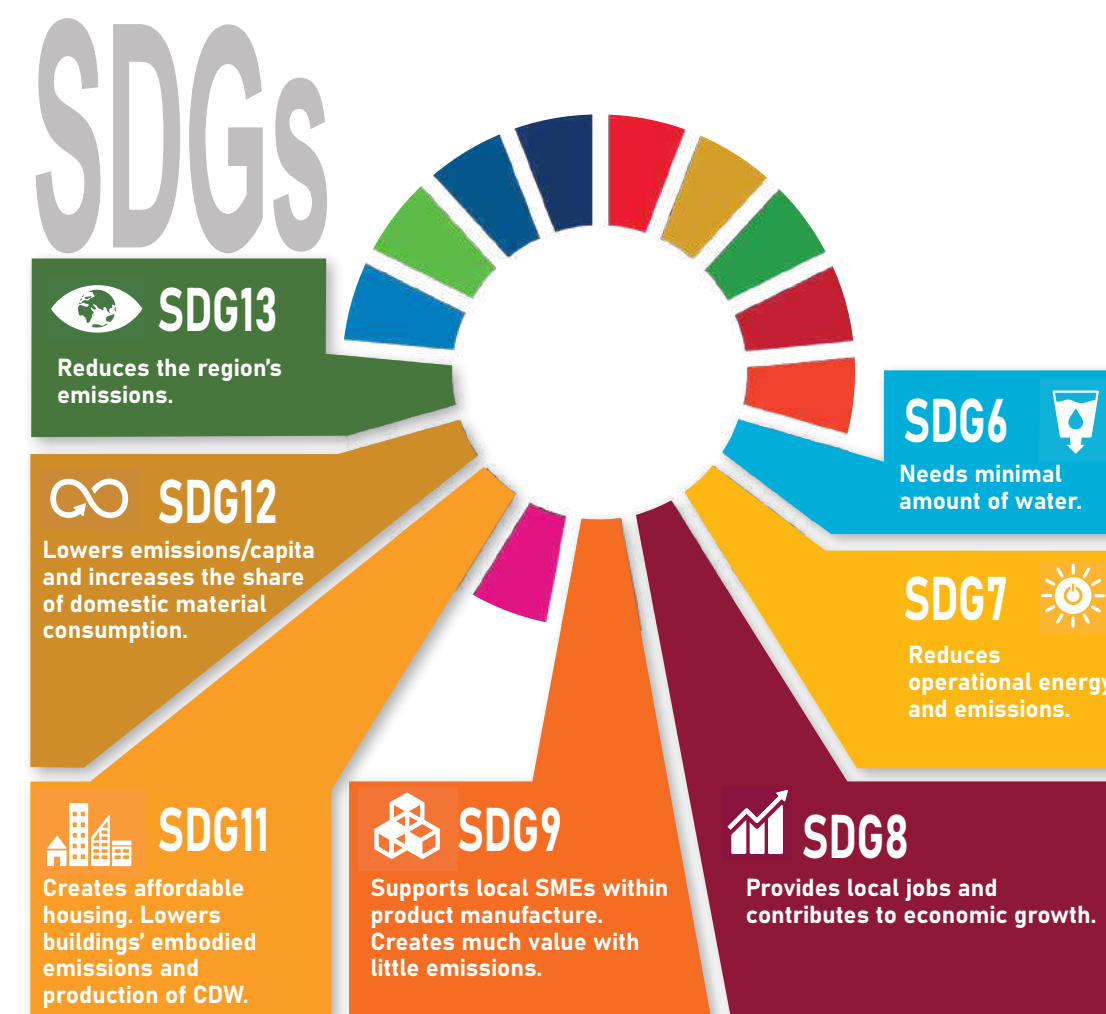


Figure 68: Illustration showing how the concept supports the SDGs

Credit: Illustration by the author

NEXT STEPS

Increasing awareness of climate change and resource limitations is providing a strong impetus for the development of more-circular built environments (Velenturf and Purnell, 2021). Architects, clients and developers are becoming more discerning about the type of materials and products they use. They are also seeking to design buildings and urban environments that are more circular. However, this is happening in a fragmented and ad-hoc way and there is limited formal support for more-circular built environments in many African countries.

