Manuel Correia Guedes
Gustavo Cantuaria *Editors*

Bioclimatic Architecture in Warm Climates

A Guide for Best Practices in Africa

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Preface

The main purpose of this book is to suggest basic strategies for the practice of sustainable building and urban design. It is aimed at students and professionals of architecture and civil engineering, being also accessible to the public with some technical preparation in the construction area. Taking into account the local climates, natural resources, and socioeconomic contexts, good practice design strategies are drawn up in a simplified way.

The book stemmed from the work carried out during the EU SURE-Africa project (Sustainable Urban Renewal: Energy Efficient Buildings for Africa). This project was implemented to deepen and disseminate the existing knowledge in African countries in the area of sustainable architecture – in particular with regard to bioclimatic design and energy efficiency in buildings, contributing to the improvement of the built space habitability conditions.

The SURE-Africa project initially involved the articulation between three EU Universities (of Lisbon, Cambridge, and Lund) and five African Institutions: the Architecture Department of the Agostinho Neto University (Angola), the Mindelo International School of Arts (M-EIA, in Cape Verde), the Ministry of Infrastructure and Transport of the Republic of Guinea-Bissau, the Ministry of Environment of the Republic of São Tomé and Príncipe, and the Faculty of Architecture of the Eduardo Mondlane University (Mozambique). At a later stage, other universities joined the team, namely, to participate in the development of this book.

Throughout the SURE-Africa project, a number of seminars, workshops, and conferences were held, a knowledge network was established between the institutions involved in the field of sustainable urban planning and architecture, and teaching materials were produced as well as good practice manuals. These manuals provided the foundation for this book, which should be regarded as a starting point for future research work, so necessary in this area.

Manuel Correia Guedes

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Chapter 1
Introduction

Gustavo Cantuaria

Due to the fast deterioration of quality of life especially in the big urban centres all over the world, man is turning to nature in a desperate quest to learn and have once more what was given to us but taken for granted.

Like most of the issues in modern society, architecture too seems to have been stricken by the influence of the “globalisation” process, where local cultural identity gives way to the mass language of ignorance and power of the strongest. In many African capitals, for example, big, totally sealed glass boxes are being constructed in the tropics, ignoring all climatic potential and resources. Hypnotised under the spell of the “trendy globalisation” architecture, glass boxes proliferate around the city, unaware of their harm and absurdity.

Importing the architectural ideas and concepts of foreign countries, whose geography, environment and climate are totally different from that of Africa, has led to improper architectural solutions and typologies. Furthermore, any interesting lessons of what was once the most proper way of building are being ignored and forgotten. When money and resources are abundant, how, where, and when one builds is frequently overlooked. On the other hand, if one considers a low-income population, where basic needs is just about sufficient for the day, it is important, not to say essential, that one makes the most benefit of its living environment, in an intelligent and sustainable manner. The appropriateness of one solution for one community is not necessarily appropriate for another. Ideas should be abundant and appropriate to each context, and knowledge never ignored, always feeding back to past experiences and ancestors. Consequently cultural values, tradition and historic memory, all that makes people and cities diverse, interesting and unique, will be preserved.

As we embark in a new century and a new millennium with an absurd increase in population, increase in hunger and more astonishingly an increase in social differences, sustainable development is no longer an option but a requirement. It

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should no longer be theoretical, but practical. In the 1987 United Nations Conference entitled "Our Common Future", it was defined that "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Architecture plays a major role in making this development possible.

Sustainability in developing countries, which hold 75% of the world's population, is a bigger challenge. They have only "17 per cent of the world's gross national product, 5 per cent of science and technology, 15 per cent of energy consumption, 30 per cent of the food grains, 11 per cent of the education spending, and 6 per cent of the health expenditure" (Rice and Rasmussen 1992). Generally, health has been seen separately from other environmental issues that affect a person's health condition. However, evidence of the connection of the environment on health is increasing considerably.

Recently there has been a spate of interest in how to combine the stressing demands of modern life and society with a healthy natural environment. Applied researchers have become increasingly interested in how to benefit the most out of natural elements and resources such as sun, wind and vegetation. The possibility that man can benefit from natural cooling instead of artificial air conditioning, humidifiers or any other energy consuming device has generated interest in the development of passive cooling environments.

Furthermore, two negative aspects of great urban societies are the overheating of a city, a process commonly known as the heat island effect, and pollution. Mann (1993) gives two main reasons for these major threats. The highly successful economic strategy of the wealthiest nations, backed by technological innovation and environmental exploitation, and the increasing pace in the growth of the world's population are arguably the major reasons for these threats. The bigger the city, the bigger the problems. The rethinking of urban centres can no longer be a caprice or will but a necessity.

With this context in mind, the SURE-Africa (Sustainable Urban Renewal: Energy Efficient Buildings for Africa) project was implemented. The main aim was to deepen and disseminate existing knowledge in African countries, in the area of sustainable architecture, in particular with regard to bioclimatic design and energy efficiency in buildings, contributing to the improvement of the living conditions of the built space. Throughout the project, seminars, workshops and conferences were held, a network of knowledge was created among the institutions involved in the field of architecture and sustainable urban planning, and manuals of good practices were produced. Much of this material is sign posted along this book. African Portuguese-speaking countries were the initial collaboration participants, but other African countries will also have in this material a reference and a starting point for future work, so necessary in this area.

The exaggerated use of natural resources and energy has also been a major concern. To create comfortable indoor and outdoor living environments or to reduce cooling loads, solar control is the most basic construction method of building in the low latitudes. It is the purpose of this work to provide valuable information on the amelioration of outdoor microclimates to achieve thermally comfortable living environments, relying on the passive interaction of the built environment with its surroundings. (Cantuaria 2001)

1.1 Urban Challenges

Urban centres have entered the twenty-first century with a paradox to discuss. As the cities look to reach the skies with their growing skyscrapers, they also reach out to attract and embrace as many people as possible. Aiming to become an important financial, commercial, cultural, technological, or tourist place and therefore attract investments, it needs to grow. The more it grows, more people it will need to make it grow. The more people it has, more infrastructures are necessary. With this ongoing trend, problems such as transportation and health become an increasing snowball. In the process of looking for a sustainable city, it is equally important to find sustainable solutions.

Every human being, with its activities and implications, affects its surroundings. The urban centres are one of the most important works produced by humanity and undoubtedly the one that has caused most environmental changes. Deforestation, heat island effect and climatic changes are examples that blame the rapid growth of the industrialised city. It is necessary to achieve thermally comfortable living environments, especially for people who have nothing else to rely on other than its surroundings.

1.2 Sustainable Architecture

Science nowadays conflicts and tries to conquer nature. It works independently and in reclusion. It looks upon nature for questions, not answers. Together they can produce better. Biology, along with chemistry, and physics have to be perceived as they once were, as natural sciences, which simply means the understanding of nature.

Environmental issues are usually situated on a global scale. Discussions include global warming, damage to the ozone layer, overpopulation, scarcity of energy, resources and food. Nevertheless, damage is also caused on a smaller and daily scale, in a microenvironment with its own microclimate. These spaces can be changed and made healthier as well as more enjoyable by seeking a symbiotic relationship with our natural surroundings.

We think of fantastic and megalomaniac solutions instead of being practical and using common sense. We want to colonise the moon before conquering our own problems on earth or even our surroundings. Being instinctive is not being naive. Being simplistic is not being underrated. It means being rational, natural, intelligent and sustainable. It is giving a step at a time and not one bigger than the legs. Great accomplishments have come from simple observations such as Pascal's law, relativity theory and the laws of physics. A falling apple inspired Newton to understand gravity. "How many times it thundered before Franklin took the hint! How many apples fell on Newton's head before he took the hint! Nature is always hinting us. It hints over and over again. And suddenly we take the hint" (Busch 2007). By observing the cooling effects of a nature, we can also be inspired in leading a more healthy and productive life.

Environmentally friendly houses do not have to look awkward like prototypes or scientific models. They can be simple and cheap or complex and expensive. It can be a humble house in a social housing settlement or a last-generation high-tech “intelligent” building. They can be of any form desired as long as they incorporate and benefit from their surroundings. An agreeable microclimate will provide the user with an agreeable space. Comfortable, pleasant and healthy outdoors will certainly also affect and reflect indoors.

Architecture is seen most of the times as something concrete, tangible, visible and perceptible. It is mainly understood as a voluminous three-dimensional form, something that occupies a certain space and has an impact (good or bad) on its surroundings. Nevertheless architecture is not only the seen but also the unseen. It is not only the inscribed space among walls but also that circumscribing the walls as well as the space without any walls whatsoever. Architecture is more than the eye can perceive; it is the extra sensorial. It is more than the physical; it is the sensational. It is more than the existential; it is the non-dimensional. It is more than volumes and surfaces; it is heart touching, emotion striking; it is peace of mind. For all this architecture is not alone; there is nature. It is the mingling of both that effective rich quality spaces are created. It is the detail that creates delight. It is the audacity that creates the new. It is through all the inspiring and creative branches, twigs and leaves of trees that fantasies become real. Dreams are no longer dreams. When nature and architecture become one, beauty comes to life, and so does man.

Environmentally friendly architecture is not only about providing buildings with the most energy efficient systems and materials. It is above anything else about people and providing them with a better life and a better place to live. It is giving people something to remember, a will to wake up to another day, instead of a mourning desire to close their eyes and forget about life, its problems. Currently, environmental issues are regarded with the cost of past progress. A more efficient green agenda will be one including not only energy efficiency, minimum waste, conservation and better use of resources but also having in the core of all questioning, the welfare of man and its healthy environment and habitat. What really matters is to understand that we do not do architecture if we only focus unilaterally on the building. “…if we are part of the landscape, our body and our mind experience it; its nuances affect us. If we are unable to experience any part of this environment with our senses, then it seems more likely that we are dead” (Sandrisser 1982).

A sustainable environment is the best, if not only, solution to avoid chaos. All segments of society have to be included in the scheme if it is to stand a chance. In the past, societies have fallen and progress been disrupted when habitable environments were pushed and surpassed beyond the limits of sustainability. The Roman Empire started to crumble when the greed for power and corruption blinded those in command and deviated their attention from the basic needs of the people and from the essential care that the cities required. The Sahara Desert is said to be at one time a luxuriant and abundant forest, which succumbed to the bad care of man. Rats and mice can still be seen roaming around in the underground of London as to remind us of the unhealthy and unhygienic times which lead to the bubonic plague. Some tragedies are of natural causes, but others we indirectly impose on ourselves. The scale of these contexts and consequences vary, but the nature of them is one, an ecologically unsound and irresponsible behaviour.

The United Nations Food and Agricultural Organization states that the primary causes for poor nutrition in the world are poverty, pressures of population, land tenure system, unsatisfactory hygiene, ignorance and bad dietary habits. Most of these conditions apply to the lives of those who live in hot and dry places, and climate plays an important role in all of the cases.

By knowing what is uncomfortable, one can at least try to avoid it. Man has been doing this instinctively since prehistoric times when it took refuge in cave dwellings. Later on man created the garden concept and found peace there. Now we try to find compatibility between comfort and taste not only in the interior of a dwelling according to the occupant's taste but also externally.

The historical precedence illustrates the challenge of survival of mankind in a healthy, sustainable environment. Alvin Toffler (1980) in his book *The Third Wave* describes the third wave of progress and development in technological advances. Knowledge is the wave of the moment, not only scientific knowledge but also the rescue of common sense in the form of popular knowledge. The speed at which modern life is lived is much dictated by duties that reason has faded into the background. As part of the animal kingdom, we naturally pollute, destroy and modify. On the other hand, counterbalancing our actions, the plant kingdom recycles our resources, reacts towards the damage and provides us with the bare essentials needed to live, food, air and water. The intelligent and reasonable balance between both parts will ensure a healthy environment and consequently our future. We cannot attempt to resolve global issues without tackling local problems. We cannot have healthy environments without comfortable microclimates. We cannot attain a sustainable community without providing basic need to the lower, yet frequently majority, class.

Surviving through time, tradition and culture are sustainable matters. Both are the core to any ethnic group and are what maintains society. Architecture is very much involved in defining and explaining traditional values and cultural backgrounds. Therefore it has the obligation to help sustain a group's beliefs and ways of life. Nature, by definition, has always been and always will be sustainable. By incorporating it, architecture will benefit and so will society, especially future generations. We will be incorporating sustainability.

1.3 Genius Loci

The sustainable interactions of the natural environment with the manmade environment, represented in our cities, bring to life the purity of the genius loci or, in literal translation, the spirit of place. Place itself can be defined as environment, and it is an indispensable part of our existence, a qualitative part. What is defined today as sustainability, in the past, was credited to the genius loci. Not surprisingly, their definitions overlap each other. In his book *Genius Loci: Towards a Phenomenology* *of Architecture*, Norberg-Schulz points out the mutual conditioning of natural environment, culture and architecture as the essence of genius loci expression. The "environment where man has found his meaningful place within the totality", Norberg-Schulz denominates this as "cultural landscape", which is a means to give man an existential purpose. The search for a purpose in life is as old as man himself. "We ought to repeat that man's most fundamental need is to experience his existence as meaningful" (Norberg-Shulz 1980).

The quest to experience fulfilment and joy has been bound with the quest of beauty. And the quest for beauty is a saga for the Divine. Through time and societies, man has experienced in different arts and manners the sublime. The arts, in all its forms, have shaped our civilizations, have shaped history of mankind and have shaped our prospects. The importance of beauty and its place can be exemplified back to the fifth century BC when the Parthenon was erected. Pericles, a statesman under whose sponsorship the Parthenon was built, addressed the theme in his funeral speech during the Peloponnesian War:

> Our love of what is beautiful does not lead to extravagance; our love of the things of the mind does not make us soft. We regard wealth as something to be properly used, rather than as something to boast about… What I would prefer is that you should fix your eyes every day on the greatness of Athens as she really is, and should fall in love with her. When you realize her greatness, then reflect that what made her great was men with a spirit of adventure, men who knew their duty, men who were ashamed to fall below a certain standard. (Gilbert and McCarter 1988)

Five centuries later Marcus Vitruvius (1960) discoursed on the importance of beauty, in his most known work entitled *Ten Books on Architecture*. His book is one of the first texts ever written connecting the body and buildings in light of beauty. Twenty-one centuries on, our buildings interacting with climate are still in search of true "venustas", as expressed by him. A venustas which touches the soul and hearts of a certain cultural group, preserving memories and values, a genuine sustainable agenda.

Living and art are undividable because they are practically the same. We long for art manifestations because it elevates the soul and ambitions as Pericles exemplifies above. Art is inextricably connected to human existence, and therefore it is impossible not to live with art. Since the earliest cave dwellings until our contemporary civilization, we are surrounded by artistic realisations, such as furniture, design utensils, books, music, movies, paintings, photographs, prints and sculptures, to name a few. These all help to give a meaning to our world, in a bigger or smaller way, according to our interests. However, probably the most inescapable in our daily activities are buildings. We are automatically immersed in these art forms every day of our quotidian. We may not even perceive it, but the buildings we live and work are fruit of artistic efforts, and although seemingly trivial, they reflect the complexity of beauty and an aspired quality of life. Architect and architecture theorist, Pallasmaa (2011), affirms this interwinding subtlety and complexity of art, man and place by stating: "I experience the city, the city exists through my bodily experience. The city and my body complement each other and define themselves. I live in the city, and the city lives in me". In a seemingly and more visual manner, it can be said that we dress up with the city, and the city is dressed up by people. It is our clothes, and we are its clothes.

Our human identity is consistently defined by our sensorial experience and tactility. Our skin is in constant dialogue with our built environment, which in turn is in constant conversation with its natural surroundings. This three-way connection is key to comprehensive understanding of our origins and potentials, of where we come from and where we plan to go. In this sense, the way we build and the buildings themselves can be seen as means of communication, one which evokes truth and integrity or one of disposable frugality. This is the conundrum of our times, the crossroads of future prospects. As a matter of fact, more than 60 years ago, Frank Lloyd Wright alerted of the need of wholeness. He stated: "What is needed most in architecture today is the very thing that is most needed in life- Integrity. Just as it is in a human being, so integrity is the deepest quality in a building…if we succeed, we will have done a great service to our moral nature- the psyche- of our democratic society…Stand up for integrity in your building and you stand for integrity not only in the life of those who did the building but socially a reciprocal relationship is inevitable"(in Kaufman and Raeburn 1960).

Furthermore, the integrity of architecture is emphasized by Pallasmaa (2011) as it reflects the integrity of our own lives. He writes: "The timeless task of architecture is to create embodied and lived existential metaphors that concretize and structure our being in the world. Architecture reflects, materialises and eternalises ideas and images of ideal life. Buildings and towns enable us to structure, understand and remember the shapeless flow of reality and, ultimately, to recognise and remember who we are. Architecture enables us to perceive and understand the dialectics of performance and change, to settle ourselves in the world, and to place ourselves in the continuum of culture and time". Architecture therefore interacts directly with us, in who we are, and how we live.

Through time, the buildings which are discovered and the artefacts which are found decipher not only our past but untangle our prospects, project us to the future and give us independence to explore. The genius loci is reflected on culture, which in return resonates on buildings. It is a connection between time and place, emphasizing the most suitable way to solve a certain problem, taking into consideration a certain way of life. This sustainable wheel is man's never ending epic. It is our duty to certify it is moving forward and not bouncing up and down or spinning back. Our culture determines our identity. Our cultural identity gives us roots and firm ground to tread the present and wings of liberty to soar new heights. Buildings are testament of the force and significance of a public identification to progress, as Le Corbusier (in Weber and Yannas 2014) prophesied: "…tradition is the unbroken chain of all renewables, and beyond that, the surest witness of the projection toward the future".

Humanities encompasses our common culture, all forms of arts like buildings, and establish achievements at the same time it provides subsequent coherence to them. The humanities as an area of study falls somewhere between aesthetics and intellectual history without quite being either. The study of climate and buildings illustrates well this concept. The humanities, after all, seeks that which is truly human. "The great tradition of the humanities is a tradition of revolution. When we understand these revolutionary moments of the past and when we are alert for them today we realize how diverse and how limitless are the riches of the human spirit" (Cunningham and Reich 1982). This book, focusing on the African context, has as holistic objective, to show precisely the infinite riches of the human vitality, in light of the endless adaptation to place and climate, through immeasurable ingenuity. By acknowledging our differences, we can appreciate the beauty of diversity, the beauty of mankind.

When environment and architecture become one, beauty comes to life, and so does man. It is the awakening of "venustas"; it's the dawning of "sustainability" and the rebirth of "genius loci". It's the call for humanity, one of values, integrity and acceptance. A call for oneness.

> No man is an island, entire of itself,
> Every man is a piece of the continent,
> A part of the main…
> Any man's death diminishes me,
> Because I am involved in mankind.
> And therefore never send to know for whom the bell tolls;
> It tolls for thee. (John Donne 1977)

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Part I
Climate

Chapter 2
Climatic Contexts

Ana Monteiro and Helena Madureira

2.1 Geographical Context

Africa's position in the globe (37°21′N–34°51′S; 17°33′W–51°27′E) is one-off as it promotes evidences of almost all possible intertropical zone climate types and subtypes, namely, the equatorial, the humid and dry tropical, the Mediterranean and the desert. The approximately 8000 km in length and 7400 km in width and a 32,000 km coastline provide unique geographical features that are shown in the numerous existing climatic contexts.

The climate system between approximately 35° latitude N and S is highly influenced by the two itinerant dynamic subtropical high-pressure belts, by the convergence zone and by the high sun declination along all the year. The continental compacity, the morphology differentiation, the hydrography and the oceans' currents contribute also to create a diverse and complex climatic puzzle in its 30,370,000 km^2.

2.2 Climate Types and Subtypes

According to Köppen classification criteria, we have, at least, 15 subtypes spread around all the territory: equatorial, tropical (wet and dry), semi-desert, desert and Mediterranean (Fig. 2.1).

Between latitudes 0° and 10°, we have mainly equatorial type highly influenced by the intertropical convergence zone (ITCZ) with high temperatures all year round (26 °C), small yearly temperature range and always high humidity and rainfall.

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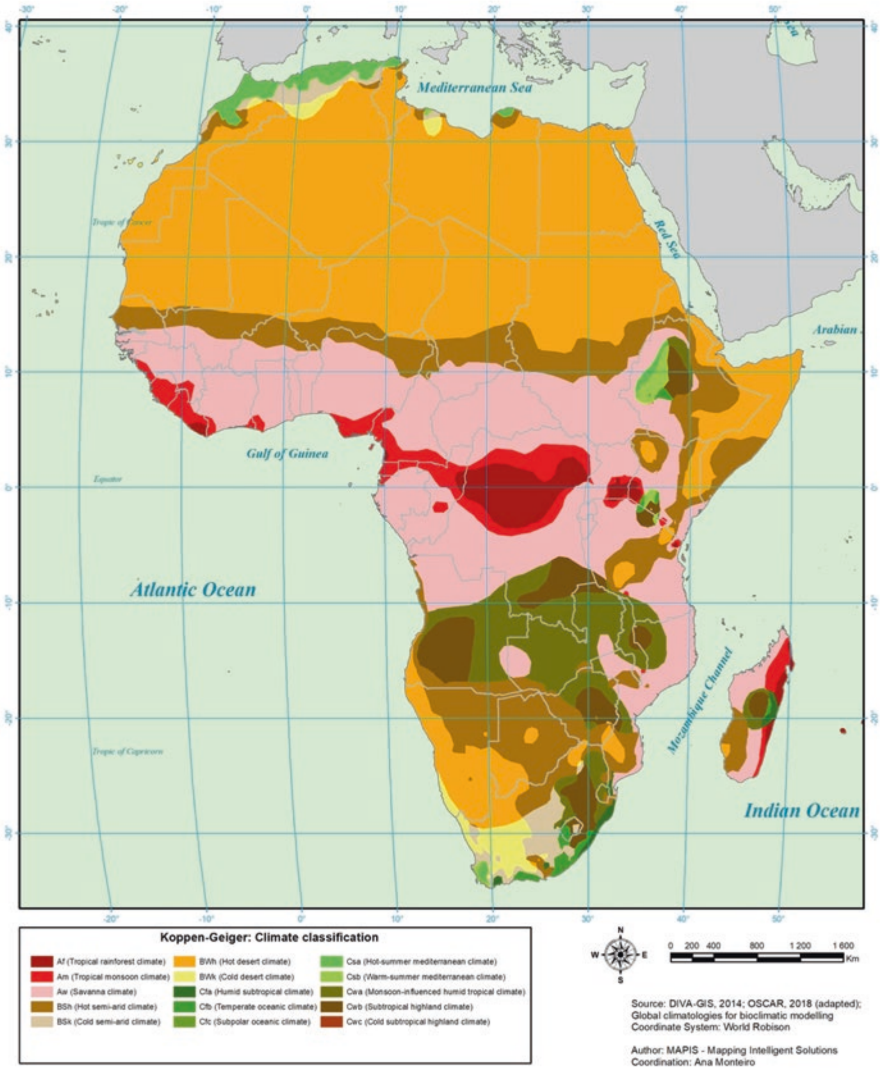

Fig. 2.1 Africa Köppen-Geiger climatic classification criteria

From latitudes 10° to 20 °C, we have the tropical (wet and dry) with two rainy seasons, high temperatures (20–25 °C) with small temperature variations in the wet subtype and slightly higher ranges in the dry one.

Above the direct influence of the subtropical high-pressure centres (latitudes 20–30°), we have the desert and semi-desert types which severity degree is affected either by air pressure or west coast oceans' currents or sea distance.

In the higher latitudes (30–40°), we have Mediterranean climates with lower yearly average temperature, higher temperature ranges and a hot and dry season and a colder and rainier season.

The more than 1000 World Meteorological Office climatological stations available let us support the multiplicity of climatic contexts that exist in Africa, although in many cases, for social, economic and political reasons, the series have quite a few record gaps (cf. Appendix 1). If we select from this extensive list only a few examples (20) and draw up the monthly temperature and rainfall diagrams for the 2017 records, we confirm precisely what Köppen and Geiger expressed visually so well by applying their classification criterion.

Looking at the results of the spatial distribution of the climatological normal (1983–2005) of temperature, diffuse radiation, insolation, relative humidity and precipitation (Figs. 2.2, 2.3, 2.4, 2.5, 2.6, 2.7 and 2.8), it is clear that this continent witnesses, from the climatic point of view, all the constraints which generate practically all the climatic contexts of the intertropical zone and of the temperate zone strongly influenced, at some times of the year, by the cells of the subtropical high pressures.

The effects of the earth-sun position along the year, the night and day duration due to the Earth's spin axis with respect to the ecliptic plane, the essential features of the atmospheric circulation, the intensity of the maritime effect, the presence of warm and cold ocean currents, the altitude, etc. are absolutely seen in each and every one of the African climate types and subtypes.

2.3 Current and Future Climate Risks

The sea level rise, the drought exposure, the unpredicted and impressive floods, the shifts in the rainfall patterns and the severity of temperature extremes have been recorded, in Africa, as more and more frequent extreme events due to the climate variability.

In Africa these signals of climate impulsivity reach targets excessively vulnerable either from the geopolitical and socioeconomic point of view or from the environmental one (Douglas 2017). Hence, we have been witnessing a considerable increase in the progression of the consequences in life quality standards and health with a prevalence increase of cholera, malaria, meningococcal meningitis, schistosomiasis and a long list of other diseases related to malnutrition and famine.

According to the ranking (1997–2016) published in the *2018 Global Climate Risk Index* (CRI), the majority of the African countries are above 100, 7 are between 51 and 100, 3 are in the class 21–50 and another 3 fall in the class 11–20. The CRI considers the total number of deaths, the number of deaths per 100,000 inhabitants, the sum of losses in US$ in purchasing power parity (PPP) as well as the losses per unit of gross domestic product (GDP).

The high dimension to climate hazard exposure combined with a huge vulnerability and the lack of institutional and individual capacity to cope with the climate variability led almost all the African countries to belong to the highest-risk trend in the world (Fig. 2.9).

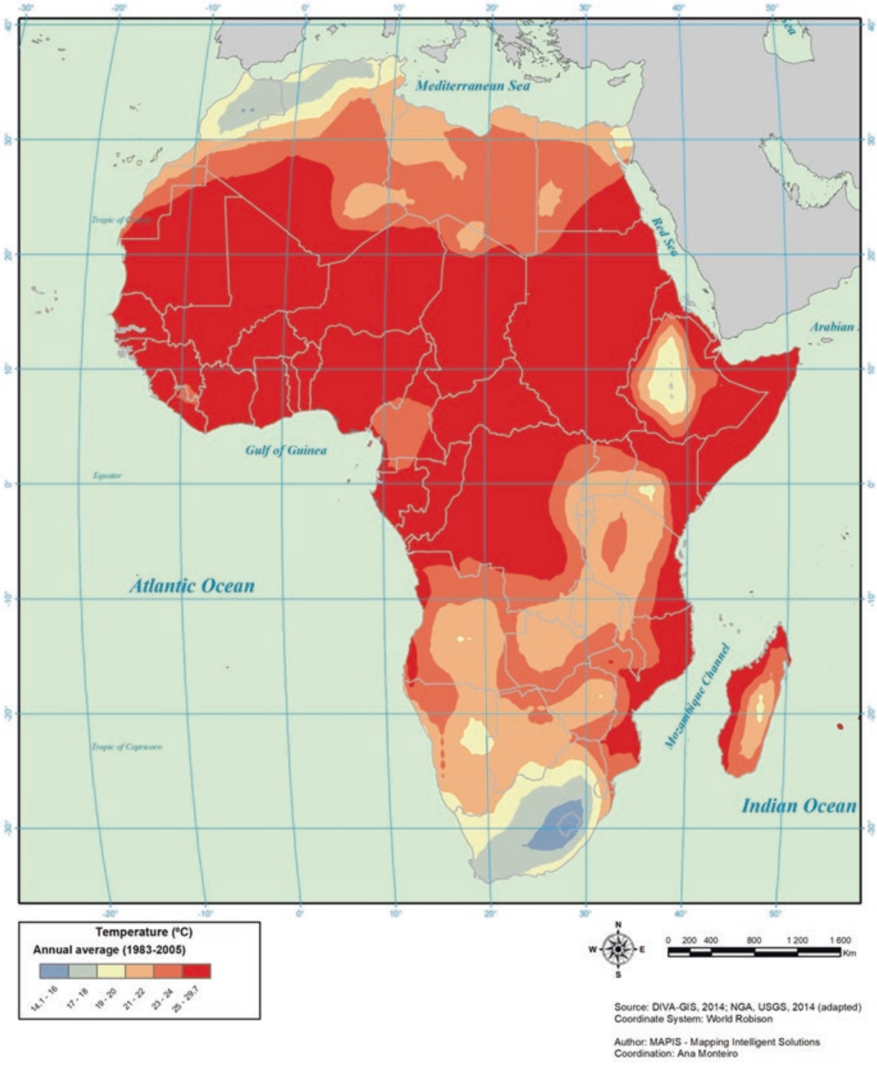

Fig. 2.2 Africa annual average temperature (1983–2005)

And that's the main reason why the top 12 ranking of countries in the world that are further away to achieve basic goals like well-being are occupied by African countries (Inform 18, p. 24).

The IPCC more recent report describes the observed trends of the main climate risks in Africa related with robust scientific evidence of weather and climate extremes already ongoing merged with the political, socioeconomic and environmental specificities (Niang et al. 2014). The report underlines a robust trend

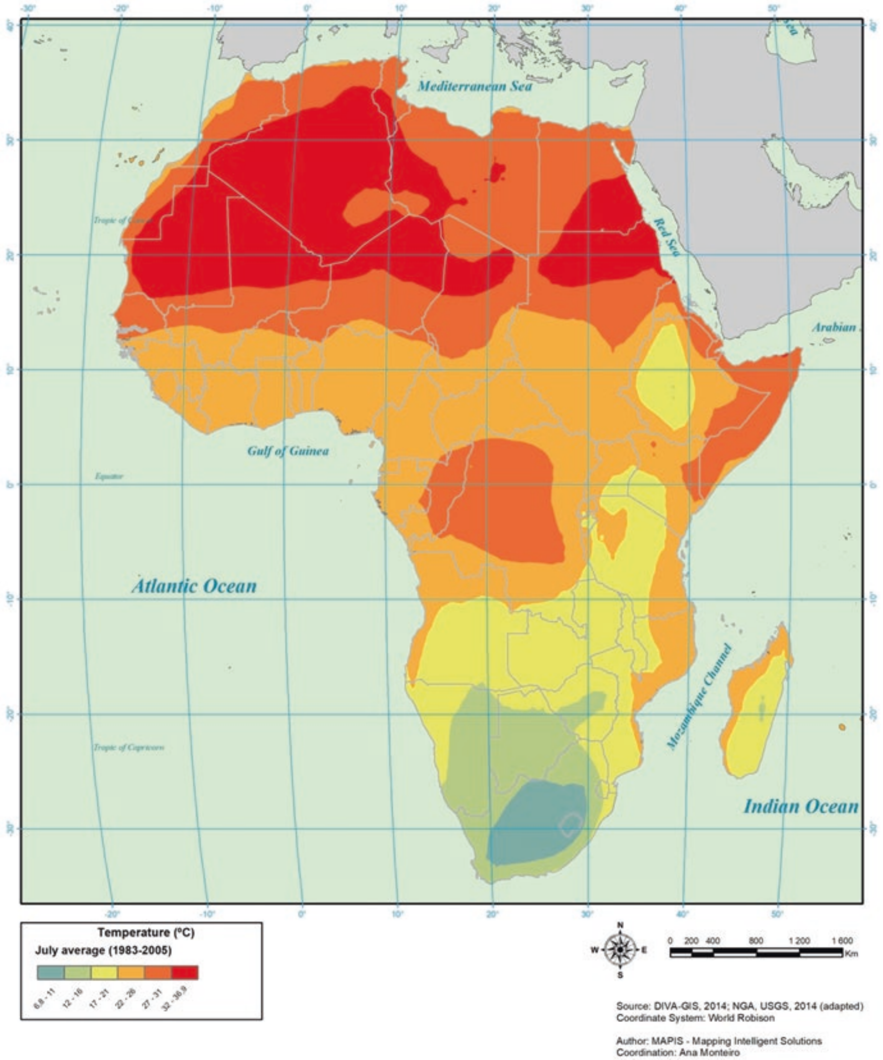

Fig. 2.3 Africa July average temperature (1983–2005)

of increase in warm days and nights in the West, East and Southern Africa as well as in Sahara and a decrease of dryness in East Africa and an increase of dryness in Southern Africa (Niang et al. 2014).

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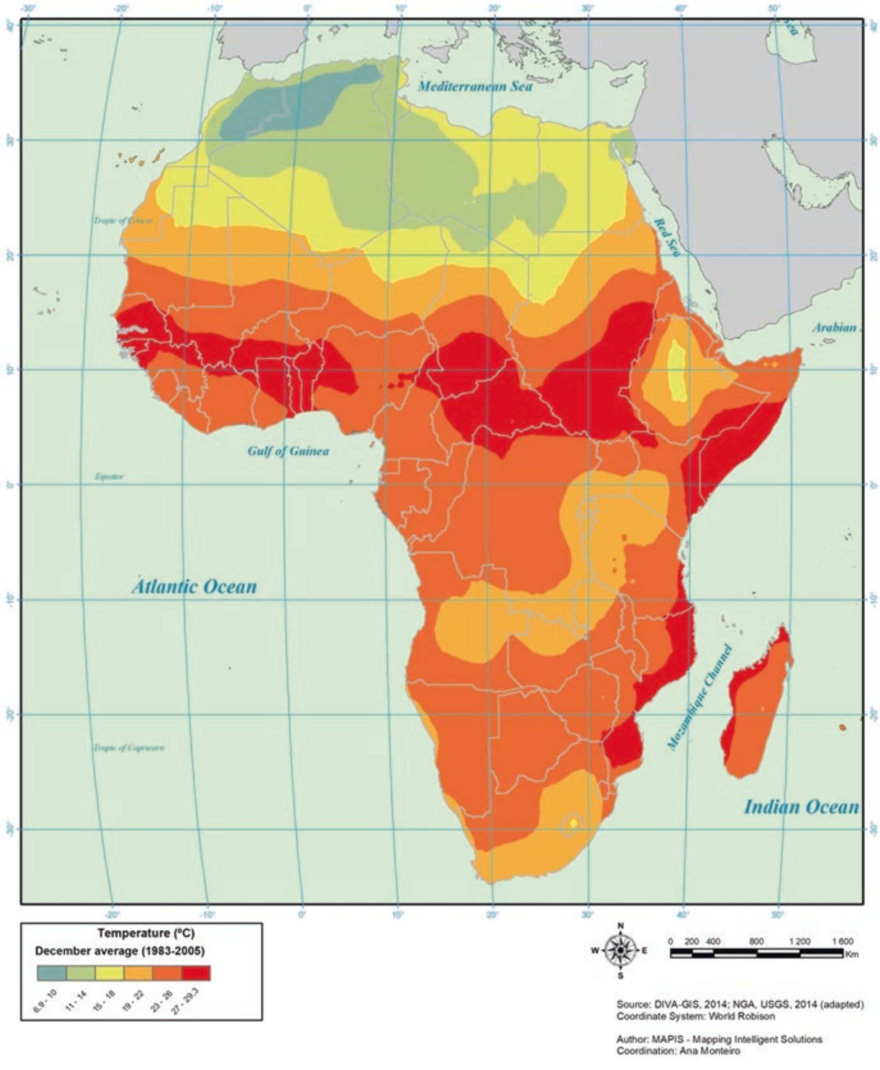

Fig. 2.4 Africa December average temperature (1983–2005)

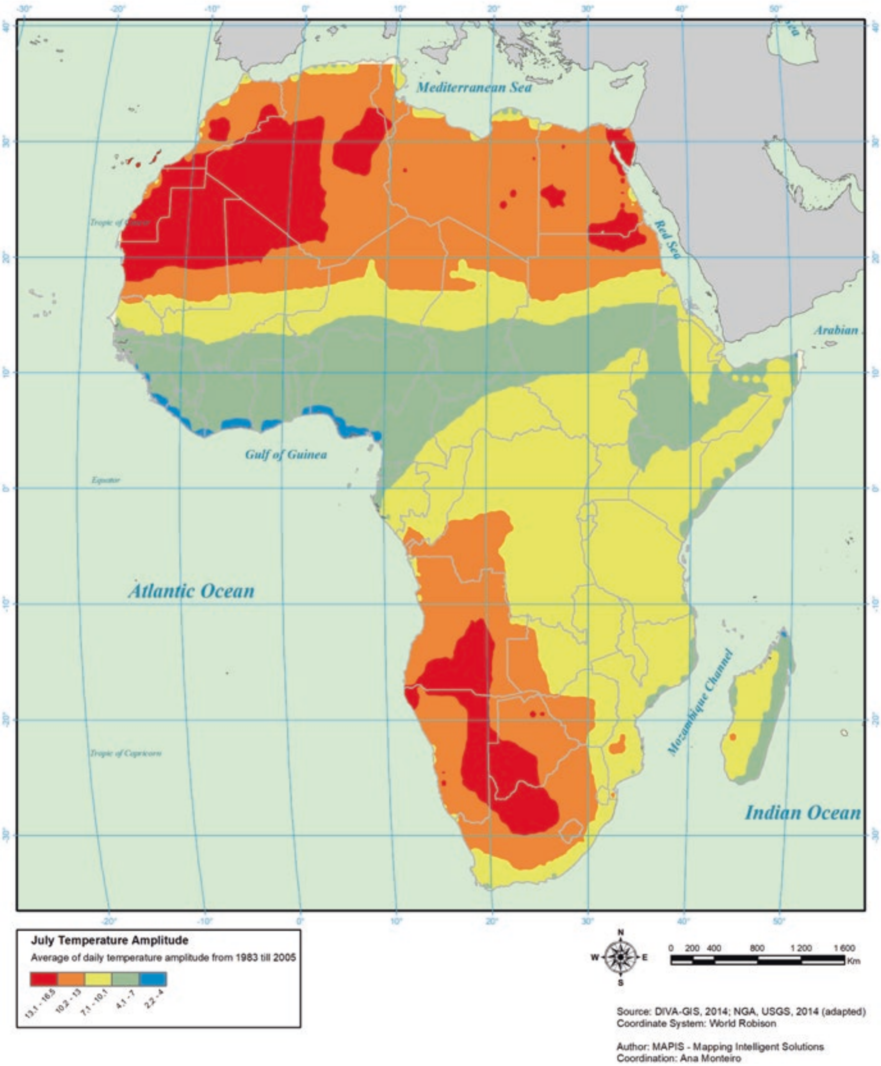

Fig. 2.5 Africa July average daily temperature amplitudes (1983–2005)

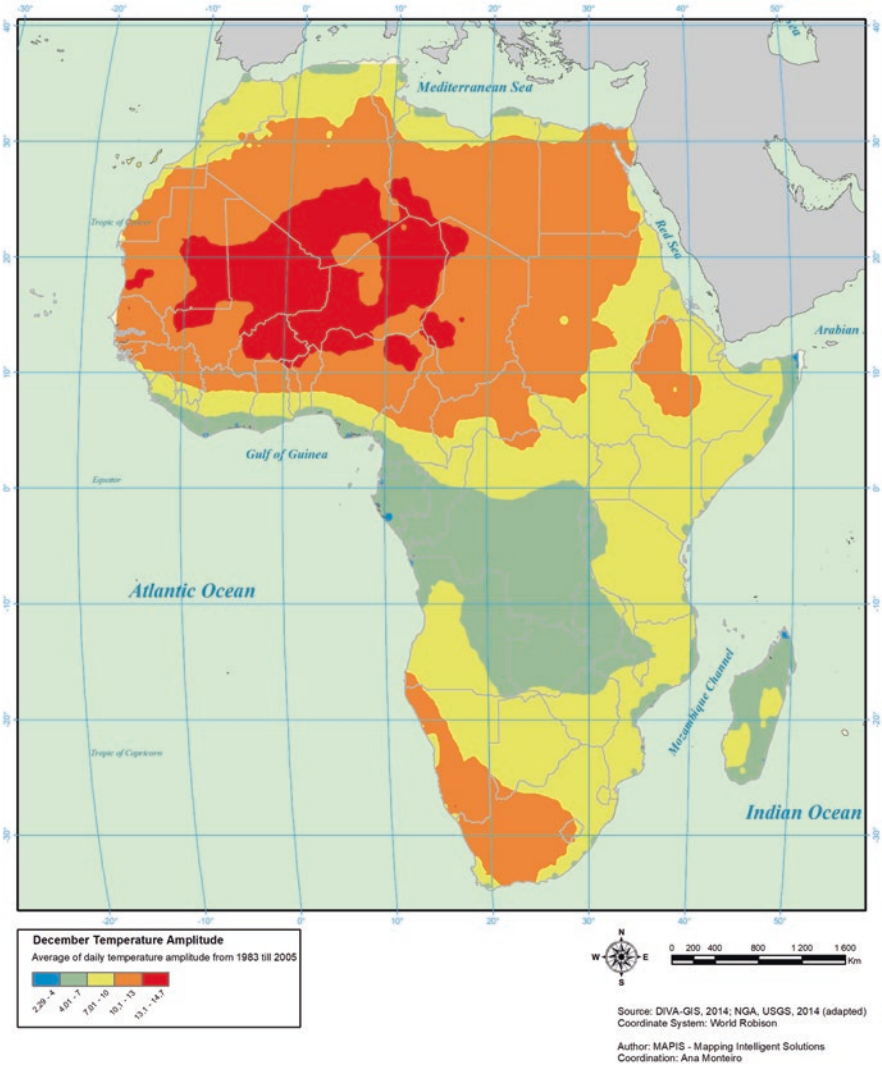

Fig. 2.6 Africa December average daily temperature amplitudes (1983–2005)