This section outlines how support that enables rapid and efficient adoption of circular economy principles in the built environment can be developed. It describes how factors such as business models, cooperation, guidelines, roadmaps, legislation, standards and awareness can work together to integrate circularity into building practices.

The benefits of a circular approach indicate that there is a strong case for the government, civil society and the private sector to work together on developing and implementing structured support for circularity in the BCS (SITRA, 2020, 2016)

5.

Key actions



Supporting more circularity and local content in the built environments can be achieved through activities that progressively integrate more such approaches into buildings and construction. The desired material flow in a circular built environment and how it can be promoted are depicted in Figure 69. Ten actions that promote circular construction have been selected and they are explained in greater detail below.

1. **Build awareness and competence**
2. **Encourage cooperation**
3. **Increase green financing and taxation**
4. **Support sustainable construction**
5. **Develop circular business models**
6. **Adopt green procurement practices**
7. **Create guidelines, standards and regulations**
8. **Adapt to local conditions**
9. **Facilitate recycling**
10. **Develop strategies and roadmaps**

Circularity can be promoted in all life cycle stages of construction. The needed change and the key actors promoting the change are presented in Figure 70. All these actors are able to take part in the previously listed 10 actions. Figure 70 also shows in which life cycle stages the actors are most actively influencing the construction value chain.

1. Build awareness and competence

Improved awareness of circular economy approaches within the BCS as well as among the general public is valuable in promoting the concept. Today, the public perception of the costs of building sustainably is significantly higher than the actual costs, as shown in Figure 71. This slows down the transition to circularity.

Greater awareness of the positive effects of circularity can be achieved through simple messages published in guidelines and on websites that explain what a circular approach is and how it can have beneficial impacts such as reduced waste and pollution, new jobs and opportunities for small enterprises, and healthier environments (Ellen MacArthur Foundation, n.d.). Many of the circular materials that could be mainstreamed in African countries are held back by stigma or restricting regulations. For instance, earth-based materials have many environmental, social and economic benefits in comparison to conventional concrete blocks, but many people still perceive them as materials for the poor and favour concrete blocks because of the status they bring.

Besides raising awareness, there is a need to build competence. The development of construction materials should ensure that their strength, durability and environmental properties are enhanced. Additionally, production should be upscaled efficiently and the properties of building materials should reach high enough standards to become appealing to big contractors.

Competence is also needed in the design and construction phases so that buildings can be designed and built to fit the local context without causing waste or high emissions. Knowledge and skills can be gained through formal education, training programmes or learning by doing. All forms of teaching have a role to play since new skills are needed at all levels – from waste collectors to artisans, architects and decision- and policy-makers, as shown in Table 20. Higher education needs to teach systems thinking to shape professionals who are able to solve complex issues in the shift from a linear to a circular economy and to fully exploit the benefits of the transition.

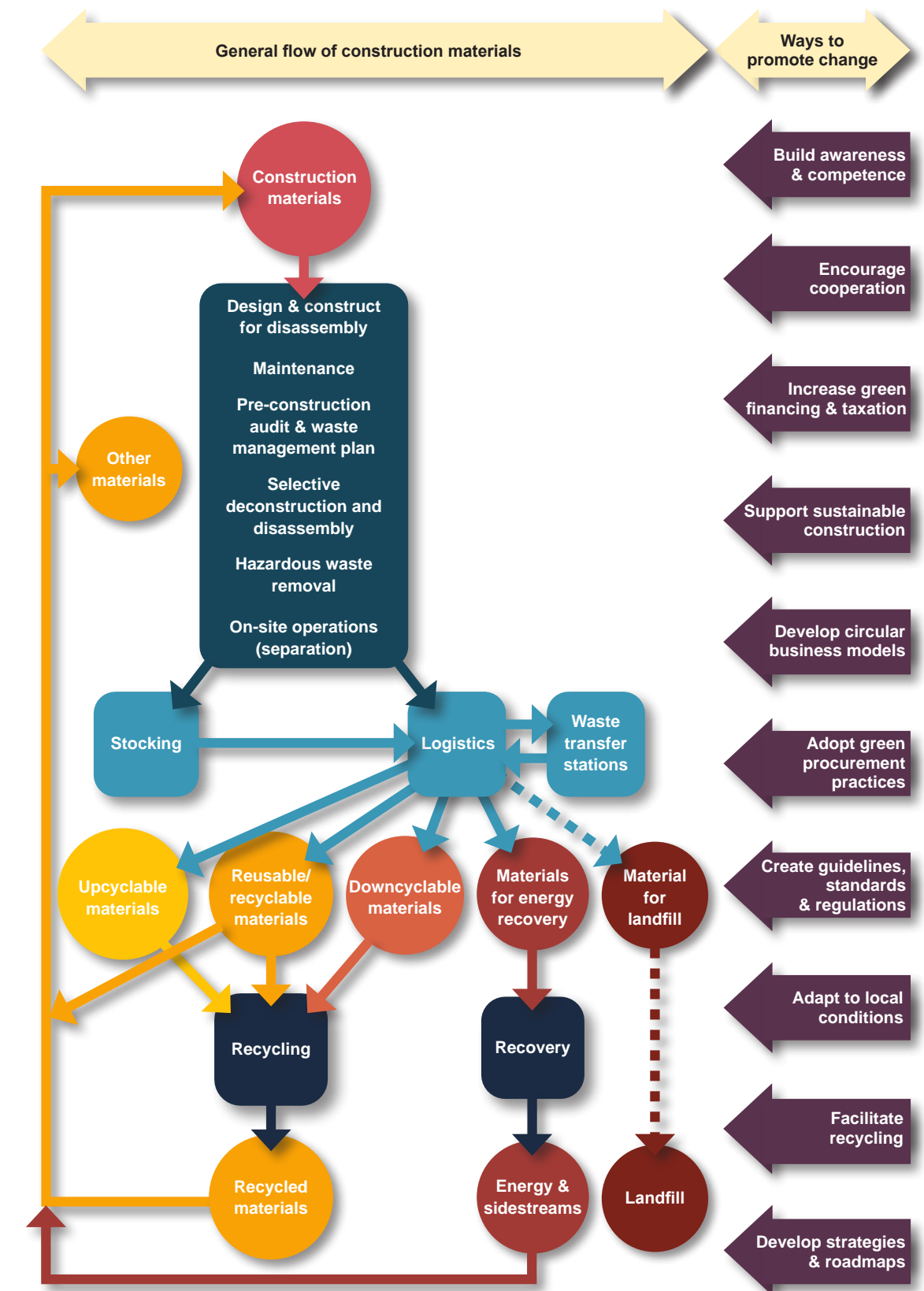


Figure 69: Illustration showing the desired flow of construction materials in a circular economy and how it can be promoted

Credit: Illustration by the author

2. Encourage cooperation

The modern BCS is currently not sustainable and making it sustainable will require a significant amount of cooperation at a range of levels. Problems are easier and faster to solve when there is cooperation between actors along the construction value chain, between the informal and formal sectors, and across disciplines. Such cooperation and potential partnerships will also contribute to a more even distribution of benefits gained from increased innovation and value.