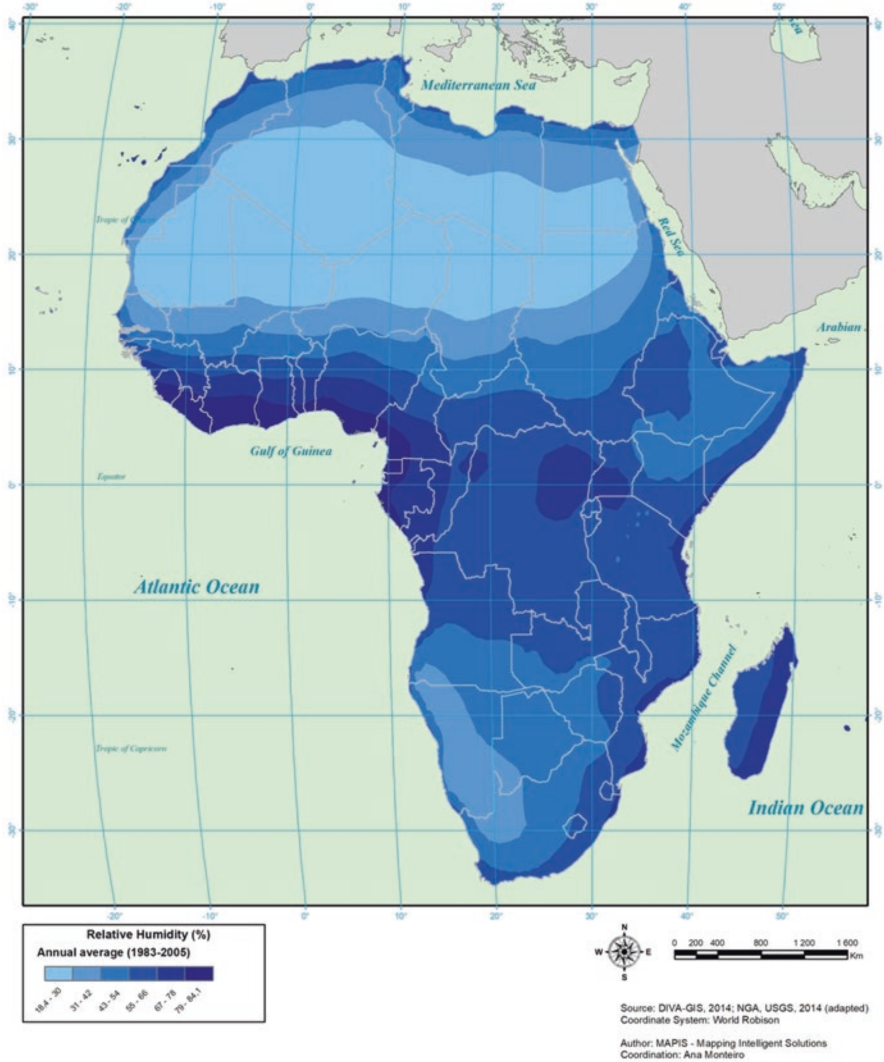

Fig. 2.7 Africa annual average relative humidity (1983–2005)

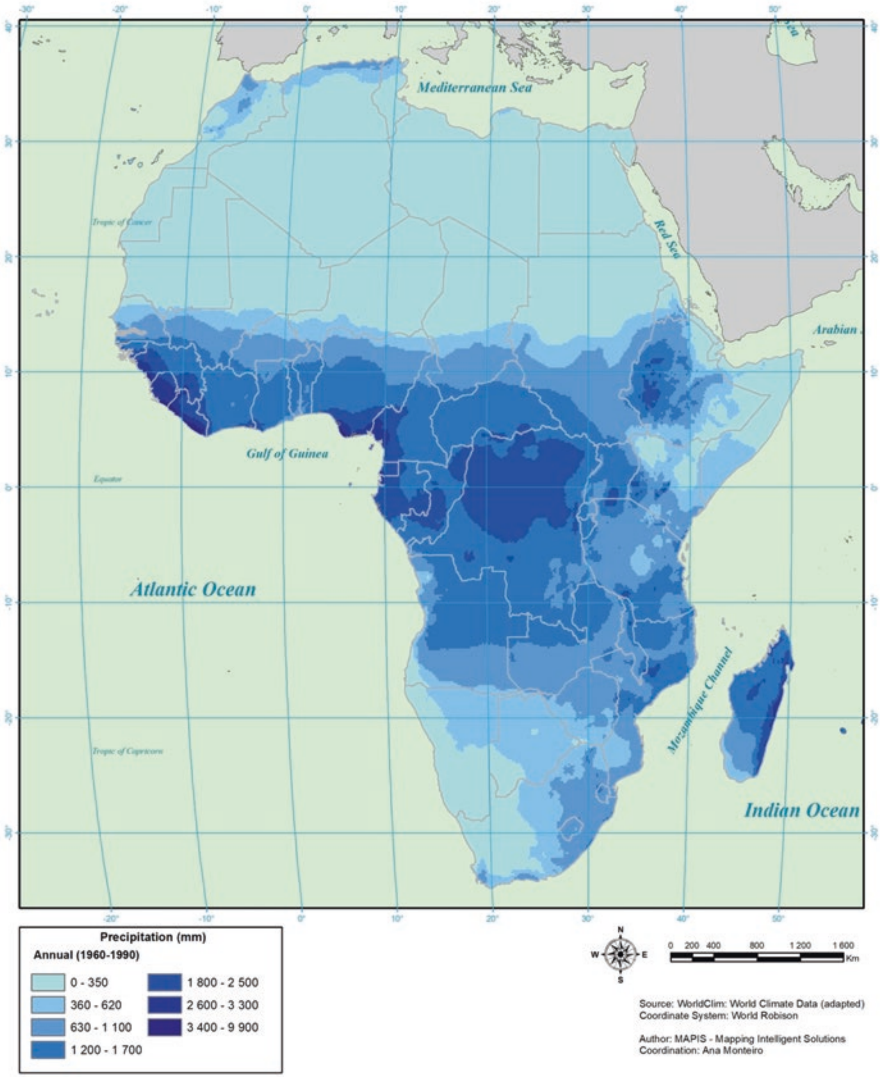

Fig. 2.8 Africa annual average precipitation (1983–2005)

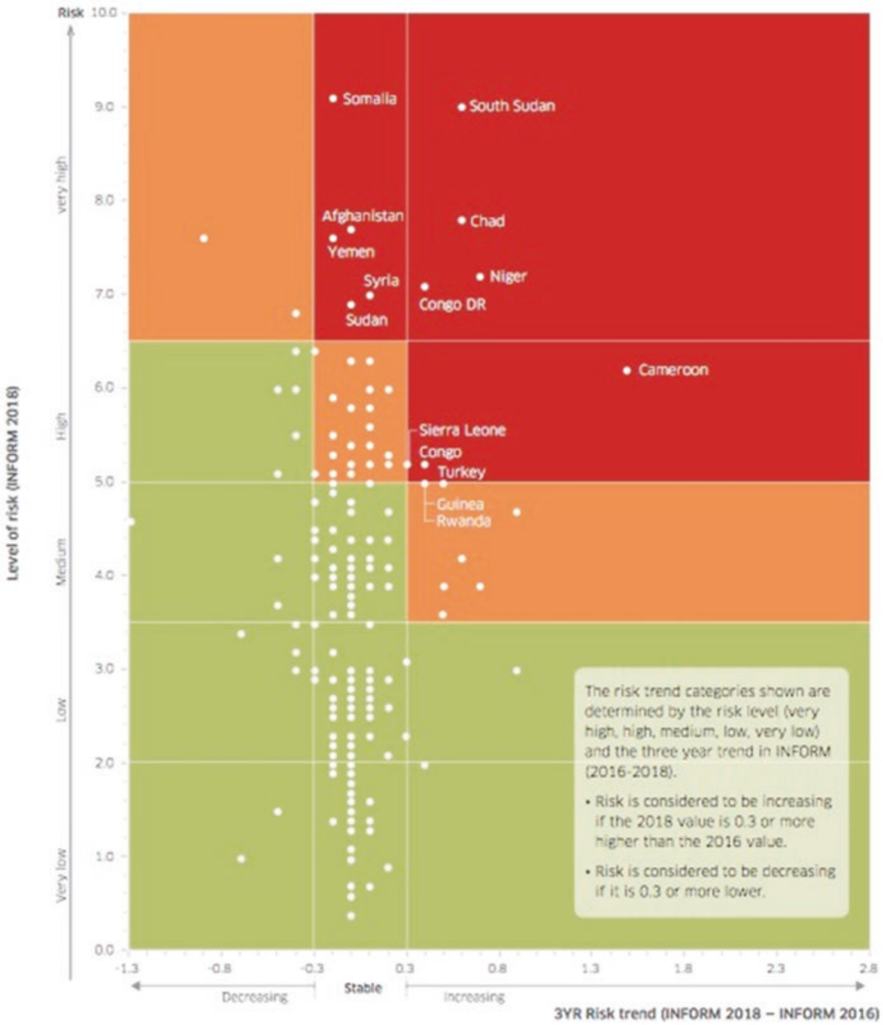

Fig. 2.9 Risk level and trends by country (Inform 2018, p. 10)

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Part II
Bioclimatic Design

Chapter 3
Bioclimatic Project: General Guidelines

Manuel Correia Guedes, Leão Lopes, and Bruno Marques

The problems of environmental sustainability and energy saving are universal and common to all countries and regions worldwide. The interdependence with climatic and environmental factors is a reality that makes all countries and all citizens equally responsible for the present ecological problems, which will inevitably worsen if we are not all aware and supportive to their mitigation, if not prevention.

The first and possibly more effective measure to reverse the general trend is certainly the information and mobilization of the public, and especially of the professionals, for a deeper understanding and accountability, leading to systematic interventions for their resolution.

The awareness of any problems affecting the human society is surely proportional to the capacity of mobilization of the media, the degree of literacy of the people, the cultural level of the information professionals and, especially, the education system's ability to frame and focus the education of the child, adolescent and adult, in this case, on the problems of sustainability and environmental balance.

All these capabilities are still in their infancy in Africa. Therefore any threat to current life that is not objective, immediate and tangible tends to be perceived by most people as not requiring a short- or even long-term change of attitude. The issues of sustainability and climate change are frequently considered as belonging to rich countries. The African continent, despite its low levels of industrialization and consumerism, is in a more vulnerable position than developed and highly industrialized countries. The hyper-consumerism should not be a role model for developing countries, which sometimes mistakenly adopt Western trends. There is a latent need not to follow the bad examples of the industrialized world and

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preserve a quality that can be considered as intrinsic to the lack of financial wealth, which is the ability to recycle and take advantage of existing resources.

The richer countries have exploited the natural resources of the poor, and the (few) rich people of the poorest countries collaborate with this system, allowing the exportation of natural resources at minimal costs. The debate against hunger, poverty and endemic diseases features prominently in Africa. This is the real situation in Africa. The consequences are multiple and harmful.

It is essential to think of strategies of ecologic planning and sustainable development, in a holistic and integrated way, avoiding short-term and low-reach solutions. The energy sustainability and the responsible use of natural resources must be an integral part of the sustainable development of the ecosystem.

Building and urban renewal have an urgency that requires a different approach from that in Europe. This is due to the scarcity of resources, energy shortages, the pressing demand for social housing and new or refurbished public buildings such as schools and hospitals and the difficulties of implementing building and town planning regulations (often deficient or even non-existent).

An indispensable measure is self-sufficiency. The high import costs may be the motivation to produce and naturally lead to the more viable solutions in ecological and environmental terms – involving the use of local resources. There must be a popular awareness of this. What can and must come from outside are the new techniques and concepts of construction, allowing a more rational use of raw materials.

Although the few measures implemented for the construction sector in recent years improved some aspects, this sector can only truly be fostered through the implementation of a new model of economic growth, based on an ecologically sustained development. In political terms, measures to promote low-cost local materials must be implemented, simultaneously developing local typologies and construction techniques, which prove to be decisive and efficient. Cooperativism and associativism should be encouraged, leading to network of solidarity and cooperation among citizens and between the eco-technosphere and the biosphere.

More than 1 billion people living in developing countries do not have adequate shelter, and an estimated 100 million are homeless. The participatory and self-construction processes should be integrated in this synergetic web of solidarity and collective union, with the objective of overcoming the problems of shortage of financial resources. The architect, in his professional practice, beyond the use of local materials and the introduction of renewable energy systems, must consider priority areas in the project and contemplate the building as an organism that can grow in a process of spatial evolution that accompanies the growth of families. The evolving shelter that includes spaces with potential for expansion for the growing families is a cultural element in Africa. Simultaneously, the definition of priority areas of construction is essential for the management of financial resources.

There are many various definitions for sustainable architecture, but the essence of sustainability is intrinsically linked to the essence of architecture. A good building is naturally sustainable. We can also find practices of sustainability in the vernacular architecture of many communities. It incorporates building technologies that result from the empirical knowledge of many generations that, through the centuries, developed strategies to adapt to the surrounding environment, using local resources.

Today there is very little information on the issue of sustainable building, adapted to the climatic, social-economic and cultural context of African countries. On the one hand customers, either private or institutional, are not sufficiently informed or motivated to commission sustainable buildings. On the other hand, technicians, engineers and architects do not assume an attitude conducting to the adoption of sustainable design strategies in the project processes. Finally, and as a consequence of this situation, there is not enough motivation, or clarifications, leading to adequate legislation, with necessary incentives or sanctions to those who implement, or disregard, the correct application of environmental, sustainable building design strategies, whatever their level of intervention in the process. This is reflected in all aspects relevant to the solution of the problem, including the commercial aspects, leading to a near-total absence in the local market, of materials and equipment to ensure a better environmental performance of buildings.

There is however a vast body of academic knowledge and analysis' tools that allow for the identification of the main design strategies to use in the project of buildings in Africa – efficient and low-cost solutions, providing a good indoor comfort performance. The information presented in this chapter results from a 3-year EU project, the SURE-Africa, which aimed at producing and strengthening knowledge on low-energy architecture for hot regions in Africa, contributing to a sustainable development through the vital area of energy efficiency in buildings and cities. The situation found in the participant countries – Angola, Cape Verde, Guinea-Bissau and Mozambique – is representative of many other countries in Africa, with developing economies often scarred by long-term armed conflicts (Figs. 3.1 and 3.2).

It is important to consider energy conservation through passive building design as a proven equivalent to renewable energy power generation. Well-established knowledge in this area can be adapted to the African economic and climatic context. In nondomestic buildings, a high priority is the avoidance of air conditioning, or the reduction of air conditioning loads by fabric design and controls, to low values. In the case of housing, it is important that basic comfort performance criteria are met, since failure in this respect will prompt the occupants to purchase package air conditioners if and when reduced costs and improved finances allow. The purpose of this chapter is to suggest basic measures for a comfortable house, which respects nature, and with reduced costs of construction and maintenance. Taking into account the climate, natural resources and socio-economic context, best-practice strategies are drawn for the architectural project. This chapter does not pretend to be more than a simplified, and therefore easily accessible, introduction to the problem of environmental sustainability in the context of architectural design, focusing on bioclimatic design strategies (Figs. 3.3, 3.4 and 3.5).

In the variety of climatic contexts existing in Africa, it is possible to achieve a balance between building and climate by applying a series of project strategies – referred as bioclimatic or passive design strategies. Passive design strategies aim

Fig. 3.1 Vernacular architecture in Santo Antão (Cape Verde): the use of local resources for construction and the adaptation to the climatic context are century-old practices

at providing comfortable environments inside the buildings and simultaneously reducing their energy consumption. These techniques allow the buildings to adapt to the external environment through architectural design and the intelligent use of building elements and materials, avoiding the use of mechanical systems that use fossil-fuel energy.

The use of fossil, non-renewable, energy is, as widely known, the main responsible for the serious problem of global warming, resulting from the emission of greenhouse gases into the atmosphere. In buildings, the use of electricity generated from fossil fuels greatly contributes to the intensification of this problem. Passive measures reduce the energy consumption of buildings throughout their existence. Two examples of passive strategies are the optimization of the use of natural lighting to reduce the need for artificial lighting systems and the promotion of natural ventilation to avoid the use of air conditioning for cooling.

One can find good examples of African architecture that is suitable to the local environmental context. However, today, the practice of a passive or bioclimatic architecture, with environmental and energy concerns, seems to be increasingly forgotten. Although existing publications extensively refer to the potential benefits of this architecture, its use is still often misunderstood, being erroneously considered a risk, inefficient, too complicated or expensive. For example, in many new buildings, climatization issues are left to air conditioning engineers, who tend to adopt the "safe" use of air conditioning. Despite the existence of many examples that prove the efficacy, improved levels of comfort and economic advantages of using passive techniques, there is still a great need for implementation of this knowledge and to increase the number of passive, bioclimatic buildings, in terms of new construction and rehabilitation (Fig. 3.6).

Fig. 3.2 Degraded slum in Luanda (Angola): the fight against poverty is a priority

Fig. 3.3 Sustainable, bioclimatic house in Mindelo: a contemporary example of adaptation to the local context

Fig. 3.4 Eco-tourism resorts in Bijagós (Guinea-Bissau): contemporary architecture inspired on local vernacular, with a good bioclimatic performance and use of local building materials

Fig. 3.5 Examples of imported architectural typologies, inadequate to the local climatic and social-economic context (Bissau, left; Luanda, centre, right)

Considering that heat is the predominant feature of African climates, particular attention should be given to the issue of cooling of buildings, which is fundamental to achieving comfortable living environments. The cooling of buildings can, and should, be achieved by natural means, avoiding the use of energívorous climatization systems. The aim of the passive cooling techniques is to avoid the accumulation of heat gains and provide natural cooling, avoiding the occurrence of

Fig. 3.6 Above: vernacular house in Santo Antão, Cape Verde, adapted to the climatic context. Below: buildings in a recent tourism complex, with building typologies inspired in vernacular architecture, in Angola (centre) and Mozambique (bottom)

overheating. The principles of passive cooling techniques have been successfully used for centuries, before the appearance of air conditioning. These traditional techniques were simply reinforced with contemporary technological knowledge and optimized so that they could be successfully incorporated in the design and operation of buildings.

The previous chapter presented a brief description of various climatic regions existing in distinct locations in Africa, as examples of the starting point of the methodological process for the practice of bioclimatic architecture, of passive design. These climatic characteristics determine the level of comfort inside the buildings, as well as the appropriateness of different building design strategies. Several issues should be analysed during the design process, which are associated with the sun, such as the orientation of the house, solar protection needs in different areas – coastal or mountain – the required spacing between buildings, the road and promenades' surface, the implementation of trees and green areas to lessen the impact of radiation and preserve fresh air and types of materials to be used. These principles are next presented, beginning with the first steps to consider – the location, shape and orientation of buildings.

3.1 Building Location, Form and Orientation

The selection of the place, shape and orientation of the building are the first options to consider for optimal exposure to the sun path and prevailing winds. In hot climates, it is essential that the implementation of the houses take into account the wind regime for efficient ventilation and a consequent improvement of the indoor comfort. In mountain areas, the houses must be located in the lower zones of the mountain and above the riverside, where there is more air circulation. Priority should be given to the slope side with more hours of shade. On the coast, the facades facing the sea should be protected by porches, generously proportioned, to lessen the impact of the sun reflection on the sea inside the housing. The exterior arrangements are essential to protect the interior from excessive solar gains (Figs. 3.7 and 3.8).

New residential areas should also be designed with a convenient distance from the road with the largest circulation, avoiding noise and other nuisances. The streets should be narrow and oriented so that there is always a shaded side (Figs. 3.9, 3.10 and 3.11).

As the outdoor environment is hot, ventilation and indoor comfort are critical aspects. In urban areas the impact of solar radiation on the roofs and the facades of buildings and the circulation of the cool breezes around buildings should be studied. Otherwise there might be a risk of creating a very uncomfortable environment inside the houses (Figs. 3.12, 3.13 and 3.14).

In terms of the *shape* of the building, the configuration and arrangement of internal spaces, according to their function, influence exposure to solar radiation as well as the availability of natural lighting and ventilation. In general, a compact building

Fig. 3.7 Left: mountainside houses on the island of Santo Antão, Cape Verde. Right: recent residential condominium located in a slope, in Maputo, Mozambique

Fig. 3.8 Houses with porch, in the island of Sal, Cape Verde

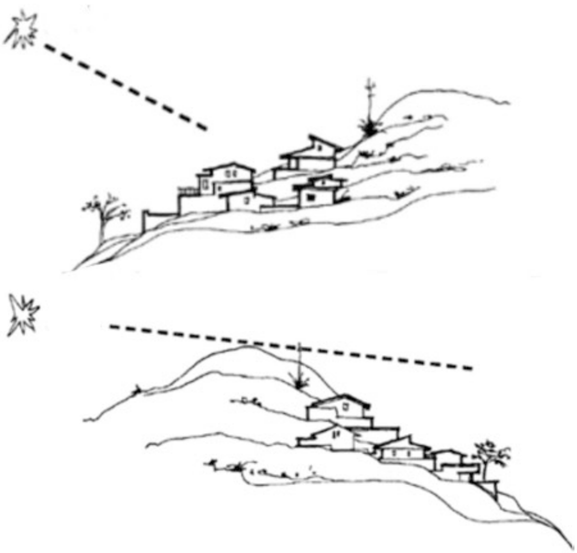


Fig. 3.9 Location on a hillside. In the first scheme, the houses are too exposed to the sun at times of peak incidence. The second diagram, below, shows a more favourable location. In times of higher incidence of the sun, the houses benefit from the shade of the hillside

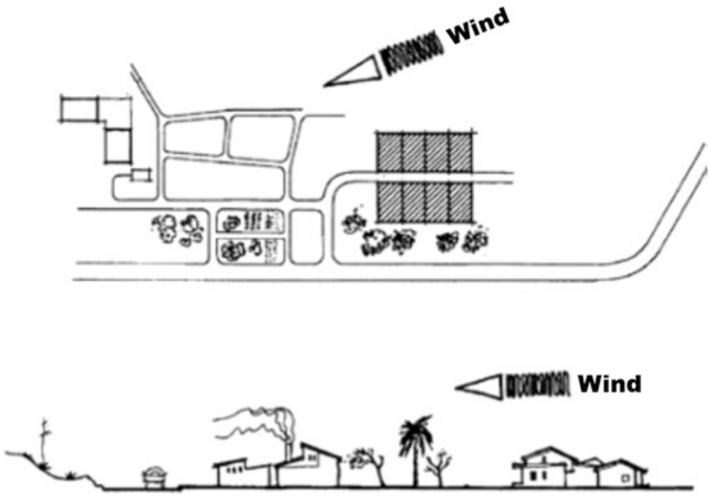
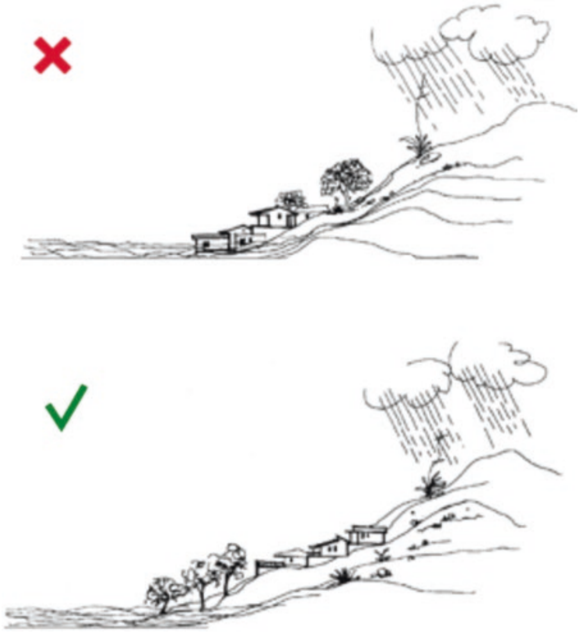


Fig. 3.10 Correct orientation, considering the wind regime

Fig. 3.11 It is necessary to prevent implantation of the dwellings too close to streams, riverbeds, flood-prone areas and slopes subject to landslides. Choose safe areas, protected from flooding. The fact that it does not rain regularly in Cape Verde is a misleading fact, because it takes people to build anywhere. In times of heavy rains, the water meets his old way. The correction draining works are always more expensive and usually only done when the rains have caused much damage. The second scheme presents the convenient location of a housing cluster



will have a relatively smaller area of exposure, i.e. a low surface-to-volume ratio. For small- and medium-sized buildings, this offers advantages for the control of heat exchange through the building envelope – however the sizing of the openings should be adequate to enhance natural ventilation. In hot humid climates such as in Guinea, window size should be maximized (cf. 1.4); in more arid regions such as in

Fig. 3.12 On a hillside location, we must study the prevailing winds, in order to favour indoor ventilation

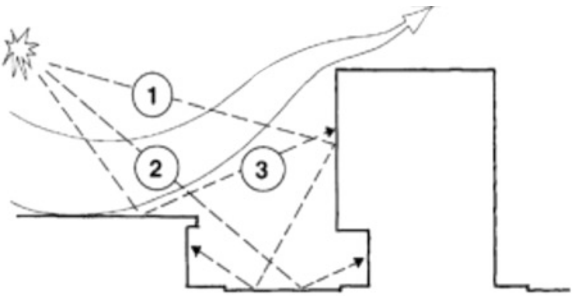


Fig. 3.13 In this scheme, the sun beams (1) fall on the building facade, which reflects them onto the pavement and then into the building interior. The beams (2) hit the pavement and are reflected in the people circulation. The beams (3) fall on the flat roof of the lower building, reflecting in the facade of the taller building. The wind slips over the flat roof and as there is no entrance in the front facade passes over the building. The environment gets too hot in and around buildings

Cape Verde, with higher daily temperature amplitudes (allowing for night ventilation), window size should be relatively reduced. The twinning of the buildings in the band also has advantages, by reducing the area of exposure to the sun, hence reducing risks of overheating.