Lifecycle consideration is needed in a circular economy. Promoting circularity along the entire lifecycle requires cooperation between actors at the different life cycle stages since they are all linked. To guarantee efficient disassembly and reuse or recycling of building components, these actions should be considered in the design phase. Additionally, the actors involved in the design phase should cooperate with the actors engaged in the construction stage to make sure that the designs result in efficient construction and that the buildings are built as designed. In relation to the proposed concept, this means ensuring that the load-bearing structures in particular – including foundations, structural frames, slabs and roofs – are built so that they are safe, of high quality, and allow for flexibility and disassembly. Since the concept allows end users to self-build parts of the building, the cooperation they are involved in will necessarily be less formal. Self-builders should be given guidance on sustainable construction methods and material choices, while the design team and contractor responsible for the load-bearing structure should understand the limitations of self-construction and provide end users with the necessary designs that guarantee safe, efficient and sustainable buildings.

Cooperation across sectors is also important because the waste produced by one sector may be a resource for another sector. Industrial waste streams such as fly-ash and slag and agricultural by-products such as excess straw, cassava husks and hemp hurds have significant potential as replacements for the linear or carbon-intensive raw materials traditionally used in construction.

3. Increase green financing and taxation

Increasing green financing can speed up the transition to circular construction by increasing or directing financial flows from banking, micro-credit, insurance and investment to projects that contribute to sustainable development (Desalegn and Tangl, 2022). This can be supported by regulations, incentives, green procurement practices, public-private partnerships and increased use of green bonds.

Taxation can be used to drive the adoption of more-circular approaches. This can be achieved through financial incentives and tax rebates for those who adopt a circular approach (Milios, 2021). It can also be achieved through penalties and increased taxation for non-circular methods that are associated with greater waste and pollution. While green taxation can tip the economic scale in favour of circular solutions, it can also create new economic opportunities in the form of local jobs and enterprises.

4. Support sustainable construction

Achieving the significant benefits of the circular economy such as innovative materials and products, new manufacturing, service and repair enterprises, and increased local employment will require support. This support can be financial, technical, capacity, management, marketing and leadership support, as outlined below.

- Financial support could include grants and access to capital to help develop new products and support the establishment of new enterprises (IDC, n.d.).
- Technical support could include access to technical expertise and specialised equipment required to develop, test and manufacture products.
- Capacity support could include access to training and systems that enable the development of circular products and built environments.