The areas of the building that can potentially be daylit and naturally ventilated, the so-called passive areas, can be considered as having a depth of two times that of the floor-to-ceiling height (i.e. usually about 6 m). This depth can be reduced when there are obstacles to natural light and ventilation, because of inadequate internal divisions and the neighbouring buildings or in the case of spaces adjacent to atria. The proportion of passive area of a building in relation to its total area provides an indication of the potential of the building for the use of bioclimatic strategies.

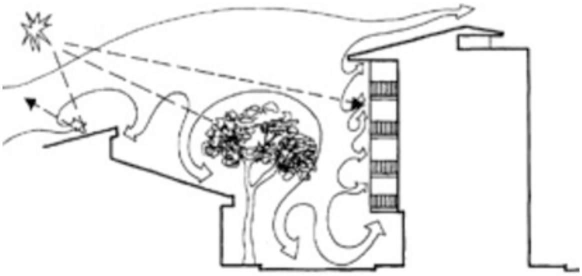


Fig. 3.14 The configuration of the facade of the tall building and of the roof of the lower building was changed to improve the external environment in the area. The tree dampens the effect of sun radiation and promotes air circulation. The effect of wind in the area, aided by sloping roof of the lower building and the balconies of taller building, becomes more diversified and thus can penetrate inside the houses

Fig. 3.15 The seaside village of Paúl

The objective is always to maximize the passive area. In buildings with non-passive (active) areas of significant size, solutions using energívorous mechanical systems tend to prevail (Figs. 3.15, 3.16, 3.17 and 3.18). In the case of the rehabilitation of buildings with active areas, these should be converted to unoccupied spaces, for example, storage. When the active area reaches large dimensions, it is advisable to incorporate light wells or atriums.

Fig. 3.16 The ventilation has a fundamental role, and one should focus on solutions to optimize the air circulation. The use of the courtyard-house typology is an effective measure in dryer climates such as in regions of Angola, Cape Verde and Mozambique. The issue of natural ventilation is further developed in Sect. 3.7, ahead

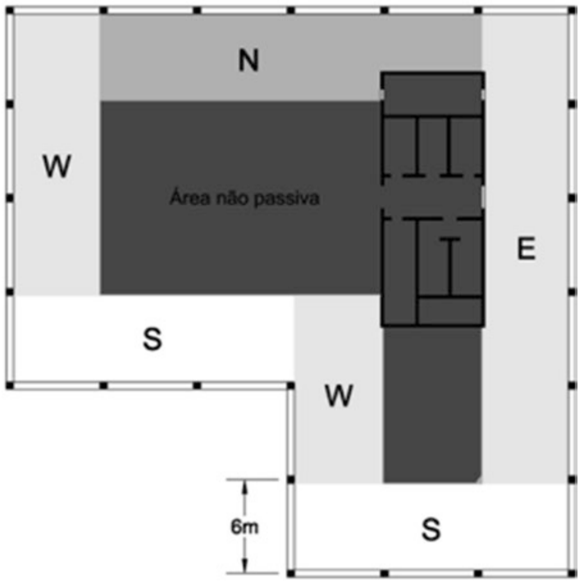


Fig. 3.17 Definition of passive areas (light colour) and non-passive areas (or active, darker colour) in the plan of a building. (Adapted from Baker and Steemers 2000)

The concept of passive zone should be considered from the first stages of the project, when one defines the shape and orientation of the building. The passive design strategies to be used vary depending on the orientation of the different areas of the building. These strategies include, for example, changing the glazing area and the use of different shading devices, which are described in the following subchapters.

Fig. 3.18 On top (1) residential areas in Maputo, Mozambique: the twinning of houses reduces the area of sun exposure, reducing the risk of overheating. Below (2): left, geminated houses in Sal, Cape Verde; right, a dominant facade of an area contributes to situations of discomfort from overheating

The *best orientation* of the building to reduce solar heat gains will be parallel to the East-West axis, as it restricts the exposed area of the facades that receive low angle sun (East and West) and facilitates the shading of the facade that receives higher angle sun (Fig. 3.19). It also improves natural lighting. In refurbishment, and in many urban situations where orientation is outside the control of the architects, an unfavourable orientation can be compensated by reinforcing other design strategies to control solar gains, such as shading or window sizing.

The correct orientation of the occupied housing spaces, depending on the sun path and wind regime, is the starting point to take advantage of these renewable energies. The insolation of the facades is defined in the process of the choice of building location and orientation and is decisive for the indoor comfort. The orientation to the South is generally recommended for the Northern Hemisphere, because it optimizes the solar gains for heating during the cold season. However, in regions where the issue of overheating is a priority, such as in Cape Verde and Guinea, South orientation should be avoided due to the high incidence of solar radiation – orientation to the North is recommended, similar to regions located below the equator (such as Angola and Mozambique). The use of porches should also be considered, in order to prevent direct solar radiation to fall directly on the external walls. The existence of these obstruction elements provides shading to the facades and eliminates the excessive solar radiation and overheating.

The bedrooms, when oriented towards the East, catch less heat and are cooler spaces during the afternoon. The facades oriented to the West should be protected from excessive solar radiation. The design of the glazed areas must be compatible

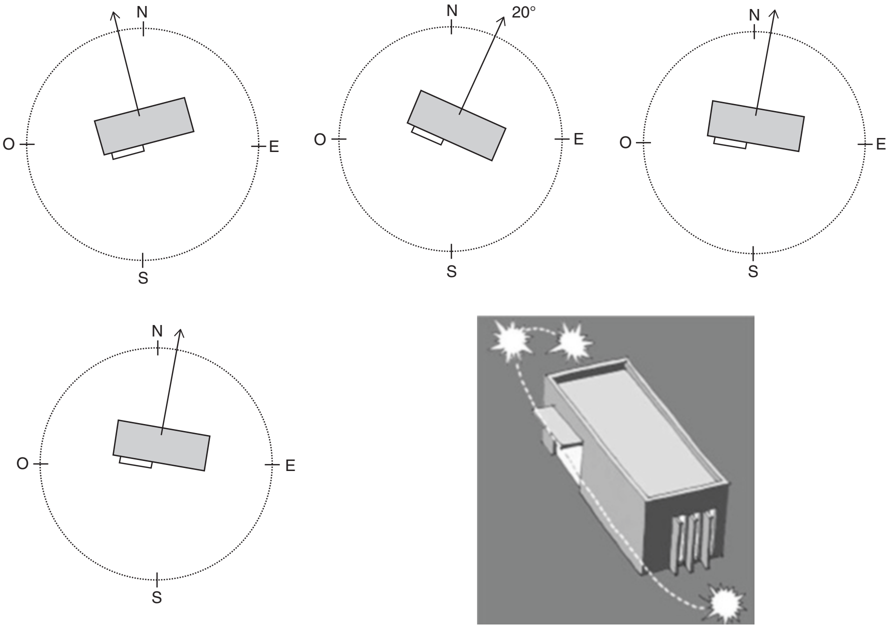


Fig. 3.19 Optimization of solar orientation for different latitudes. Above: (left) Luanda, Angola (8°50′S), the best orientation for the main facade is 352°05′N; (centre) island of Sal, Cape Verde (16°35′ N), the best orientation is 20°N; (right) for Maputo, Mozambique (25°58′S), the best orientation is 5°N. Below: (left) the best orientation for the main facade in Bissau (11°5′N) is 2°5′N. The acceptable orientation should not exceed a variation of 45° (East or West) from the optimum orientation

with the orientation of the facade. The kitchen space should be the cooler one in the house, so it cannot be oriented towards the South (or North in the Southern Hemisphere) or West. The direction of prevailing winds should be taken into account, so that heat and odours are not dragged to the rest of the house.

Thus, for the more permanently occupied spaces, the privileged orientation is to the North in hot African countries located both in the Northern and Southern Hemispheres, as shown in Fig. 3.15 – yet a variation of 45° (between Northeast and Northwest) may be acceptable (Fig. 3.20).

The optimization of the orientation and passive areas contributes to the avoidance of overheating situations, of overheating, being the first step towards promoting strategies for heat protection and dissipation. The *heat protection techniques* such as shading, the sizing of windows, the reflective coating of the building envelope or thermal insulation provide protection against the penetration of unwanted heat gains into the building and minimize the internal gains. In Cape Verde, it is essential to value the building elements that provide obstruction and shade so that thermal comfort is achieved inside the compartments. These elements can be tectonic: flaps or porches, vegetation or porches with vegetation (*cariço*, *sisal* or vines). The vegetable elements near the facades or even the cladding of facades with vegetable elements increase the internal comfort and act as a filter for solar rays. In

Fig. 3.20 Use of porches and vegetation canopies for protection against solar radiation in residential buildings (Cape Verde)

semiarid regions, the walls must be thick or double to retard the penetration of heat by day and cold at night (allowing for night ventilation).

Heat dissipation techniques maximize the heat losses, of heat accumulated inside the building, dissipating it through natural ventilation and thermal mass, evaporation, radiation or to a "heat sink" as the soil. The use of these techniques avoids overheating, leading indoor temperature to values close to the outside air temperature or even below this (Fig. 3.21).

The direct solar radiation is by far the main heat source. The use of solar control techniques in architectural design is a high priority strategy to minimize the impact of solar gains in the building. The best project solutions combine different passive cooling strategies, in order to achieve greater efficiency – such as cooling by night ventilation with thermal mass and external insulation. The effectiveness of passive cooling techniques can often be improved through the use of mechanical systems that use renewable energy such as solar panels or photovoltaic systems or low-energy systems such as fans.

3.2 Shading

Shading is a very effective strategy to reduce the penetration of solar radiation into the building, providing protection to areas of glazing (windows) and also to the opaque envelope. The heat gain through windows can be very significant, since windows have very little resistance to the transfer of radiant heat. In hot climates, a shaded building can be between 4 and 12 °C cooler than one without a shadow.

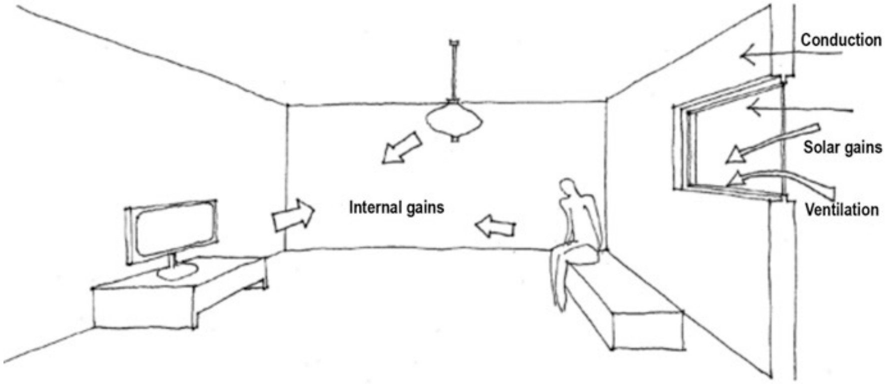


Fig. 3.21 The heat gains: (I) solar gains, caused by the incidence of solar radiation on the external surfaces, which is driven into the building (external solar gains), and the passage of radiation through the windows (internal solar gains); (II) internal gains, from the occupants, lighting and equipment; (III) conduction gains, from the conduction of heat from the warmer outside air into the building through the external surfaces of the building (facade and roof); (IV) ventilation gains, from the infiltration of warm outside air into the building

Fig. 3.22 Shading is a century-old heat protection technique. Vernacular buildings in Guinea-Bissau (left) and Angola (right)

Shading, of windows and of the opaque building envelope, can be done by fixed devices, by vegetation or through adjustable devices. Balconies, patios or courtyards can be useful typologies for solar protection (Figs. 3.22, 3.23, 3.24, 3.25, 3.26 and 3.27).

In terms of shading of the areas of glazing, the building should be especially protected from solar gains on windows oriented in the East and West, due to the low angle of the sun in the early morning and late afternoon. The East orientation can easily cause overheating, especially in poorly insulated and low inertia buildings. There is a wide variety of shading devices, fixed or adjustable, internal or external and more or less light. Table 3.1 shows the characteristics of different types of shading, which can be used in homes or services' buildings.

Fig. 3.23 Left: a house with covered courtyard in Porto Novo. Right: adjustable external shading in a house in Mindelo, Cape Verde

Fig. 3.24 Fixed shading – market on the island of Sao Vicente

Fig. 3.25 Patio and arcades of the Old School in Sao Vicente (left). Veranda and porch in a residential building in Bafatá (Guinea-Bissau)

Fig. 3.26 Shading using vegetation in Cidade Velha (left). Adjustable wooden venetian blinds in modern building in Bissau (Guinea)

Shading systems cut the incidence of solar rays before penetration through the glazed areas, preventing the greenhouse effect. There are several elements that may have this function, such as venetian blinds, shutters, awnings, shutters and eaves. It is important to ensure some distance between the shading element and the glazing area, so that the thermal radiation captured by the shading device is not transmitted into the building (Figs. 3.28, 3.29, 3.30, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37, 3.38, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44 and 3.45).

3.3 Envelope Reflective Coatings

The light colours of some coating materials reflect a considerable amount of solar radiation. The whitewash (limestone-based white paint) to paint the buildings is an example. The light-coloured coatings help to reduce the temperature of the building envelope and avoid the heat conduction into the building. The light colour reflects more energy. The dark materials absorb more quantity of energy (more heat), such as lava fields, black sand and paved roads. Non-metallic surfaces, such as concrete and wood, all emit long-wave (invisible) radiation well, even if they are painted white. This allows them to cool at night. Metallic surfaces, especially if polished, are poor emitters and thus retain the heat. Table 3.2 describes the characteristics of light-coloured reflective coatings (Figs. 3.46, 3.47, 3.48, 3.49, 3.50, 3.51 and 3.52).

3.4 Insulation

The correct location of the insulation protects the building against heat gains during warm periods and improves thermal comfort throughout the year. The sealing of the walls is also improved (preventing the infiltration of hot air) and reduces condensation problems on surfaces in areas with humid climates (Figs. 3.53, 3.54, 3.55, 3.56, 3.57, 3.58 and 3.59 and Table 3.3).

Fig. 3.27 Use of fixed shading devices ("Brise-soleil") in modernist buildings in Maputo (Mozambique, above); in Praia, Cape Verde (centre); and in Luanda, Angola (below)

Table 3.1 Characteristics of the various shading strategies

Shading type	Description	Performance
Fixed devices	Usually external elements like horizontal overhangs, vertical fins, egg crates or fixed external louvres	Horizontal overhangs, generally used above a southern window, can provide shading during summer and allow for solar heating during winter. In the East and West facades, a horizontal fixed device is better than vertical, but the facade is never completely shaded. Vertical fins can protect the North facade from the rising sun and sunset. The use of grid systems (from wooden jalousies to prefabricated ceramic or cement elements) can also be very effective and offers advantages in terms of privacy. However, they may reduce view to the exterior. Daylighting and natural ventilation must be considered in their design *Light-coloured shading* is preferable to dark-coloured, as it performs better in reflecting solar radiation, reducing its penetration in the building's envelope. They also can have a better performance in terms of daylight
Intermediate spaces	Balconies, courtyards, atria or arcades	These features can be very useful as a form of fixed shading, if their design is adequate. As in all shading strategies, design should also consider daylight and ventilation requirements. Shading performance depends on the building configuration or on the balconies' design
Neighbouring buildings	Buildings across the street can provide shading of the facades, particularly for lower floors	Neighbouring buildings can provide efficient shading, although in some situations, such as in narrow streets, they may decrease daylight availability The impact of this type of shading should be considered in the design process, in terms of the choice of shading devices and window sizing, e.g. increasing window size in permanently shaded areas, to improve daylight
Vegetation	When possible, vegetation can be used to shade the lower building floors	In situations where some passive heating may be necessary during the dry season, use preferably deciduous trees, in order to provide shading in the hot season, and let solar radiation and daylight in during the colder periods. Trees generally have the effect of reducing wind speed. However a row of trees with bare trunks for the lower 3 m may, if the foliage is dense above, deflect and enhance the breeze at ground level
Adjustable devices	These devices can be *external* – such as shutters (hinged, sliding), rotatable fins, horizontal plates, retractable venetian blinds, canvas awnings, tents, blinds or pergolas – made of wood, metals, plastics, fabrics, etc. They can also be *internal* – like curtains, roller blinds or venetian blinds – or positioned between the glass panes of the window	Adjustable devices are more effective than fixed, as they can admit all the solar radiation when it is desirable, like in winter, and offer more protection in summer. Their flexibility also allows a better use of daylight, when compared with fixed shading. They also allow for occupant control *External shading devices* are more efficient than internal ones, as they prevent solar radiation from falling upon the glass, while internal shading devices aim only to reflect back the already entered radiation. Louvres between panes of double gazing can also have a good performance, similar to external shading. However, roller blinds, found in various cases of domestic-type offices in the present survey, can be a poor choice in terms of view, daylight and ventilation *Light-coloured external opaque shading devices* can reflect up to 80% of the radiation impinging on the building, if properly controlled. Translucent white external devices (such as adjustable canvas devices) can reflect up to 60% of this radiation

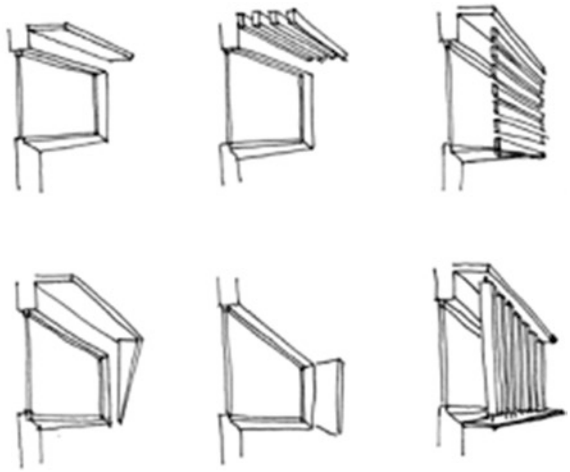


Fig. 3.28 Some typical examples of external shading devices for windows

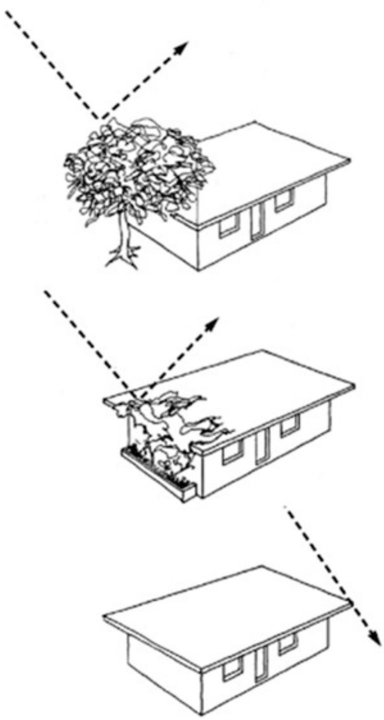


Fig. 3.29 The trees and plants, and the projecting eaves, reduce solar incidence

Fig. 3.30 Fixed shading in the facades of modernist buildings in Luanda

Fig. 3.31 Fixed shading in Luanda. Above: porch (left), shaded roof (centre), "Brise-soleil" (right). Below: arcades (left) and a fixed shading device at the Faculty of Architecture's building

Fig. 3.32 Examples of fixed shading in Cape Verde: (1) projection of the roof to shade the facades, in the Amilcar Cabral house museum; (2) projection of the roof in institutional building; (3) shading of esplanade in Santo Antão; (4) grid system for shading and ventilation in a building in Mindelo; (5) vertical shading in a services' building in Praia

Fig. 3.33 Fixed shading in Cape Verde: double facade shading system, in an institutional building in the city of Praia. The exterior facade shades the glass and opaque areas through the use of an ingenious grid system using overlapping tubes, allowing for natural light and ventilation

Fig. 3.34 Adjustable external shading: wood shutters (venetian blinds) provide shade and simultaneously allow for natural lighting and ventilation. (Right) Adjustable shading: leisure area in the fort museum, at the Cidade Velha. The shading strategy allows natural lighting and ventilation

Fig. 3.35 Removable and adjustable shading: (1 and 2) the terrace of the Club Nautico in Mindelo (shading also using ships' sails), (3) shading of outdoor space of a house, using a single sheet

Fig. 3.36 Shading by vegetation: (1–4) buildings in Old Town, (5 and 6) street in the city of Luanda, (7) terrace in Maputo

Fig. 3.37 Examples of shaded porches in colonial buildings in Guinea-Bissau

Fig. 3.38 Fixed shading: (above) shading projection of roof in a contemporary residential building in Guinea-Bissau. Below: shaded streets in Bissau

Fig. 3.39 "Brise-soleil" in modernist buildings in Maputo, Mozambique

Fig. 3.40 Fixed shading in modern buildings, Maputo, Mozambique

Fig. 3.41 Fixed shading: Arcades. (Above) island of Mozambique (XVIc.), (below) Maputo, Mozambique

Fig. 3.42 Shaded porches, Mozambique

Fig. 3.43 Shading in vernacular architecture (above) and in contemporary buildings (below), Mozambique

Fig. 3.44 Shading from vegetation: (above) city of Maputo; (below) rural area, Mozambique

Fig. 3.45 Adjustable shading: (above) colonial buildings in Maputo; (below) canvas, Mozambique

3.5 Glazing Areas

Much of the heat gains of a building pass through the glass areas of the facades, as the windows offer very little resistance to the transfer of radiant heat. The orientation and sizing of the glazed areas, as well as the choice of glass, determine to a large extent the penetration of solar radiation in the building.

For a warm climate, with high incidence of solar radiation, it is important to avoid large glazing areas on the facades, which lead to overheating and the use of air conditioning. In general, the area of glazing should not exceed 30% of the

Table 3.2 Characteristics of the use of light-coloured envelope coatings

Reflective coatings	Description	Performance
Light-coloured paint or tiles	Light-coloured paint of the opaque external envelope (e.g. white) Light-coloured tiles can also be used in facades The roof, when possible, should also have a light colour	White paint is a very cost-effective way of reducing the building's heat load in summer. The colour that reflects most radiation is white Painting the internal walls in a light colour can also improve the internal levels of daylight, hence reducing the need for artificial light Near the houses, one should avoid the use of dark-coloured pavements, in order to reduce solar radiation absorption In some urban situations, the reflectance of solar radiation to other buildings may sometimes be undesirable, but it may constitute an advantage in terms of daylight. Undesirable reflection from neighbouring buildings can be avoided through the use of shading devices Metallic foils only are effective when they are facing a void between building elements. This is because heat is transferred across air gaps partly by radiation, which the foil reduces due to its low emissivity. They have no effect at all when in contact with materials on both sides. When heat transfer is downwards across a void, e.g. an attic space, the largest proportion of heat is transferred by radiation. This is when reflective foils are most effective

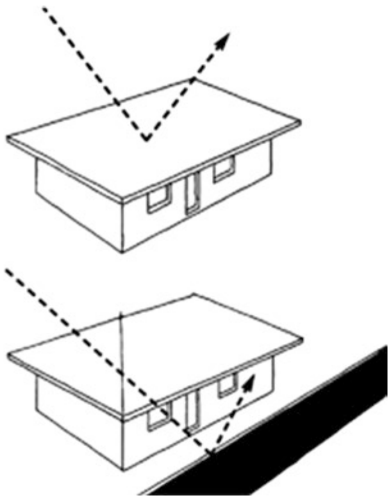


Fig. 3.46 Whitewashed surfaces reduce solar incidence (top). The proximity of the house to dark-coloured pavements should be avoided, to avoid heat absorption and radiation into the housing (below)

North and South facades' areas, considering that windows have adequate shading. This value can raise up to 40% in the case of tropical climates with high humidity values and low temperature amplitudes between day and night, such as in Guinea-Bissau. In the East facade, this value should be reduced to a maximum of 20% in any situation. In the West facade openings should be, if possible, avoided. The design of windows is a complex task. There are however a number of software

Fig. 3.47 View of the city of Mindelo, Cape Verde. Light-coloured paint reflects radiation, avoiding overheating

Fig. 3.48 Heat protection: (1) whitewashed vernacular house, on Santo Antão, (2) contemporary building painted white, in Mindelo, Cape Verde

simulation programmes available for designers to assist in the sizing of the openings, for example, EnergyPlus, DOE or, for architects, Ecotect or the Design Builder. The use of double-glazing can also reduce the gains and heat losses. One can also resort to a type of glass that selectively transmits only the parts of the visible solar spectrum required for natural light, reflecting unwanted radiation – the so-called low-emissivity glass. Table 3.4 describes the strategies for solar radiation protection, through window sizing and choice of glass (Figs. 3.60, 3.61, 3.62, 3.63 and 3.64).

Fig. 3.49 Suburban area in the island of Santiago, Cape Verde: the use of light-coloured paint would be an inexpensive strategy to reduce discomfort due to overheating

Fig. 3.50 Buildings painted white, in Luanda, Angola: the painting of buildings with light colours (e.g. using whitewash) would be an economical way to significantly reduce the discomfort from overheating

The sizing of the openings and the insulation of the opaque envelope, and protection against solar radiation, also prevent the entry of heat gain by conduction, caused by the flow of heat from the warmer outside air, through walls and glass areas, when the outside temperature is greater than the internal temperature. They are a cause for concern, especially in warmer regions, with high temperatures, which in summer can reach 40 °C, as many regions of Africa. However, the conduction gains generally tend to have a relatively minor impact on cooling requirements compared to solar and internal gains. It is particularly important in an air conditioned building where the internal temperature is maintained at a lower temperature than outside, for prolonged periods.

Fig. 3.51 Buildings painted white, in Guinea-Bissau, to reduce the discomfort from overheating

3.6 Natural Ventilation

Natural ventilation is the flow of air between the outside and the inside of the building. Natural ventilation is originated by two natural forces: by pressure differences created by the wind around the building, wind-driven ventilation, and by temperature differences – "stack-effect" ventilation. Table 3.5 shows the various objectives and requirements of natural ventilation (Figs. 3.65, 3.66, 3.67, 3.68, 3.69 and 3.70).

Wind-pressure ventilation is influenced by the wind intensity and direction and also by obstructions caused by nearby buildings or vegetation. The knowledge of wind conditions around the building and its pattern of speed and direction (information can be obtained from meteorological institutes) are necessary data for the design of the openings. The wind direction varies throughout the day. In addition to the prevailing winds, the earth winds (night-time) and the sea breeze (daytime) are also important.

The distribution, size and shape of the openings are fundamental elements to the achievement of efficient ventilation. The openings should be widely distributed

Fig. 3.52 Buildings painted white, in Mozambique: vernacular buildings in the region of Pemba; in the Ilha de Moçambique (centre); and in the city of Maputo (bottom)

in different facades, according to wind patterns, ensuring they will have different pressures, improving the distribution of airflow in the building. The entrance and exit openings (windows, doors, other openings) shall be located so as to reach an effective system of ventilation in which air flows through the occupied space, also considering the elements that can act as obstacles (internal partitions). The openings located in a high position allow for high rates of ventilation for heat dissipation. Openings located on a lower level can provide air circulation throughout the occupied zone. The markedly vertical windows facilitate high-level ventilation and achieve a better performance in terms of natural lighting and arrangement of interior space.

In the design of windows for natural ventilation, there must be a compromise with other environmental needs, such as natural lighting, sealing, solar gains,

Fig. 3.53 Vernacular houses in Praia, Cape Verde (above), and Pemba, Mozambique (below), with thatched roofs. Thatch is an insulating material that protects the building against heat gains

Fig. 3.54 Contemporary use of thatch: Hotel in Sal, Cape Verde (left), and Barra do Cuanza (Angola). Using this typology of local tradition also brings benefits of solar protection

Fig. 3.55 (1 and 2) Roof with mixed construction system. The thatch is superimposed to the corrugated metal sheet (sub-layer): the benefits of sealing and durability conferred by the use of the metallic layer and the insulating ability of the thatch (tourism building, Guinea-Bissau)

Fig. 3.56 Guinea-Bissau: The use without protection (insulation) of metal roofing should be avoided since it leads to situations of internal overheating. Furthermore, with the oxidation, the metal cover darkens, transmitting more heat to the internal spaces

Fig. 3.57 Internal roof insulation in a recent building, using local materials (thatch), in Guinea-Bissau (left) and Mozambique (right)

spatial performance, maintenance, noise, safety, costs and control of air circulation. The problem of noise, typical of urban environments, can be minimized through the use of acoustic shelves on the outside of windows or absorbent acoustic panels on the inner surfaces. The pollution problems can also be avoided with the use of buffer space and bringing into the building the air coming from a less polluted area. Security problems can be solved by sizing the openings or placement of external shutters (Figs. 3.71, 3.72, 3.73, 3.74, 3.75, 3.76, 3.77, 3.78, 3.79, 3.80, 3.81 and 3.82).

The "stack-effect" ventilation is appropriate for higher-rise buildings, especially in situations where the wind cannot provide an adequate air movement: when there

Fig. 3.58 Use of thatch in vernacular (left) and contemporary (right) buildings, in Guinea-Bissau

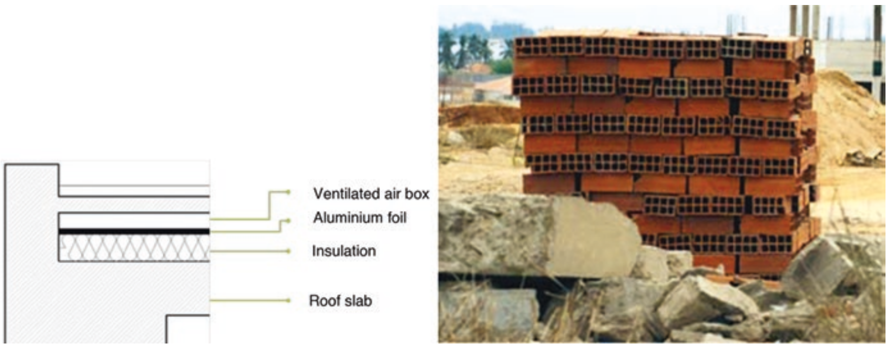


Fig. 3.59 Left: schematic representation of a radiant barrier on a roof, with ventilated air box. Right: the use of perforated brick may improve the building's insulation, though it should be further reinforced with external or cavity wall insulation materials

Table 3.3 Characteristics of insulation and radiant barriers

	Description	Performance
Insulation	Insulation material can be added either to the inside or the outside surface or by filling the cavities within the wall structure. In terms of heat avoidance, insulation materials prevent heat conduction due to the existence of trapped gas in many layers (fibreglass bat) or in cells (polystyrene), increasing the material's thermal resistance to conduction in proportion to their thickness, but do not necessarily restrict radiant heat External insulation can be added using prefabricated insulating panels. Should have a light colour	The insulation of the external opaque elements, or the use of additional insulation to the facades, is one of the simplest and most effective measures for cooling and heating load reduction The air existing in the brick's cavities or in the space between walls (double-wall facade) also provides insulation to the building, but this can be significantly improved with additional material (external or cavity wall insulation) *External insulation* is preferable to internal insulation, making maximum use of the internal thermal storage mass, and has a better performance in preventing heat gains in summer. It plays an optimum role in passive cooling, when associated with thermal mass. It also minimizes or even eliminates thermal bridges and condensations Internal insulation should be avoided, as it reduces the amount of exposed thermal mass, reducing the benefits of thermal inertia *Roof insulation* is also very important, as it decreases the risk of high temperatures on the top floor of buildings in hot conditions
Radiant barriers	*Radiant barriers*, made from aluminium foil-coated products, can be installed in the ventilated air gap of cavity walls and roof. The aluminium foil reflects long-wave radiation, and the airspace prevents heat movement downwards by conduction	The effectiveness of this method depends on the ventilation required to transport the heat from the foil by convection. When cooling is the main concern, it is preferable to use a foil radiant barrier, as an alternative to high insulation levels that could create moisture and increased roof temperatures This system can however be more expensive than simple insulation

are low wind speeds or the wind has an unpredictable pattern. This method can also be used in conjunction with ventilation by wind pressure, to enhance the performance of the ventilation system, especially in deeper-plan buildings where it is difficult to achieve cross ventilation. The "stack effect" is generated by a vertical pressure difference, depending on the average temperature difference between the column of air and the outdoor temperature, the opening sizes and location and height of the air column. The hot air rises and exits on openings located in top the

Table 3.4 Description of strategies involving window sizing and glazing type

	Description	Performance
Window sizing	Windows, glazing ratio, facade orientation	Windows also influence performance of daylight and natural ventilation, acoustics and the visual contact with the external environment. They must be designed to allow this integration Windows must also be sized according to orientation. There is appropriate software for this purpose, such as DOE, Design Builder (EnergyPlus) or Ecotect. These can be used both in new design and in refurbishment Glazing area should be reduced to the indispensable. It is recommended that it is not greater than 30% in North and South facades, considering adequate shading (or up to 40% in more tropical climates). In the East facade this value should be reduced to a maximum of 20%. In the West facade openings should be, if possible, avoided Horizontal glazing areas should only be used with adequate shading, and in zones with high floor-to-ceiling height (at least 6–8 m), as they can easily cause overheating problems. Large areas of horizontal glazing should be avoided
Glazing type	Double-glazing, low-emissivity glazing, HOE	Double-glazing increases the insulation value of the glazing area and also has the advantage of reducing condensation at the window back, draught risk and infiltration rates. Compared to single-glazing, its use can significantly reduce heat gains. A greater reduction in heat gains is achieved if low-emissivity glazing is used. Amortization of double glazed windows can be achieved between 5 and 25 years, according to the quality of the materials and size of the windows *Low-emissivity glazing* can be almost opaque to infrared radiation, reducing the solar transmission by more than 50%. This glazing type and *HOE* do not reduce daylight levels, although being efficient in reducing solar radiation. However, they can be expensive The use of *tinted and reflective glass* for shading and glare prevention should be avoided, as these materials also substantially reduce daylight levels, increasing the use of heat producing artificial light. It is preferable to use clear glazing (double, low-e), shading and a reduced glazing area

of the stack; the cooler air will penetrate into the building at ground levels. The problem of "stack-effect" ventilation is that the system reaches its maximum efficacy when registering lower outdoor temperatures and when there are greater differences in temperature inside the building. In warmer climates, such as Cape Verde, a solar chimney can be used to raise temperatures in unoccupied areas, increasing the temperature differences. The performance is weaker than the wind-pressure ventilation, as it requires larger temperature differences and larger areas of openings (e.g. cross ventilation achieved from a 3.7 m/s wind can overcome a chimney with a height of 3 m and with 43 °C at the top).

Tables 3.6 and 3.7 show the characteristics of wind-pressure and "stack-effect" ventilation. Table 3.8 refers to particular cases day and night ventilation techniques, including wind-pressure and "stack-effect" ventilation. Table 3.9 refers to the use of assisted ventilation (Figs. 3.83, 3.84, 3.85, 3.86 and 3.87).

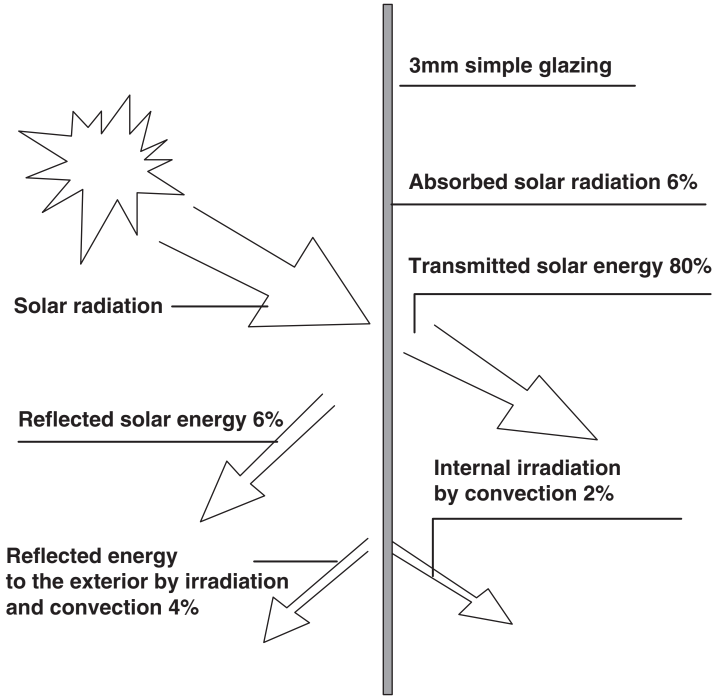


Fig. 3.60 Energy exchange in a 3 mm single glass window

When the outside temperature is too hot, it is necessary to prevent heat gains for ventilation – caused by the infiltration of external hot air to the interior of the building. This type of gains can be minimized by reducing the rate of ventilation when the outside temperature is higher than the indoor temperature. The ventilation rate should be increased substantially in periods when the outside temperature is lower than the indoor temperature – for example, during the night (night ventilation) (Figs. 3.88, 3.89, 3.90, 3.91, 3.92, 3.93, 3.94, 3.95, 3.96, 3.97, 3.98, 3.99 and 3.100).

Some of the measures to lower the temperature of the roof slabs are as follows: insulate the coverage with thin lime, whitewash and pozzolana; provide openings for hot air outlet on the highest part of the walls; improve air inlet openings in the lower walls oriented in the direction of the prevailing winds in order to provide cross ventilation; use cavity wall insulation; and introduce vegetation in the perimeter of the house. The lightened, hollow concrete slabs supported by pre-stressed beams are the most appropriate solution to more arid climates such as in Cape Verde and parts of Angola and Mozambique. Besides being lighter, they have lower costs and allow good ventilation.

The construction with vaults is another energy-efficient solution. The vaulted, curved surface of the roof increases the air movement over it. To exploit this advantage, the vaults must be constructed in the opposite direction of prevailing winds.

Fig. 3.61 Large glazing areas should be avoided in the facades' typologies, as they are largely responsible for the overheating of the building and subsequent use of energívorous air conditioning systems. The sealed facades with large areas of glazing are an imported typology, inadequate to the hot climates (Luanda, Angola; Praia, Cape Verde)

In regions with very hot periods, natural ventilation can be enhanced with low-energy mechanical cooling systems, such as fans. These energy-efficient devices can be very useful in cases of existing buildings, especially those where the potential of natural ventilation is limited (Figs. 3.101, 3.102, 3.103 and 3.104).

In very specific situations, where the potential of natural ventilation is reduced and the use of ventilation low power systems, such as fans, are not sufficient to meet the needs of ventilation and cooling of the building, it is preferable to use the so-called "mode mixed" systems – that is, to use the HVAC systems only when and where necessary. The use of "mixed-mode" strategies can avoid oversizing of centralized systems, reduce operating costs of the building and save energy.

Fig. 3.62 Most residential buildings we find in more established urban areas in Cape Verde (above), Angola (centre), Guinea (below) and Mozambique (bottom) have very reasonable glazing areas. They are a good reference for the design of new buildings. The area of glass should not exceed 30% of the total area of the main facade and should be fully shaded

Fig. 3.63 Rehabilitated vernacular house in Santo Antão. The window area is sufficient and adequate to meet the needs of natural lighting and ventilation

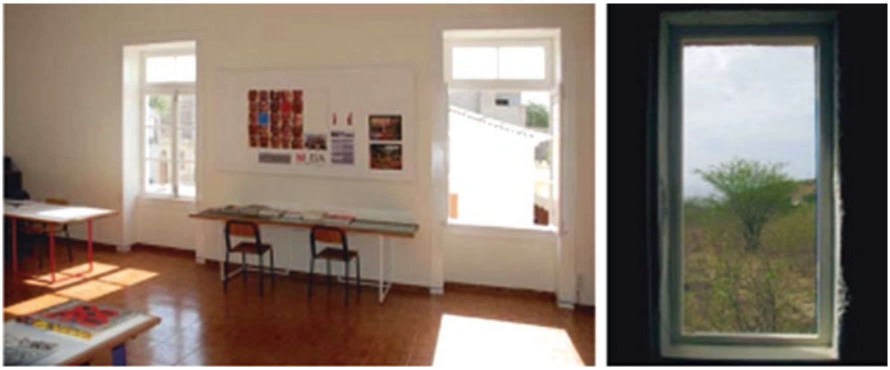


Fig. 3.64 School building in Mindelo. The vertical arrangement of the horizontal window is preferred because it avoids problems of daylight discomfort (glare and contrast) and has advantages in terms of the arrangement of furniture inside. It also allows ventilation at a higher level for the renewal of air and cooling of the building mass at night

Table 3.5 The various objectives of ventilation and respective requirements

Objectives	Description	Requirements
Provision of fresh air	Ventilation is necessary to provide fresh air to the office occupants, replacing stale air and controlling odours, moisture, CO_2 and pollutant concentration	Typically 0.5–3 air changes per hour per person, depending on the intensity of occupation. The CIBSE (1997) building regulations consider a minimum standard of 5 l/s per person (which is achieved by average infiltration rates), this standard being raised to 16 l/s in smoking areas
Heat removal from the building	This type of ventilation is used to remove excessive heat from the building interior, providing more comfortable temperatures and reducing the cooling loads	Requires higher ventilation rates than the previous, at high level to remove the accumulated heat. When the external air temperature is lower than the internal air temperature, typical ventilation rates for space cooling are 5–25 ach/h, depending on the temperature difference. The greater the heat gains, the more ventilation is required
Convective and evaporative cooling of the human body	A higher air speed increases the sweat evaporation from skin, broadening the comfort temperature upper limit. A thermal sensation corresponding to an effective temperature of 27 °C can be achieved if air movement of 1 m/s is applied to a room with an air temperature of 30 °C	This process requires air speeds between 0.5 and 3 m/s It is accepted that each increment of 0.275 m/s increases 1 °C to the upper comfort limit The upper velocity recommended in offices is 1.5 m/s. In houses, this value can increase to 2,5–3 m/s

3.7 Thermal Inertia and Earth Architecture

In high-inertia buildings, the opaque elements surrounding the building, structures and internal divisions are built with massive materials such as stone, earth (rammed earth or adobe), bricks or concrete. Thermal mass acts as heat and cold storage, regulating and smoothing fluctuations in temperature. The high thermal inertia of the massive building components reduces the maximum temperature values in the summer, providing better comfort conditions. The heat stored during the day can be dissipated at night, by night ventilation. Inertia slows the heat exchanges by conduction to the outside, which is particularly beneficial during heat waves.