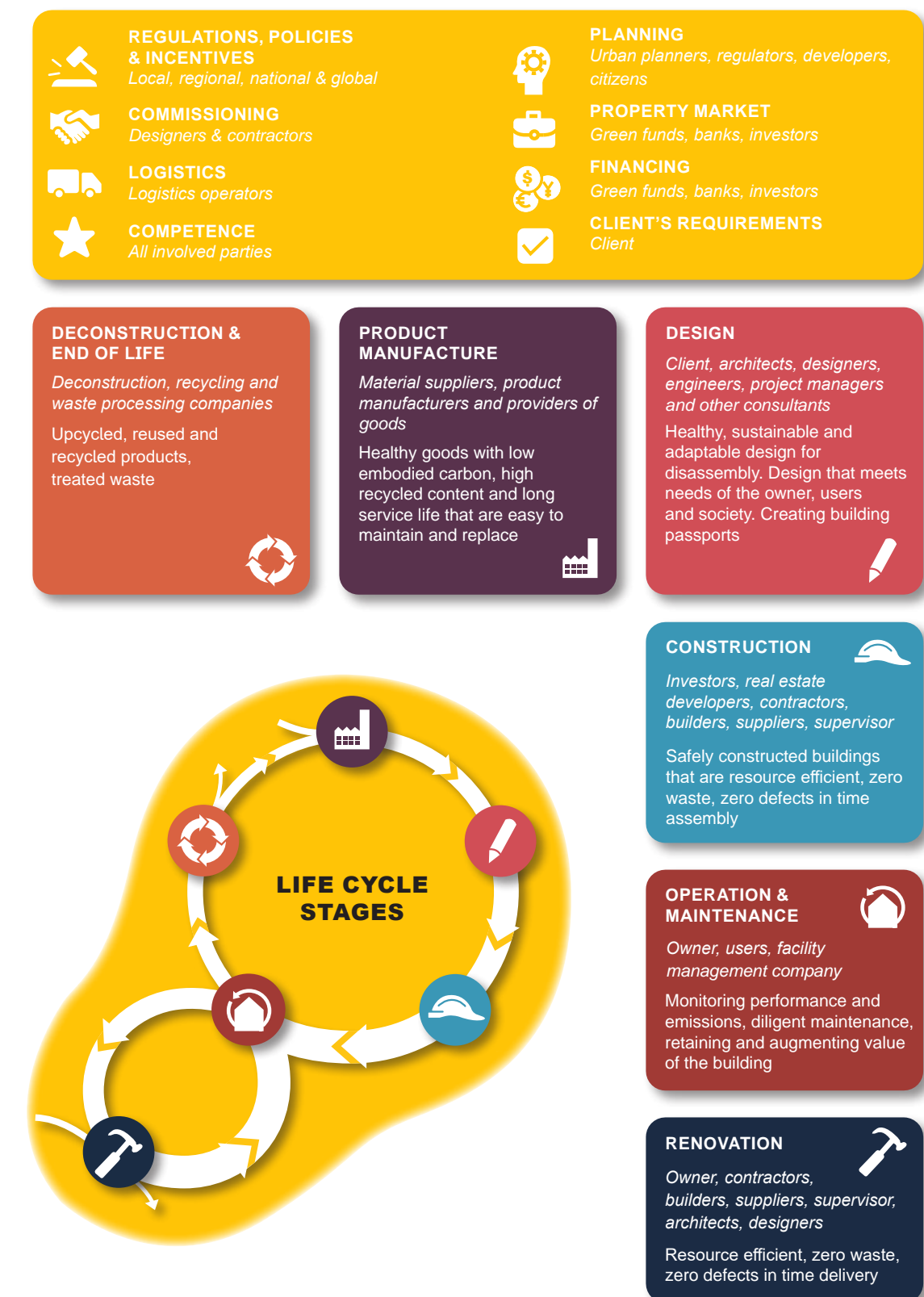


Figure 70: Life cycle stages, key actors and desired outcomes

Credit: Adapted from (Huovila and Westerholm, 2022)

- Management support could include access to mentors who can assist new and existing enterprises to adopt more-circular approaches in their businesses.
- Marketing support could include improving awareness among potential built environment clients and the public about the benefits of a circular approach.
- Leadership support for circular roadmaps could be valuable in ensuring that they are integrated into plans and processes within the public and private sectors. Thus, active endorsement of a circular approach and roadmaps by the government, civil society, built environment professionals and the private sector should be pursued. This can be achieved through public statements, articles, speeches, presentations and press releases as well as through the inclusion of circular approaches in new policies and strategies.

5. Develop circular business models

Circularity provides new business opportunities through, for example, sharing economy – spaces and products can be rented, leased as services, shared or co-owned. In a circular economy, more businesses are needed to provide reused, recycled or even upcycled materials. Additionally, the role of repair and maintenance contractors becomes more important when moving from a make-take-waste culture to one that prioritises long-lasting products. There is also increasing pressure to develop new circular materials that utilise waste streams or sustainable renewable raw materials. Many of these circular business models do not require high initial investment capital, which makes them suitable for SMEs.

6. Adopt green procurement practices

Including a requirement for more-circular building materials and products in procurement is an effective way of supporting the development of more-circular building materials, products and buildings (Transition Agenda, 2018).

In particular, governments, with their very large building budgets, can drive significant change by requiring that more-circular, locally produced building products and components be included in new buildings (SARS, 2022). An ongoing requirement for circular materials and products is a valuable incentive for manufacturers to invest in the development and upscale the production of such products.