Unlike other heat sinks, like the atmosphere, the sky or the ground, which provide an almost unlimited resource for this purpose, the use of thermal mass is a temporary, transition solution. After a certain point, the heat starts to accumulate in the mass of the building and decreases its efficiency. Therefore, the use of thermal mass should be combined with ventilation strategies to remove the accumulated heat, especially with night ventilation. The night ventilation strategies coupled with

Fig. 3.65 External venetian blinds in Ribeira Grande and in Mindelo. As well as shading, they allow and direct the flow of natural ventilation

a good thermal mass can reduce the average temperature inside during the day, below the outside daytime average temperatures. However, in buildings with high internal gains, such as office buildings with a large concentration of occupants and equipment, this is more difficult to achieve. But even in these particular cases, the average daytime temperatures inside can still be reduced to values close to the average outside, or a little above this, with a still reasonable performance in terms of passive cooling.

Figures 1.5 and 1.6, presented in Chap. 1, show the average daily temperature amplitudes for the months of July and December. The regions of influence of thermal inertia and night ventilation are presented in yellow, orange and red, with amplitudes above approximately 8 °C.

When auxiliary cooling systems are necessary, as in the case of "mixed-mode" buildings, the use of thermal mass can delay the need for refrigeration and reduce periods of time when cooling becomes necessary.

Fig. 3.66 External fixed shading systems in Luanda, Angola. As well as shading, they allow and direct the flow of natural ventilation

Fig. 3.67 External fixed shading systems in Guinea-Bissau. As well as shading, they allow and direct the flow of natural ventilation

Fig. 3.68 Ventilated roofs, Guinea-Bissau

The performance of thermal mass depends on the ability of the constructive characteristics of the building for the transfer of heat into space, that is, depends on the heat transfer coefficient of the materials used. The performance also depends on the physical capacity of these materials to store heat, i.e. its specific heat. The amount of thermal mass used in the process typically corresponds to a thickness of 50–150 mm from the surface. The solid material must be as exposed as possible. The acoustic problems, sometimes caused by increased exposure of massive elements (walls, slabs), can be reduced by the use of sound-absorbing perforated ceilings (Figs. 3.105, 3.106, 3.107, 3.108, 3.109 and 3.110).

Fig. 3.69 "Brise-soleil" grills in Mozambique, for shading and natural ventilation

Fig. 3.70 Maputo, Mozambique: adjustable devices for natural ventilation

Fig. 3.71 External shutters are a typology traditionally used in Cape Verde and Bissau. They provide window shading and allow the control of the natural ventilation flow to the interior of the building

Fig. 3.72 The use of fixed grids, although not allowing adjustments to control shading and the ventilation flow, can also be an effective solution in some cases

Fig. 3.73 Modernist building in Praia, with facade ventilation openings at various levels: high, for air exchange and cooling of the building mass, and lower (windows) for the comfort of occupants. The need for natural ventilation and shading was considered factors in the design of the building, which is visible in the facade typology

Fig. 3.74 Interior of a school in Mindelo. (1) The inner openings have a generous height, allowing the flow of ventilation at a higher level and contributing to a good performance in terms of natural lighting. (2) Open windows for natural ventilation when the outside temperature is comfortable during the day

Fig. 3.75 Windows protected with mosquito net, in Praia

Fig. 3.76 Vents with mosquito nets in a house in Mindelo

Fig. 3.77 Openings at the top level for removal of hot air

Fig. 3.78 Ventilated roof, Maputo, Mozambique

Fig. 3.79 Ventilated atria in two buildings, Maputo, Mozambique

Fig. 3.80 Use of mosquito net in an old building, in Maputo

Fig. 3.81 Naturally ventilated market, Ilha de Moçambique

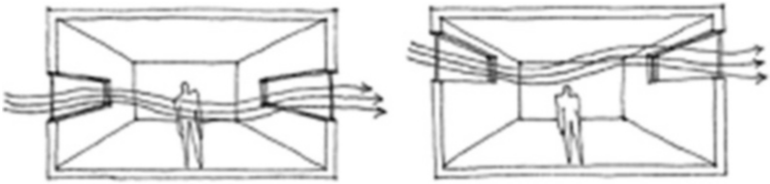


Fig. 3.82 Openings' position for two types of cooling. The situation in the first scheme is ideal for occupant comfort (cooling) – the entry of cooler air is made at lower level. The situation of the second scheme is for the cooling of the building – the indoor heated air rises and is accumulated near the ceiling, and its exhausting ventilation is made at higher level. The use of vertical, tall windows is ideal to allow control of these two levels of ventilation

Table 3.6 Wind-driven natural ventilation strategies for building and occupant cooling

Wind-driven	Description	Performance
Single-sided ventilation	Ventilation provided by openings in only one side of the room or facade	Single-sided ventilation has a more shallow penetration than cross ventilation – typically 3–6 m or about twice the floor-to-ceiling height. It is created as air enters the room at one time, and a few seconds later some air exits because of the fluctuating static pressure of the wind
Cross ventilation	Openings on both sides of the building and an airflow route within the building	Steady cross ventilation is usually the strongest mechanism of natural ventilation, especially in larger buildings It has a useful depth of 9 m or three times the floor-to-ceiling height – 18 m zones can be ventilated if they are back-to-back. Courtyards can be used instead of deep floor plans, to promote cross ventilation If the building is facing the prevailing wind direction, and the wind has a good intensity, the use of ducts and underfloor space for building cross ventilation can also be efficient alternatives to openings in the room facade. Circulation areas such as corridors and stairwells can also be used to supply rooms that have no access to the windward side Patios can be used, instead of deep plans, to promote cross ventilation If the building is facing the dominant wind, and the wind has a good intensity, the use of special conducts and slab cavities for cross ventilation can be efficient
Wind towers	If the building is not in a favourable position towards wind and prevailing breezes' directions for natural ventilation, wind-channelling devices could be used, such as wind towers	Wind towers, such as the ones used in some hot countries (2–20 m tall) can also be useful to create air movement, when wind for cross ventilation is not available at the building's level. The stack supply and extract are wind-driven, reverting to stack in the absence of wind In certain hot and dry regions, pools or ceramic pots with water are placed in the base of the wind tower to provide additional evaporative cooling

Table 3.7 Stack-effect natural ventilation strategies

Stack effect	Description	Performance
Single-sided double openings	Openings in a low and high position, in a window or wall, i.e. near the floor and ceiling	It could be effective up to 9 m or three times the floor-to-ceiling height. It can increase the depth of natural ventilation in open plan rooms. It depends on the difference in height between inlet (lower) and outlet (higher)
Atria	The introduction of atria offers good potentials for stack ventilation	Atria can be used specially in larger buildings. They must be carefully designed, as they can sometimes cause overheating in hot countries
Solar and thermal chimneys	In solar chimneys, solar radiation is used to increase the stack effect; as the sun warms the surfaces of the chimney, the ventilation rate increases	The stack must terminate above the roof peak, so that the stack top is always under suction compared with lower inlet level. Otherwise a wind coming in the wrong way can introduce the hot stack air into the room. The wind pressures on the top of the chimney also influence it
Vent-skin walls	Ventilated cavities within the walls (see also "thermal mass")	Vent-skin walls improve the dissipation of heat stored in the building. This technique is exclusively for heat removal of the building (not comfort cooling)

Table 3.8 The use of natural ventilation strategies according to the difference between external and internal temperatures; daytime and night-time (wind-driven or stack-effect) ventilation

Day/night	Description	Performance
Daytime ventilation	The simplest strategy to improve comfort when the indoor temperature is higher than outdoor temperature, providing comfort through higher indoor air speed. It can use wind-driven single or cross ventilation or stack effect	Suitable when indoor comfort can be experienced at outdoor air temperature and with diurnal temperature swings of less than 10 °C
Night ventilation	Used to cool the building mass during the night. At the end of the day, the temperature of storage will be increased without degrading comfort, raising the cold storage capacity and heat dissipation capacity of the system. Heat is then flushed through by ventilation during the night, and the building is cool the following morning (see also thermal mass)	It is especially suitable to situations when daytime outside temperature is too hot and ventilation is impossible. Its performance can be improved by fan-driven mechanical ventilation. Night-time ventilation works when night temperatures are lower than daytime temperatures, by more than 8–10 °C This technique is used for heat removal of the building, not comfort ventilation

Table 3.9 Fan-assisted ventilation

	Description	Performance
Fans	The use of fans can improve the performance of natural ventilation techniques Box, oscillating or ceiling fans increase internal air velocities and convection exchange, improving comfort by increasing the convective processes. They can be used specially when opening windows may cause heat penetration, excessive air speeds or security or noise problems Fan-assisted mechanical ventilation systems involving ducts and special ventilation paths can also be used to improve air circulation through the building, being specially useful in the refurbishment of deep plan buildings and in ventilation systems for cooling the building mass, such as night cooling	The use of box, oscillating or ceiling fans alone can allow an increase of the indoor comfort temperature of 3–5 °C, at 1 m/s, say from 24 to 28 °C, much reducing cooling requirements Ceiling fans can have a payback period around just 3 years The turbulent and variable air motion quality produced by fans also produces more comfortable effects than uniform air motion A *ceiling or desk fan* is not annoying or draughty at 1 m/s, and does not move loose papers Fan-assisted mechanical ventilation systems involving ducts and special ventilation paths outside the occupied zone are used not for convective cooling of the body, but for the cooling of the building mass and fresh air provision. These systems can be much cheaper and less energy consuming than air conditioning

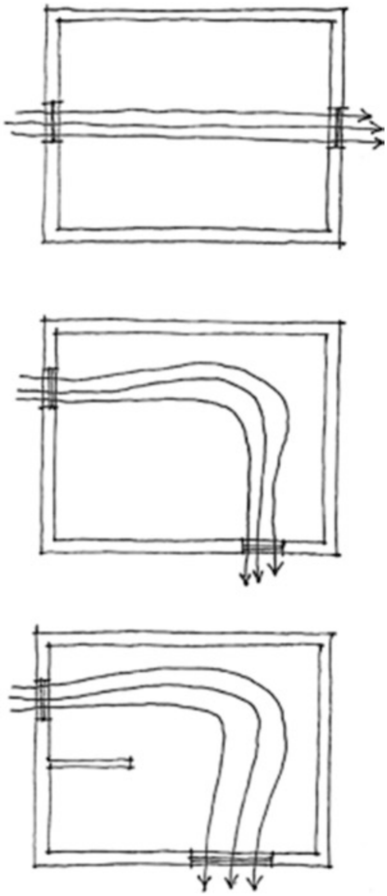


Fig. 3.83 Some ventilation schemes for different window sizes and positions

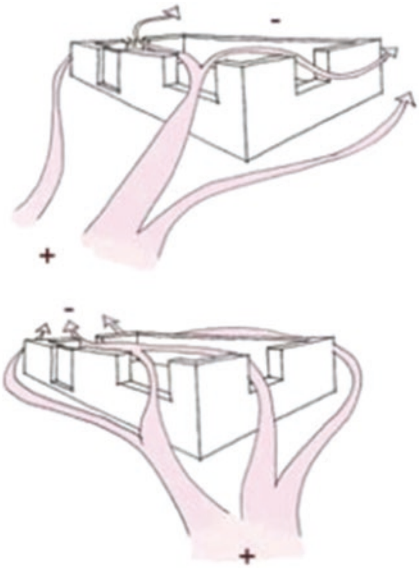


Fig. 3.84 The positive and negative pressures caused by different wind directions and positions of the openings

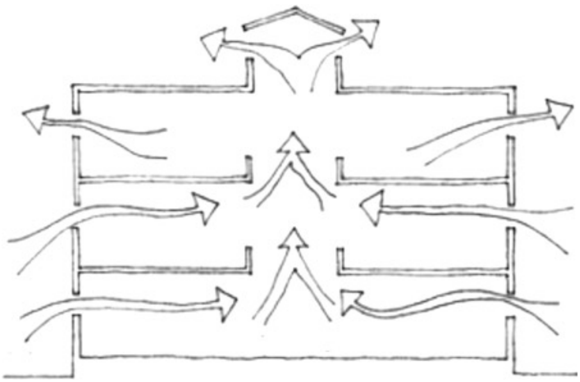


Fig. 3.85 Stack-effect ventilation in an atrium building

Fig. 3.86 Building for cultural activities in Lagedos. Openings at top and opposing fronts, for cross ventilation, and opening on the roof for stack-effect ventilation

Fig. 3.87 Atrium inside a building in Praia promotes natural lighting and stack-effect ventilation. In hot climates, the top of the atrium must be at least 5 m above the occupied space and must have outlet air vents in order to prevent the accumulation of hot air

Fig. 3.88 Interior of a stack ventilation tower in a house in Sao Vicente

Fig. 3.89 The hot air must be flushed to the outside to prevent accumulation on the ceiling

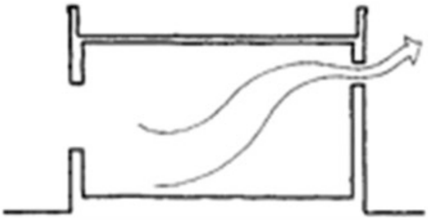


Fig. 3.90 When the air intake openings are smaller than the air outlet, there is greater efficiency in the suction of cooler air that flushes hot air

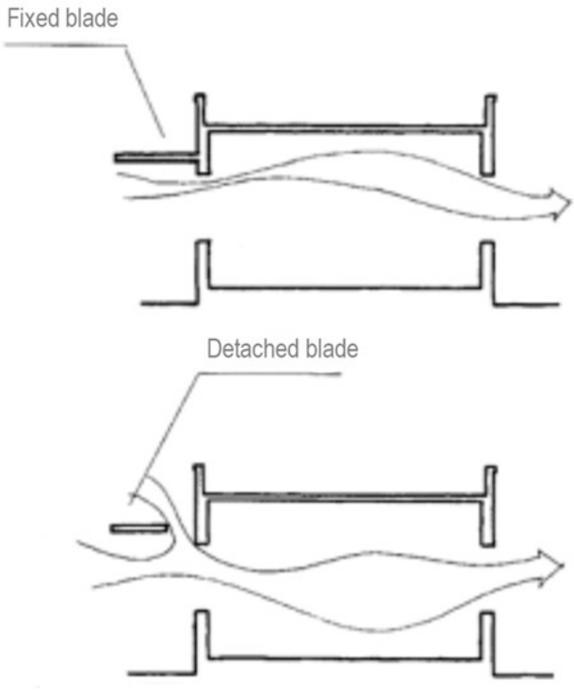


Fig. 3.91 A blade away from the wall increases air intake

Earth Architecture

The use of land as a building material is an age-old practice, developed over time in many different ways depending on the climate, the purpose of the building (dwelling place, prayer place, meeting place, etc.), the social context (war-shaped societies, open to the exchange of cultures, isolated, abundant in resources, etc.) and the very type of earth and other natural resources available on the construction site. In fact, earth is one of the earliest building materials in history, predominant in almost every dry and temperate climate in the world. Currently, more than half of the population in developing countries still lives in buildings built with earth, accounting for about a third of the world's population.

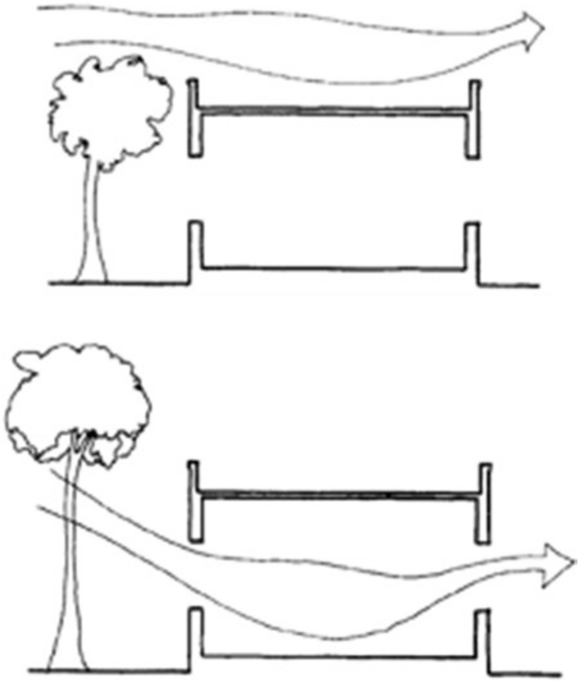


Fig. 3.92 The breeze rises with low trees; with tall trees, the breeze comes down and cools the room

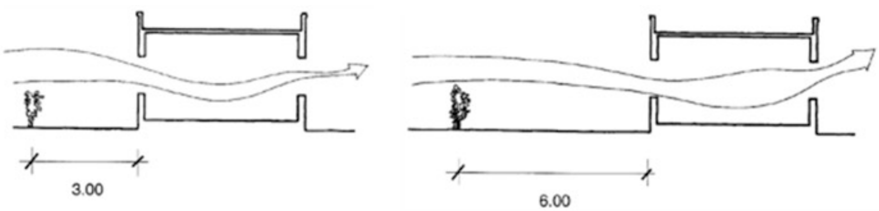


Fig. 3.93 The greater the distance between the building and trees, the stronger will be the incoming breeze

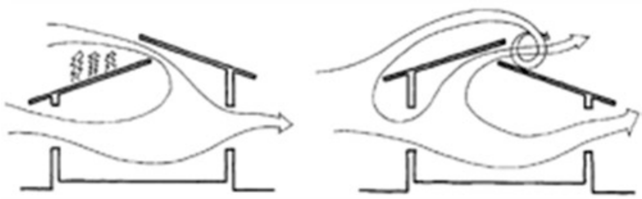


Fig. 3.94 In the first scheme, the skylight is poorly located, because the warm air gets into the roof of the building. In the second scheme, there is a good position – the hot air of the compartments can be flushed through the skylight

Fig. 3.95 In the case of pitched roofs, the opening should be in the higher wall

Fig. 3.96 Two resources to force air movement, through the opening in the ceilings

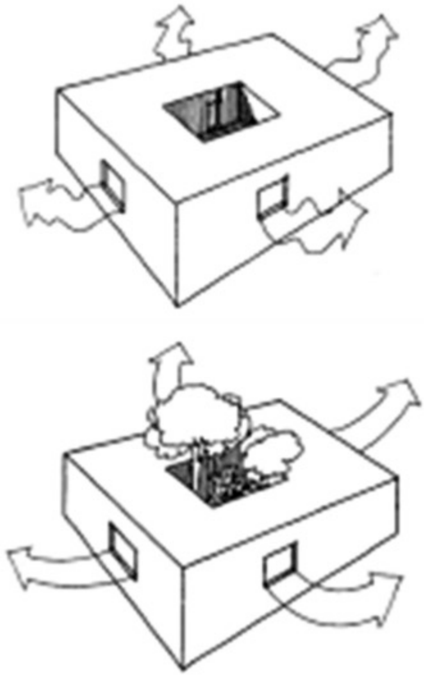


Fig. 3.97 The inclusion of courtyards brings additional benefits to the climatization of the house. Fresh air from the courtyard circulates in the compartments. If the patio has plants, cooling will improve. In areas where there are few trees, a situation very common in Luanda and in the islands of Cape Verde, the house can be cooled using a courtyard to create shaded zones, where the air is cooler. The use of the courtyard facilitates more openings in the facade, for ventilation of indoor rooms

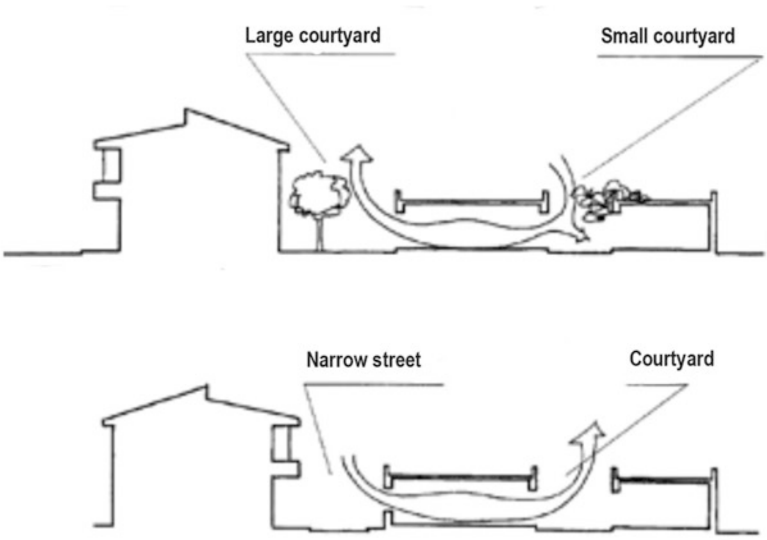


Fig. 3.98 The movement of fresh air can also be produced through two courtyards, one smaller than the other. The air from the smaller patio, which is more shaded, is cooler than that of the larger patio. Thus, hot air rises, causing cool air to penetrate better in the compartments between the two courtyards

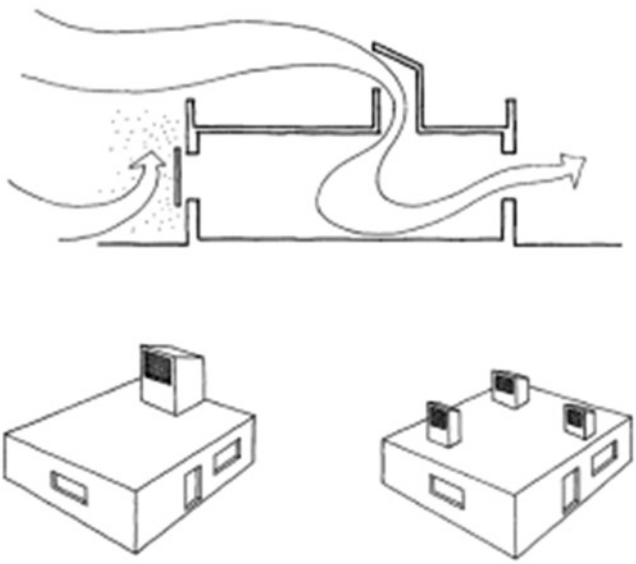


Fig. 3.99 We can build a central wind catcher for ventilation of all rooms or small individual catchers (wind towers). One way to get cool and clean air to the inside of a building is to use wind catchers that allow the recycling of the warm and stale air. The greater the height of wind catcher, the cooler is the breeze, also preventing the entry of dust carried by the wind. In Angola and Cape Verde, the direction of the breeze is more or less constant, which makes this solution extremely effective

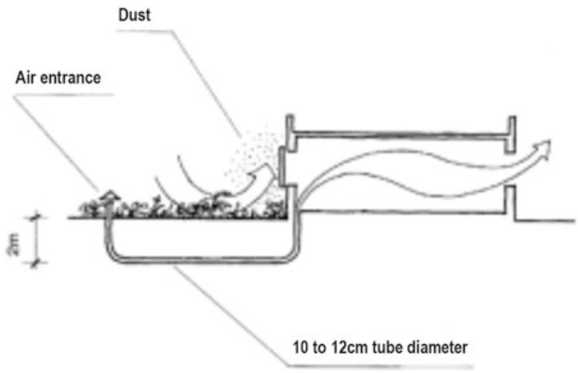


Fig. 3.100 Scheme of a building ventilated through the underground. One can lower the temperature inside the house through an underground ventilation system. This technique consists of passing the air below ground through a tube, about 2 m deep, to make the air cooler. It is important that the tube is that deep to get cool air. The tube is driven to the room that needs cooling. The capture is done in a cool area, shaded by trees or plants. The outlet opening of the tube, inside the room, must be protected with a mosquito net to prevent entry of insects and shutters with movable blades to control the air intake

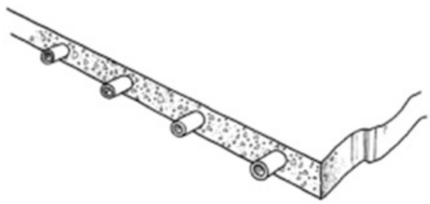


Fig. 3.101 A detail of floor slab, ventilated with PVC pipes. The slabs may have channels for air circulation for cooling the house. These channels must have entry and exit to the outside so that air can circulate and be renewed. Openings must be protected against the entry of insects

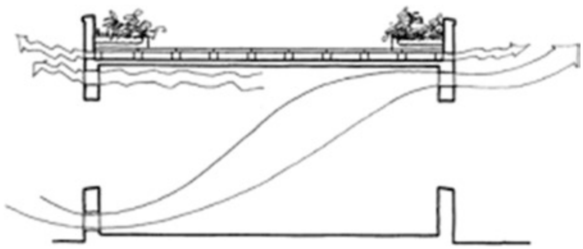


Fig. 3.102 A scheme for building with ventilated roof. Most of the heat gain and loss occurs through the roof, more exposed to solar radiation. In hot and dry regions, the problem of rainwater infiltration is reduced, so roofs are generally flat or with a low slope. The most usual roof is a reinforced, massive, concrete slab, a poor solution in terms of energy efficiency. The massive concrete slabs absorb the sun's heat and are costly

Fig. 3.103 Recessed vault roof, half-round vault roof and prefabricated roof vault

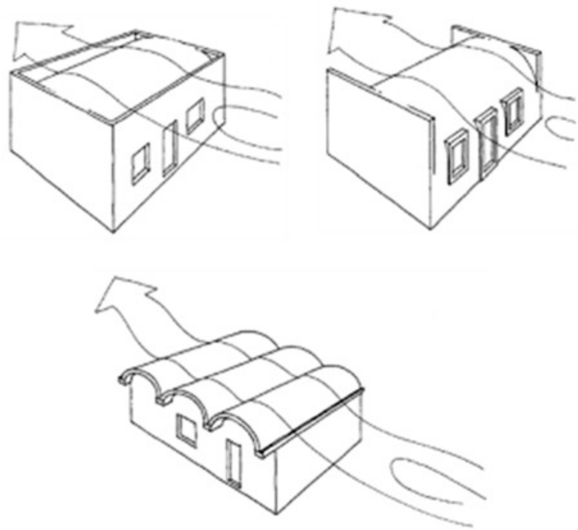


Fig. 3.104 Tourist information building in Santo Antão, using hollow concrete slabs and openings on the roof for ventilation

Fig. 3.105 New construction near Luanda, using massive materials – brick, stone and concrete – which provide thermal inertia to the building. This type of construction is adequate to hot climates with significant amplitudes between daytime and night-time temperatures

Fig. 3.106 New construction (above) and traditional, popular construction (below) in Cape Verde, using massive materials

Fig. 3.107 Hostel designed by Alvaro Siza in Cidade Velha. New constructions using materials with high thermal inertia (stone and concrete)

Fig. 3.108 Examples of use of massive building materials in Guinea-Bissau

Knowing that, with particular relevance in developing countries, there are no solutions to meet the housing needs construction through the use of industrial materials such as concrete, steel or even baked brick; it becomes not only increasingly necessary but constitutes in fact the best solution, to recover, learn and develop construction methods through the use locally available materials.

Fig. 3.109 Guinea-Bissau: the use of lightweight buildings may offer advantages in zones with low thermal amplitudes (below 8 °C between night and day during most of the year), where thermal inertia has little effect. Building features like elevated structures, ventilated roofs and wind-catching verandas can be used to improve ventilation

In this context, earth is the most abundant building material on most of the planet, usually being possible to extract the same directly on the construction site or in a nearby location, being cheap and avoiding transport over long distances. In addition, it assumes itself as a sustainable material since the material extraction and production is direct, with eventual little energy incorporated in relation to other building materials. Also, it does not use any harmful products, nor does it originate any unwanted by-products.

By using a raw material, without changing the properties of the same (uncooked, only dryed in the sun), at the end of its usage cycle, the material can be fully recycled or reused.

As previously mentioned, earth constructions are an age-old practice, with records of its practice associated with the sedentarization processes, dating back to between 8000 and 6000 a.c. Throughout history, there are several vestiges of earthworks, used not only for dwellings construction but also for worship and fortresses buildings, some of which constitute true testimonies of beauty, culture and durability in the history of humanity, been classified as world heritage by UNESCO

Fig. 3.110 In Mozambique, the use of massive building materials, like earth, stone, bricks or concrete, can be observed throughout the country. Above: adobe and stone vernacular houses in Ilha de Moçambique. Below: brick and concrete construction in Maputo (Tables 3.10 and 3.11)

Table 3.10 Various techniques that can be used in office buildings to optimise the use of thermal mass

Thermal mass	Description	Performance
Night ventilation	Massive elements, like walls, structure, slabs Night ventilation of the thermal mass provides an efficient means of cooling the building At night, when outside air temperature is considerably lower than inside, night ventilation is used to dissipate and exhaust the heat accumulated during the day in the building's mass into the low temperature atmospheric heat sink, preventing overheating the following day The outside air is introduced to the building, either through special channels that contact with the building structure (allowing higher air speeds for convection) or through the windows In night ventilation using windows, these can have openings on top for this type of ventilation. For reasons of safety and privacy, ground floor windows remain closed, and safety window screens are used	Night cooling systems may be one of the most efficient passive cooling techniques. This system requires amplitudes above 8–10 °C between day and night, ventilation rates of 10–25 ach/h and the structure to be massive enough to store the cooling effect until the next day. It is most suitable when daytime temperatures are higher than 30 °C and lower than 36 °C. The storage mass can be cooled up to 2 or 3 °C above the outdoor minimum. It is recommended for climatic regions such as in Cape Verde, Angola and some zones in Mozambique (e.g. Tete, Lumbo, Lichinga, Quelimane and Maputo) The walls and the structure must be sufficiently exposed to the air stream, avoiding the use of false ceilings, and any other elements that could prevent this contact This system does not usually require complex and costly actions – it may be enough to increase the thermal mass exposure, e.g. by removing false ceilings and opening existing windows and keeping in mind safety precautions and insect protection. To facilitate night ventilation, windows can be left opened overnight. This type of ventilation can be natural or assisted by fans
Chilled beams and chilled ceiling systems	Consist of an array of pipes embedded in the beams or ceiling slabs, through which cold water is circulated, lowering the temperature of the mass	These systems have been successfully used in the refurbishment of office buildings., but still tend to be expensive

(Figs. 3.111, 3.112 and 3.113). In addition to the contextualization of building with earth in relation to climate; to the technical knowledges; to the tools available at the time, with social influences; and to other available natural resources, a fundamental condition of this building material is its own composition.

In general, the soil is formed by four base elements: gravel (thickness between 5 and 100 mm), sand (coarse, medium and fine, 0.05–5 mm thick) and silts or limos (thickness 0.002 and 0.06 mm) and the clays (of thickness less than 0.002 mm) as active elements. With the difference between the percentages of each of these elements in the soil, we obtain different types of earth. This represents the basis for earth construction, being able to mould the material to the specific needs of the techniques by the addition or subtraction of elements like water or straw.

Table 3.11 Strategies to reduce internal gains

	Description	Efficiency
Artificial light	The use of artificial lighting is often excessive, either because the lighting levels are too high, because the lighting systems are inefficient or due to poor switching controls Internal gains from artificial light can range from 6 to more than 20 W/m^3	It is recommended to use task lighting, with low background illumination levels High-efficacy light sources with low heat emissivity, like fluorescent lamps, should be used instead of incandescent tungsten or halogen lamps Reduce the excessive indoor illumination levels: background lighting be reduced to 200 lx and even to 150 lx if task lights and VDUs are used Extract ventilation through the luminaries can also be used to reduce heat gains
Daylight	The use of daylight can reduce substantially the cooling loads by delaying the use of artificial light Daylight should be well distributed in the rooms, without glare and contrast	It is estimated that for 1 kWh saved for lighting in the cooling season, about 0.3 kWh of electricity used by air conditioning is saved Consider that the space area that can be effectively daylit is around 6 m, corresponding to twice the floor-to-ceiling height. As a rule of thumb, high-level windows have a better performance than low-level windows, and tall windows perform better than wide windows (as daylight goes deeper into the space). The use of clear (reflective) colours in wall painting and decoration, as well as light shelves, also increases illumination levels The use of skylights in the top floors can cause overheating during summer, as well as glare Glare control is essential when using computers. Glare and contrast can be avoided by using splayed reveals, light shelves, prisms or reflectors, light ducts or fibre optics
Courtyards and atria	The introduction of courts and atria in buildings with a very deep plan could improve daylighting and ventilation, reducing energy consumption from artificial lighting and air conditioning (see also natural ventilation)	The introduction of glazed atria must be very carefully considered in warmer Mediterranean climates, as they often lead to problems of overheating. The daylit zone facing the atria to be considered is limited to the sky view zone (corresponding to about a 3 to 1 ratio between the height and width of the atrium) Courtyards are traditionally used in some countries in Africa
Occupants and office equipment	Internal gains from occupants and office equipment like computers or photocopiers can produce annual heat gains in the range of 15–30 W/m^3	The reduction in internal gains can be achieved by locating the heat-generating equipment in special areas (e.g. computer room), with higher ventilation rates (or special climatization if required), serving as buffer spaces and away from the occupants if possible Internal gains from occupants can be reduced by avoiding high occupant density through layout design

Fig. 3.111 World map with location of earth architecture and UNESCO World Heritage Sites in 2012. (Source: CRATerre)

Figs. 3.112 and 3.113 On the left, considered the oldest arches in history, detail of the Ramesseum (funerary temple of Pharaoh Ramses II) – URL: http://www.ancient-egypt-online.com/ramesseum.html. On the right, view of the Old Walled City of Shibam, UNESCO World Heritage Site – http://whc.unesco.org/en/list/192/gallery/

Throughout history, due to the characteristics indicated above, along with the techniques and constructive pattern development, a diagram was defined identifying 18 earth-building techniques, grouped into three families: monolithic and bearing, bearing masonry and filling or coating (earth as secondary element).

The first set of constructive techniques, in category A, use of earth in the monolithic and bearing form, includes "in situ" five methods:

(i) The first technique, "Excavated Earth", possibly the most primitive, consists in excavating the ground to form the housing compartments. It is a technique applied to solid and dry earth, more usually in hills or in arid highlands.

(ii) Next we have the "Plastic Earth" technique that comprises the use of the earth in almost liquid state, similar to concrete, as a way of building walls or pavement slabs. This technique presents some problems related to the retraction of the material when dry, so it is currently more applied with a mixture of materials in order to stabilize the support in that process.
(iii) The "Stacked Earth" consists, as the name implies, in overlapping balls or layers of earth in the form of mud mixed with straw, in rows, thus forming the walls. The technique was a little used all over the world, of which we can find examples in Germany, the United Kingdom, Yemen or Afghanistan.
(iv) The "Modelled Earth" technique is widely applied on the African continent, especially near the equator, and is characterized by the use of circular plants, often decorated, because of the little labour and tool needs. The technique consists of modelling the rows of earth in the "plastic" state, forming the walls.
(v) Finally, we have the "Pressed Earth" technique. It consists in pressing layers of almost dry soil into formwork, therefore needing instruments for its execution. However, this is still a simple and widely applicable technique, with examples all over the Mediterranean Europe, China, Australia, Africa and America, among many other sites with dry and hot climate characteristics. By its adaptability, it is a technique that has been recovered and improved, being adopted to the construction of several contemporary works.

The following set of techniques in category B, use of earth like masonry, comprehends the previous production of earth units that are to be later used in the building construction, allowing more complex elements such as arches, vaults, walls, etc.

(i) The first technique, called "Apiarized Blocks", refers to the production of compressed earth units with a mallet in rectangular- or square-shaped wooden moulds, later dried in the sun. Examples of this have been recorded in some European countries and in the Indico region.
(ii) The "Press Blocks" technique, also known as "BLT", was initially developed in Central Europe and is one of the most widely used in the world. It allows the rapid production of blocks with good mechanical characteristic through the compression of dry earth mixed with fine particles in moulds. With the evolution of the technology, this technique also benefited from the development of the presses, being able to produce quickly and easily more elements.
(iii) The "Blocks Cut" technique consists on the extraction of earth blocks from places where this raw material is revealed cohesive, with a method similar to the extraction of stone. Examples of this technique can be found in several countries of Africa and India, with a humid tropical or subtropical climate and soils with a high ore concentration.
(iv) In Asia, Latin America and some Nordic countries, we have the "Earth Touches" technique, comprising the cutting of blocks of consistent earth from the soil surface, being then dried and used for the construction of walls.
(v) Within the most developed earth-building techniques, we have the construction with "Extruded Earth". It is a modern technique, with resource to

mechanical equipment, that allows the production of blocks mixed of dry earth and a large percentage of fine elements. This allows to correct the percentage of the different elements and produce more controlled and homogeneous units on a large scale that are then dried.

(vi) The "Mechanical Adobe" technique is similar to the prior art, differentiating itself by using earth in plastic (with liquid) state, thus resulting in higher drying times. Its application is more common in North America as in dry and wide places that allow the production and drying of the blocks.

(vii) Most common in Africa, the "Manual Adobe" technique consists of modelling plastic earth units only with their hands that are then dried and used in building construction.

(viii) However, the most common technique is the "Moulded Adobe" technique, in which the blocks are formed by filling moulds of wood with wet clay, acquiring a regular shape, and then allowed to dry in the sun.

The last set of techniques in category C, earth used as a support structure filling, consists of using this material in the filling or coating of other materials' support structures (traditionally wood), assuming itself as a secondary element.

(a) Thus, we have the technique of "Earth Overcoating", consisting of the covering of crossed structures with earth, known in Portugal as "partitions" or "taipa de fasquio", but also being a common technique to several European, African and Latin American countries.
(b) Similarly, we have the "Earth on Crate" technique, where it is used for coating and for filling the support structure. This is also common in Portugal, as well as in other tropical and Nordic countries, in Latin America and in Central Europe.
(c) The "Earth-Straw" technique consists of the creation of a liquid paste of clay with straw, being used as filler or insulation in the construction of walls or floors in formwork.
(d) The "Earth Fill" consists in the use of this material as filling, insulation or reinforcement of existing structures, usually in brick or stone masonry.
(e) Finally, the "Earth Coverage" technique, which consists in the use of land as cover layer, as a way to protect structures built with other materials, can be applied in different types of roofs or terraces. It is a common technique in America and Africa but also in Asia and some Nordic countries.

Earth-based construction is particularly significant on the African continent, especially in the context of a sustainable architecture, although there is still much in which this practice can be enhanced. However, in spite of the great number of good examples and the proven validity of these constructive techniques, there are a stigma and resistance in their adoption in relation to the so-called modern building systems, commonly used on the European continent which has other resources and social context.

Particularly in the southern African countries, earth construction is marginalized, seen as unwanted, poor-quality architecture for the underprivileged. In fact, alternative systems adopted at these sites, usually using iron and steel structures, backed brick and concrete, are inadequate for the real needs as well as for the resource availability, meaning that materials have to be imported at enormous distances, as well as the technical knowledge to apply them.

Fortunately, there are also countries where earth constructive practices are in full development and application and are seen as a clear asset. This is the case, for example, of Morocco, where the use of earth construction methods is seen as a means of revalorizing the architecture and built heritage.

This also arises from the awareness that this type of construction is not only part of the local culture but that also translates into benefits for the local economy: in relation to labour costs and raw material prices, in the valuation of cultural heritage and in the development of tourism and in the fact that they are sustainable construction methods.

With regard to this last question of sustainability, it is enough to prove the life cycle of the materials. In the case of earth architecture, we have a base material without the need of transformation, being removed, modelled and used in the site. At the end of the building life cycle, the material can be returned directly, being 100% recyclable. As far as the ecological footprint is concerned, it is a free of charge material or with a very low cost in regard to transport and processing, especially when compared to cooked or forged materials.

Therefore, we can define as a good practice the application of earth walls, with high thermal inertia, in cases where the climate is hot, with a daily thermal amplitude of 7 °C or higher, allowing that element to absorb the ambient heat at the most warm time of the day and to release the same to the external environment as the day becomes colder, regaining its thermal response capacity for the next day (Figs. 3.114 and 3.115). We also have situations of the "Excavated Earth" technique, where the compartments are created by omission or extraction. Considering that, in these situations, all the surrounding walls of the housing consist of a huge and compact thickness of raw earth, the thermal inertia will be maximum, dissipating any heat gains throughout this mass. This type of construction has the peculiarity of being suitable to practically any situation in relation to temperature, since it will be naturally conditioned by the inertia and mass of the constructive element (Figs. 3.116 and 3.117).

Figs. 3.114, 3.115, 3.116 and 3.117 Both on the left, thermal image comparison of the building thermal behaviour, showing the material interior surface temperature much lower than the measured temperature of the material external surface; both on the right, example of the Excavated Earth technique, showing entrance to a house built by extraction

Practical Application

In view of the diversity of climates in Africa and the characteristics of the earth architecture, although it is not intended for all sites, it can be applied in most warm but temperate areas, whether by the influence of rivers, sea or other phenomena that allow to assure a daily thermal amplitude. However, the most commonly used techniques differ in relation to specific climatic conditions but also in terms of urban and constructive density, technical knowledge, availability of technical, human and raw material resources, etc.

Considering this, the earth construction practices for several centuries in that continent presents examples of different constructive methods, marked by the evolution of the systems, being therefore easy to find cases of application of different techniques in a certain building. That fact also demonstrates the adaptability and compatibility of the different techniques between them.

Among the most common constructive systems, we have the Pressed Earth and the Modelled Earth. The first technique consists of the construction of thick walls through the filling of earth in forms of wood, then compacted with a pack. Although it is currently a less used technique than the others, we can verify several walls constructed with this system, evidenced by the holes that result from the formwork (Figs. 3.118 and 3.119).

The more primitive Modelled Earth technique, being applied without the use of tools, consists of the construction by superimposition of rows of wet earth, modelled and compacted by hand. We can find several examples of this technique in Guinea, were it is still widely used (Figs. 3.120 and 3.121).