7. Create guidelines, standards and regulations

Achieving greater circularity in the built environment can be supported by accessible, evidence-based, practical guidance and standards. This provides the detail that enables planners, designers, contractors and managers of built environments to effectively integrate circular local materials into current built environment processes, as highlighted in Table 20. Examples of this include:

- Circular materials and products – guidance and standards can define how circularity within materials and products is measured and stipulate the requirements for how high-quality circular materials are produced and used (Agrément, 2019).
- Circular buildings – guidance and standards can describe circular built environments and advise on how required technical and performance aspects are to be achieved.
- Circular neighbourhoods – guidance and standards can define circular urban areas and provide technical standards for these. This could include performance standards for buildings as well as for associated systems such as water, waste, energy and food systems.

Regulation can support circular sustainable approaches by making practices that support circularity a requirement of construction and built environments (Boza-Kiss et al., 2013). For instance, town planning regulations and land use zoning can require more circular approaches in the design and management of urban areas (City of Tshwane, 2021). Similarly, building regulations can require new buildings and building refurbishments to achieve more circularity.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Unclear and incomplete technical standards	7%	14%	27%	47%	5%
Lack of tools for assessing the performance	7%	14%	20%	48%	12%
Lack of technical knowledge of the use and installation	8%	17%	17%	50%	8%
Immaturity of the technology employed for developing the local building materials	4%	13%	25%	42%	15%
Technically difficult during the construction process	4%	18%	24%	39%	14%
Lack of experience in the design and construction of buildings with local building materials	5%	18%	21%	37%	18%
Lack of training and education for developers, contractors, and policy-makers	5%	11%	12%	45%	27%
Lack of skilled labour on local building materials	7%	17%	13%	38%	25%
Lack of database and information on local building materials	8%	9%	12%	46%	26%
Unavailability of rating and labelling systems for local building materials	7%	9%	17%	47%	21%
Difficulties in providing technical training for construction workers	4%	12%	13%	47%	24%
Higher requirements for handling, construction and demolition	3%	13%	20%	48%	16%
Incompatibility with other building components	4%	18%	26%	39%	12%
Unavailability of approved local building materials	5%	18%	26%	38%	12%
Risks and uncertainties involved in adopting local building materials	7%	13%	34%	34%	13%
Lack of tested and reliable local building materials	4%	21%	24%	33%	18%
Procurement and contractual issues	3%	15%	17%	41%	23%
Quality control management	5%	14%	16%	45%	20%
Lack of standards and specifications	5%	21%	21%	38%	15%

Table 20: Most prominent barriers to the mainstreaming of local construction materials

Professionals within the construction sector in South Africa were asked to indicate the level to which they agree with the following technical challenges to the adoption of local building materials. The survey got 92 responses

Source: Windapo et al. (2022), illustrated by the author

Some examples of regulations that can support circular approaches are provided below:

- Construction waste – regulations can be developed that ensure that construction waste is minimised (City of Tshwane, 2021). Landfilling of CDW can also be restricted.
- Extended service life of materials and components – regulations can be developed that ban materials and products that have a very short service life and cannot be re-used or repaired.
- Certification of circular materials and products – regulations can be developed that require building manufacturers to provide information on the circularity of their materials and products to enable specifiers to understand and evaluate this.
- Mixed-use integrated urban planning – land use zoning, town planning schemes and building regulations can be developed that require more-circular, mixed-use, integrated, higher-density urban forms and buildings that include circular energy, water, waste and food systems.

8. Adapt to local conditions

To improve African countries' resilience to the changes caused by the environment, economy and politics, it is important to plan how to reduce the dependence on global supply chains and how to utilise local materials and knowledge more efficiently. Local engagement and drawing on local knowledge will support bio-climatic construction and passive solutions, making buildings more comfortable, efficient and connected to their natural and cultural environment. Such construction utilises local knowhow, skills, techniques and materials while simultaneously creating jobs. Supporting local supply chains comes with multiple environmental, social and economic benefits. For example, using local materials, techniques and knowledge celebrates local cultures and helps preserve their heritage.

9. Facilitate recycling

In many African cities, most of the recycling is carried out by the informal sector because it is significantly cheaper than formal waste services, there is no municipal waste collection or recycling service, and/or municipalities struggle to manage the high volumes of waste. In Bamako in Mali, it is estimated that 85% of the waste is collected by informal waste pickers (UN-Habitat, 2010).

The global informal waste recycling sector is estimated to create employment for more than two million waste pickers, a significant proportion of whom work in African countries (Hoorweg and Bhada-Tata, 2012). More efficient recycling could create even more local jobs and local SMEs.

Recycling can be made easier and more efficient by, for instance:

- requiring households, blocks or neighbourhoods to deposit their sorted waste in locations where waste pickers can easily collect it
- developing waste microgrids, which allows for the sorting and stockpiling of materials and therefore their recycling and reuse
- coordinating the waste picking so that it becomes more efficient
- creating a market for recycled materials (Gibberd, 2020b).

10. Develop strategies and roadmaps

Circular economy approaches are still in their infancy, so developing strategies and roadmaps for circular built environments is valuable (SITRA, 2016). Ideally, these strategies and roadmaps would be created through cooperation between all of the key built environment actors, including governments, developers, built environment professionals and civil society (ibid). A circular roadmap or strategy should define the circular built environment, highlight the advantages of the approach, provide an implementation plan and be widely disseminated.



Appendix 1 – LCA data for the concept building

Since the concept building is designed so that it can be constructed with different material palettes, the dimensions of load-bearing structures had to be estimated for different structural systems. The parameters according to which dimensions have been calculated are as follows; the self-weight of the slab = 4,95 kN/m² and imposed load = 2,0 kN/m² (if in residential use). A conventional top screed has been included in these calculations since it affects the structural design but has been excluded in the LCA, where the focus is on the main structures. The dimensions of the load-bearing structures have been estimated according to Eurocodes 1, 2 and 5 (EN 1991-1-1; EN 1992-1-1; EN 1995-1-1). Bracing has not been accounted for but can be solved on a case-by-case basis when creating a more detailed design.

Self-weight:

g_slab-150mm=3,7 kN/m²

g_screed-50mm=1,25 kN/m²

total: 4,95 kN/m²

Imposed load:

Q= 2,0 kN/m²

There is limited available data on the emissions of materials produced in Africa. Therefore, where this has not been available, general emission data has been gathered from other sources. Emission data were gathered from: InEnergy (2010) [in-situ concrete], Menzies and Wherrett (2005) [wooden windows], Arrigoni et al. (2017) [hempcrete], UNIDO (2015) [CsEB], Pouzaint et al. (2020) [African concrete blocks], (Ministry of the Environment Finland, 2019) [stairs], and co2data (n.d.) [rest of materials]. Since the emission data that has been used is general data and not product-specific, the real emissions might differ from the presented results.

Gross floor area of the concept building is 700 m² and this is the value used to turn the emissions of the entire building in Table 21 to emissions per square metre used in Tables 18 and 19.

Calculations for the dimensions of the load-bearing structures were done by Aku Aspila and LCA was done by the author.

	Construction	Material	Area (m2)	Volume (m3)	Amount (pcs)	Amount (pcs)	Carbon factor	Carbon storage	Unit	Total Embodied CO2	Total carbon stored	Carbon balance
Base scenario	Columns, 225x225 mm	Reinforced concrete		10		72	356	0	kgCO2e/m3	3633	0	3633
	Beams, 225x300 mm	Reinforced concrete		38		135	356	0	kgCO2e/m3	13445	0	13445
	Slab, 150 mm	Reinforced concrete		146		4	356	0	kgCO2e/m3	52033	0	52033
	Roof slab, 150 mm	Reinforced concrete		37		1	356	0	kgCO2e/m3	13008	0	13008
	Infill, 200 mm	Concrete blocks		110		56	373	0	kgCO2e/m3	40881	0	40881
	Interior wall, 200 mm	Concrete blocks		94		40	373	0	kgCO2e/m3	35062	0	35062
	Windows	Aluminium frame	60			60	105	0	kgCO2e/m2	6300	0	6300
	Doors	Wooden door, steel frame			25	25	77	-96	kgCO2e/pcs	1925	-2400	-475
	Stairs	Concrete			4	4	543	0	kgCO2e/pcs	2172	0	2172
										168459	-2400	166059
Option 1	Columns, 225x225 mm	Reinforced concrete		10		72	356	0	kgCO2e/m3	3633	0	3633
	Beams, 225x300 mm	Reinforced concrete		32		110	356	0	kgCO2e/m3	11222	0	11222
	Slab, 200 mm	Hollowcore concrete		146		4	185	0	kgCO2e/m3	27040	0	27040
	Roof structure, s=900 mm	Wooden trusses			27	1	17	-366	kgCO2e/pcs	451	-9882	-9431
	Roof planks, 20 mm	Wooden planks		5			35	-758	kgCO2e/m3	169	-3695	-3526
	Infill, 200 mm	CsEB		109,6		56	57	0	kgCO2e/m3	6247	0	6247
	Interior wall, 200 mm	CsEB		94		40	57	0	kgCO2e/m3	5358	0	5358
	Windows	Wooden frame	60			60	55	-2	kgCO2e/m2	3300	-102	3198
	Doors	Wooden door			25	25	41	-80	kgCO2e/pcs	1033	-1988	-955
Option 2	Stairs	Wooden			4	4	37	-801	kgCO2e/pcs	148	-3204	-3056
										58601	-18870	39730
	Columns, 225x225 mm	Reinforced concrete		10		72	356	0	kgCO2e/m3	3633	0	3633
	Beams, 225x300 mm	Reinforced concrete		32		110	356	0	kgCO2e/m3	11222	0	11222
	Slab, 200 mm	Hollowcore concrete		146		4	185	0	kgCO2e/m3	27040	0	27040
	Roof structure, s=900 mm	Wooden trusses			27	1	17	-366	kgCO2e/pcs	451	-9882	-9431
	Roof planks, 20 mm	Wooden planks		5			35	-758	kgCO2e/m3	169	-3695	-3526
	Infill, 200 mm	Hempcrete		109,6		56	193	-238	kgCO2e/m3	21153	-26085	-4932
	Interior wall, 200 mm	Hempcrete		94		40	193	-238	kgCO2e/m3	18142	-22372	-4230
Option 3	Windows	Wooden frame	60			60	55	-2	kgCO2e/m2	3300	-102	3198
	Doors	Wooden door			25	25	41	-80	kgCO2e/pcs	1033	-1988	-955
	Stairs	Wooden			4	4	37	-801	kgCO2e/pcs	148	-3204	-3056
										86290	-67327	18963
	Columns, 215x300 mm	Glulam timber		13		72	47	-688	kgCO2e/m3	611	-8946	-8335
	Beams, 215x360 mm	Glulam timber		36		110	47	-688	kgCO2e/m3	1699	-24868	-23169
	Floor structure, 90x215 mm, s=600 mm	Wood		8		20	35	-368	kgCO2e/m3	272	-2891	-2619
	Floor planks, 20 mm	Wooden planks		5			35	-758	kgCO2e/m3	169	-3695	-3526
	Roof structure, s=900 mm	Wooden trusses			27	1	17	-366	kgCO2e/pcs	451	-9882	-9431
	Roof planks, 20 mm	Wooden planks		5			35	-758	kgCO2e/m3	169	-3695	-3526
	Infill, 200 mm	CEB		109,6		56	23	0	kgCO2e/m3	2521	0	2521
	Interior wall, 200 mm	CEB		94		40	23	0	kgCO2e/m3	2162	0	2162
	Windows	Wooden frame	60			60	55	-2	kgCO2e/m2	3300	-102	3198
	Doors	Wooden door			25	25	41	-80	kgCO2e/pcs	1033	-1988	-955
	Stairs	Wooden			4	4	37	-801	kgCO2e/pcs	148	0	148
										12534	-80935	-68402

Table 21: Data used for the LCA of the concept if it were constructed using different materials

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