In addition to these techniques, it is increasingly common to check buildings using masonry blocks. Although we are progressively starting to find more cases of compressed blocks constructions and Mechanical Adobe techniques, mainly using simple but effective manual presses (Figs. 3.122, 3.123 and 3.124), in most cases we have Moulded Adobe blocks, where plastic earth is moulded with the use of wooden formwork and left to dry in the sun (Figs. 3.125, 3.126 and 3.127).

Figs. 3.118 and 3.119 Morocco – on the left, example of the formwood and other instruments used in the Pressed Earth technique. On the right, example of wall built with this technique, clearly noticing the holes resulting from the formwork and the different construction levels

Figs. 3.120 and 3.121 Guinea – on the left, example of the construction process used in the Modelled Earth technique. On the right, example of dwelling built with this technique, clearly noticing the different construction levels still drying

Figs. 3.122, 3.123 and 3.124 Guinea – on the left, image of a manual press; on the centre, stack of mechanical adobe blocks used for constructions; on the right, example of wall being built with this technique

Figs. 3.125, 3.126 and 3.127 Morocco and Guinea – on the left, example of Moulded Adobe technique; on the centre, stack of blocks used for construction; on the right, Moulded Adobe blocks drying in the sun, showing that same technique can produce different blocks

Figs. 3.128, 3.129 and 3.130 Morocco – on the left, example of floor slab (in ruin), allowing to understand its construction; on the centre, example of building construction in overlapping floors; on the right, thermal image of buildings' rooftops, clearly noticing the increased temperature on the roof slab and the progressive cooling of the elements on the lower floors

With a progressively smaller expression, to the detriment of the easier and faster prior art, we also have several constructions of the type Manual Adobe, in which the blocks are moulded by hand and left to dry in the sun, being a technique obviously more cumbersome and that gives rise to irregular elements.

In addition to the walls with great thermal inertia, depending on the social conditions, the urban density and the availability of other constructive resources, we can verify examples of earth architecture with roofs in the same material or, traditionally, in wood and straw. The main constraint will be the density and the need for building in height, in which cases the buildings have two, three or more overlapping floors, usually in compact housing complexes, as we can find in Morocco (Fig. 3.128).

In these cases, since there is a need to use a consistent material for floor slabs and roofing slabs, we have a type of earth coating construction type, consisting of the covering of a wooden support cross structure that acts as a frame, in which earth will serve as a binding and protective element of this structure, also giving density to it (Fig. 3.129).

Although these elements also act as heat accumulators, this practice takes advantage of the share of inertia by the urban density. Besides that, with the use of different floors, although the higher one will register higher temperatures, the lower floors are benefited by being protected from solar gains (Fig. 3.130).

In the case of regions with less urban density, which are subject to similar climatic conditions, we usually have constructions with high and sloped roofs, in light materials and without thermal inertia, mainly intended to allow the interior ventilation of the spaces and to provide some shading of the exterior elements. Traditionally, these coverings were made with wood structure and thatched or straw coating. Currently, although wood is still used as a structural element, it is common to find covers with metal or zinc coating, depending on the availability of the material, with a worse thermal behaviour but with less maintenance (Figs. 3.131, 3.132 and 3.133).

Figs. 3.131, 3.132 and 3.133 Guinea – on the left, example of a traditional roof; on the centre, example of roof with wood frame and zinc cover; on the right, thermal image of metal roof, noticing a very high heat transmission

Figs. 3.134 and 3.135 Guinea – on the left, example of a more traditional house, more roughly built, but with attention to raising the floor; on the right, a more modern example of a more carefully built structure intended as a school, sharing the same solution

It is also important to mention the aspects that relate to the protection of the earth-building construction foundation of the influence of water, particularly in regions subject to heavy rainfall and flooding periods, as their effect could damage the elements and crumble the construction. In the case of dense urban areas, normally not subject to heavy rainfall, the objective is often to collect and reuse rainwater, so the roadway has means of rapidly channelling and collecting that resource, therefore providing protection for buildings. In areas more affected by frequent bad weather, even in urbanized areas, we find that almost every construction is built on a raised base above ground, often with care to ensure drainage in its perimeter (Figs. 3.134 and 3.135).

In some cases, we also find that a percentage of lime is added in the mixture that gives rise to the building blocks used in the base of the building, or in the final plaster/coating, in order to waterproof those elements and to assure a greater resistance to water effects (Figs. 3.136 and 3.137).


Figs. 3.136 and 3.137 Guinea – on the left, example of construction blocks with added lime to assure water resistance; on the right, application of a coating layer rich in lime, in order to protect the building foundation blocks from water damages

Adaptation in Contemporary Architecture: Conclusion

With the evolution of the techniques, the construction patterns and the ways of living, there is also a new individual and social awareness of construction models. The search for increasingly energy-efficient buildings is a reality, opening doors to other concepts such as sustainability and the health of the internal environment. Thus, we have the reintroduction and promotion of earth as a building material per excellence, being a local resource, inexpensive, easy to apply, with good thermal and mechanical behaviour and, especially in this context, totally recyclable. Furthermore, in addition to these characteristics, earth as a constructive material is also advantageous in relation to other industrial materials such as cement or baked brick, in its ability to produce a healthier internal environment, since the material itself acts to filter the air particles, regulating the natural humidity and absorbing odours and noise, and by the absence of any toxic products in its composition.

As we said earlier, earth architecture could also be an essential factor in the response to the housing needs, especially in the developing countries of the African continent, where the answer to this question, for the time being, can only be given by the resource to local materials supported by self-construction techniques. Also taking into account the lack of local resources and infrastructures, it is particularly worrying that most recent studies point to the worsening of the climatic conditions, resulting in the general increase of temperatures and the need for air conditioning systems (https://www.theguardian.com/cities/ng-interactive/2018/aug/14/which-cities-are-liveable-without-airconditioning-and-for-how-much-longer), resources that are unavailable for the general population in Africa.

In this context, more than the need for thermal insulation of the building, widely promoted in the European architecture as a response to the problems of the used constructive systems that give rise to the necessity of active systems to condition the internal environment, the African answer will have to be given using passive bioclimatic models, making particular use of thermal inertia as a means of counteracting the increase in daily temperatures, of which earth architecture is a perfect example.

Unfortunately, despite some exceptions, many African countries and societies look at earth architecture with disdain, curiously in some of the countries that may most benefit from it. Fortunately, in addition to the aforementioned examples, where these constructive systems have been progressively restored, a little throughout the world has emerged works of contemporary architecture, with exceptional technical and aesthetic quality, rediscovering the qualities of earth as a material and constructive system, attesting and promoting their validity in contemporary application.

These are the kind of cases we wish to promote as good examples of their potential and applicability, encouraging them as a way of demystifying and altering preconceived ideas. Truly, earth architecture today represents one of the main constructive models for the future of Africa, having the potential to assume itself as a basilar tool for the sustainable development of the societies.

3.8 Evaporative Cooling

Evaporative cooling is achieved by an adiabatic process, in which the sensible air temperature is reduced and compensated by latent heat gain. The use of fountains and vegetation in the courtyards, the act of pouring water on the floor and the use of large porous clay pots filled with water in the rooms are good examples of direct evaporative cooling techniques, used in some of the warmer countries of Africa. These can also be applied successfully in Cape Verde, and also in Angola and Mozambique during the dry season, when the relative humidity content does not exceed 60%. Figure 1.7 in Chap. 1 shows the regions of Africa where evaporative cooling may be used.

There are also indirect evaporative cooling techniques, where the air is cooled without increasing its water vapour content. Through this system, the air temperature can be lowered to match the wet-bulb temperature. Water consumption is much lower than in direct systems. However, the indirect systems involve the use of mechanical devices, which can be expensive and require complex maintenance (Figs. 3.138, 3.139, 3.140, 3.141 and 3.142).

3.9 Control of Internal Gains

The main sources of heat inside the building are electric lighting, the concentration of occupants and the mechanical equipment they use. The internal heat gains can also contribute significantly to overheating, especially in office buildings with larger dimensions. The main strategies to reduce internal heat gains are:

Fig. 3.138 Use of vegetation in the interior of a house in Mindelo: in addition to being pleasant, it slightly reduces the air temperature

(a) Avoid excessive use of artificial lighting.
(b) Optimize the use of natural light.
(c) Avoid excessive heat gains from occupants and equipment.

3.10 Environmental Controls

Some passive cooling techniques, such as the use of thermal insulation or reflective coating to reduce heat penetration into the building, do not involve the use of operational controls, i.e. the systems are fixed, are inherent to the building and do not require occupant control or automatic interaction.

However, in many other passive strategies, such as opening windows for natural ventilation, shading adjustment or the use of fans, system performance is governed by operational controls. In these cases, the efficiency of the energy consumption reducing systems and the creation of comfortable environments are conditioned not only by the efficiency of controls but also by the way the occupants use them. The use of environmental controls allows users to change the environment, adapting it to their thermal comfort needs. Consecutively, there may be a significant improvement in thermal satisfaction, allowing the occupants to meet their specific comfort needs, reducing discomfort from overheating.

It is important that the occupants are aware that the use of controls not only leads to an improved efficiency of the system itself but also has a major impact on energy savings. To do this, the design must be simple in order to facilitate an intuitive understanding of its use.

Fig. 3.139 Examples of use of vegetation in open spaces in Santiago and Sao Vicente: aside from providing shade and contributing to the beauty of the place, the vegetation also contributes to a slight reduction of local temperature through the process of evapotranspiration resulting from photosynthesis (evaporative cooling)

Fig. 3.140 Examples of use of vegetation in open spaces in Luanda and Cuanza

3.11 Bioclimatic Design and Thermal Comfort Criteria

Passive design techniques can be applied with a good degree of efficacy. It is true that the use of these techniques does not promote the kind of uniform, low temperature environments found in air conditioned buildings. A question must then be placed: is that kind of uniform indoor environments really necessary and desirable?

In surveys conducted throughout the world in naturally ventilated buildings, where environmental conditions vary outside the conventional thermal comfort standard, a majority of people reported feeling, in fact, comfortable with their thermal environment. Other studies, conducted in buildings with central air conditioning, showed a significant dissatisfaction with the thermal environment by the occupants. This dissatisfaction could be attributed to various causes such as lack of "naturalness" and the health problems inherent to the system or yet another very important factor: the lack of environmental controls in existing buildings with a centralized system, which inhibit the natural process of human adaptation.

There is now a major controversy about which thermal comfort criteria should be adopted. The conventional standards accept only a limited temperature range as theoretically "ideal", i.e. within which the vast majority of the occupants of a building would feel comfortable. These conventional standards of comfort, as the current ASHRAE and ISO standards, are still regarded as applicable anywhere in the world, with only a small seasonal variation for summer and winter situations, despite the existing wide variety of climates. They consider summer temperatures around 22 °C as ideal, with maximum temperatures of around 26 °C. In warmer countries, this would require the extensive, in many cases permanent, use of air conditioning systems.

Fig. 3.141 Guinea-Bissau: examples of use of vegetation in open spaces, in Bafatá, Buba and Bissau

On the other hand, there is now a large body of evidence that shows that people living in countries with warmer climates are satisfied at temperatures higher than those living in countries with colder climates, and these temperatures are significantly different (upper and lower, respectively) of the temperatures considered "ideal" by conventional standards.

Fig. 3.142 Maputo, Mozambique: examples of use of vegetation in open spaces. Trees generally have the effect of reducing wind speed – however a row of trees with bare trunks for the lower 3 m may, if the foliage is dense above, deflect and enhance the breeze at ground level

Buildings that use passive cooling techniques can be an efficient and economic, energy-efficient and environmentally friendly alternative to air conditioning buildings. These bioclimatic buildings also offer more satisfactory thermal environments – not in its ability to meet strict standards but in improving the physiological and psychological comfort of the occupants.

For a better understanding of what might mean the internal comfort of a building, Figs. 3.143, 3.144, 3.145 and 3.146 show the psychometric graphs for various cities, representative of the diversity of climates existing in Angola, Cape Verde, Guinea-Bissau and Moçambique. The dark blue area on the chart represents the climatic characteristics (wet- and dry-bulb temperature, relative humidity and vapour pressure), and outlined in yellow is the ASHRAE conventional comfort zone, considered by the Ecotect Weather Tool software.

In these graphs one can observe the overlapping zones of influence of the various passive cooling techniques, based on the research by Givoni (1969). The diagram shows how the conventional comfort zone can be enhanced through the use of various passive cooling techniques. The referred strategies are the most appropriate to the performance of the building in these climatic zones. Outside these areas, the use of air conditioning would be required.

It can be seen that, despite the variety in climatic profiles, the strategy with the greatest impact is the natural ventilation (2 – highlight in light blue), followed by night ventilation (3 – dark blue) and, specially in the dry season, thermal inertia (4 – light pink) and evaporative cooling (5 – green).

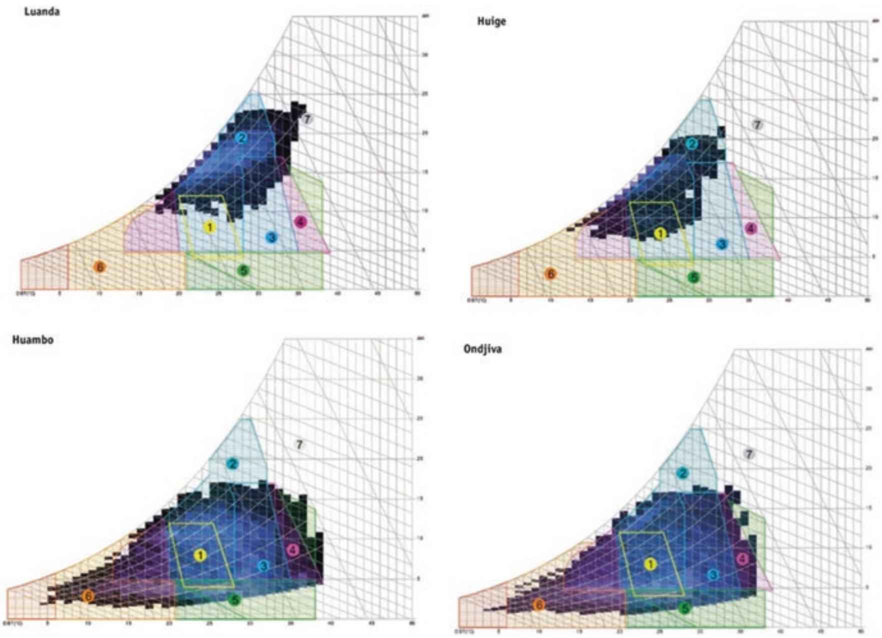


Fig. 3.143 Psychometric diagram – for four cities in Angola – representative of the main climatic zones of the country. The dark blue area illustrates the climatic profile of the region. The diagram shows how the ASHRAE conventional summer comfort zone can be expanded through the use of various passive cooling techniques. The various areas shown on the graph were defined by Givoni (1969) and correspond to (1) ASHRAE conventional summer comfort zone, used as standard for the use of air conditioning (yellow); (2) zone of influence of daytime ventilation (light blue outline); (3) zone of influence of night ventilation (blue outline); (4) zone of influence of thermal inertia (pink contour), including zones 2 and 3; (5) zone of influence of evaporative cooling (green outline) (the evaporative cooling can also be used in zones 2, 3 and 4, for dry-bulb temperatures above 21 °C); (6) passive heating zone (dark yellow) and the zone of active heating (brown outline); and (7) zone where air conditioning is required (white background)

The need for cooling is predominant, though in some cases such as here a small period of passive heating is also required (yellow zone), during the dry season which can also be obtained passively (using solar energy), for example, by a proper orientation and window sizing. In very few cases, such as in Huambo and Ondjiva, in Angola, active heating (orange zone) may be required during a short period of the year – in these cases, solar thermal systems may prove useful.

Also noteworthy is that these passive strategies cover most of the climate profile (dark blue area), in a significant number of situations, such as in Uíge, Huambo and Ondjiva in Angola, Sal in Cape Verde or Tete and Lichinga, in Mozambique, showing that, in theory, there is virtually no need for air conditioning active systems for cooling in these regions.

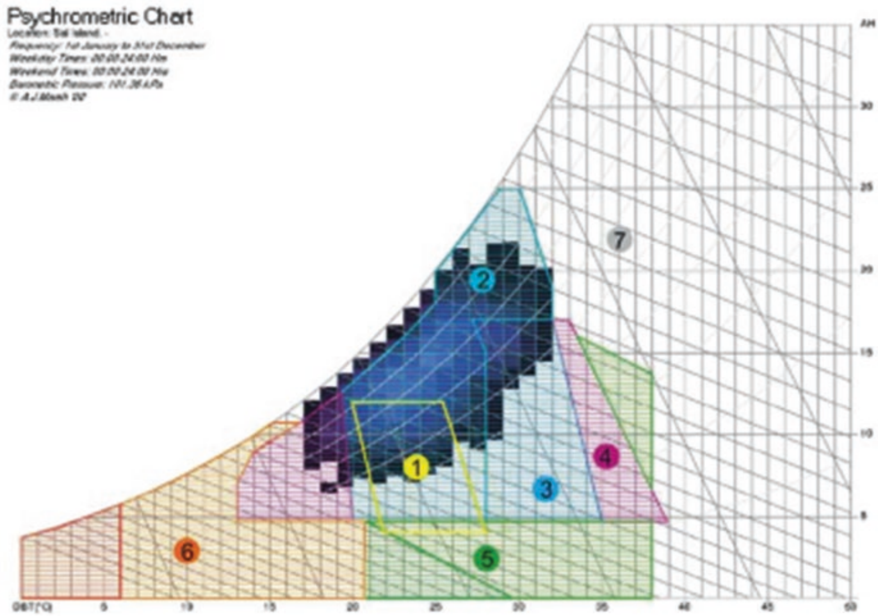


Fig. 3.144 Psychometric diagram for the island of Sal, representative of the climate of the Cape Verde archipelago. The dark blue area illustrates the climatic profile of the region. The diagram shows how the ASHRAE conventional summer comfort zone can be expanded through the use of various passive cooling techniques. The various areas shown on the graph were defined by Givoni (1969) and correspond to (1) ASHRAE conventional summer comfort zone, used as standard for the use of air conditioning (yellow); (2) zone of influence of daytime ventilation (light blue outline); (3) zone of influence of night ventilation (blue outline); (4) zone of influence of thermal inertia (pink contour), including zones 2 and 3; (5) zone of influence of evaporative cooling (green outline) (the evaporative cooling can also be used in zones 2, 3 and 4, for dry-bulb temperatures above 21 °C); (6) passive heating zone (dark yellow) and the zone of active heating (brown outline); and (7) zone where air conditioning is required (white background)

In other cases, such as in Beira and Quelimane, in Mozambique and especially in Bissau or Bolama, in Guinea-Bissau, the area which is located in the active zone (7 – where artificial cooling is needed) is significant: it corresponds to the hot and rainy season, with high temperature and humidity values, surpassing the upper limits of comfort prescribed by Givoni. In these cases, one can use, for example, fans (a low-energy and economic system), or a mixed-mode system, to increase upper comfort limit – or there is now an alternative technology to conventional air conditioning, the so-called solar HVAC, air conditioning mechanical systems in which the use of electricity from fossil fuels is replaced by solar energy, a renewable source, thereby reducing the negative impact on the environment and also maintenance costs.

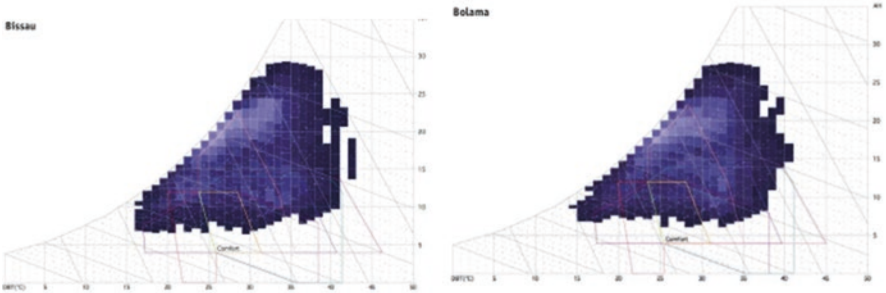


Fig. 3.145 Psychometric diagram – for two cities in Guinea-Bissau – representative of the main climatic zones of the country. The dark blue area illustrates the climatic profile of the region. The diagram shows how the ASHRAE conventional summer comfort zone can be expanded through the use of various passive cooling techniques. The various areas shown on the graph were defined by Givoni (1969) and correspond to (1) ASHRAE conventional summer comfort zone, used as standard for the use of air conditioning (yellow); (2) zone of influence of daytime ventilation (light blue outline); (3) zone of influence of night ventilation (blue outline); (4) zone of influence of thermal inertia (pink contour), including zones 2 and 3; (5) zone of influence of evaporative cooling (green outline) (the evaporative cooling can also be used in zones 2, 3 and 4, for dry-bulb temperatures above 21 °C); (6) passive heating zone (dark yellow) and the zone of active heating (brown outline); and (7) zone where air conditioning is required (white background)

However, for tropical hot and humid zones like these in Guinea-Bissau and certain regions in Mozambique, existing comfort criteria may prove rather conservative and unrealistic, since they were based in empirical formulas and standards of comfort typical of cold or temperate climates. For example, field studies recently carried out in Guinea-Bissau show that with external temperatures of 39–43 °C, and up to 75–80% RH%, people feel comfortable at 31 °C; hence most of the area where air conditioning would be needed would be reduced (in the presented graphs). This is an area where research is still necessary – to clarify the actual comfort requirements in hot and humid tropical regions, as in the presented cases – in order to avoid unnecessary energy consumption, with serious economic and environmental consequences (Figs. 3.147 and 3.148).

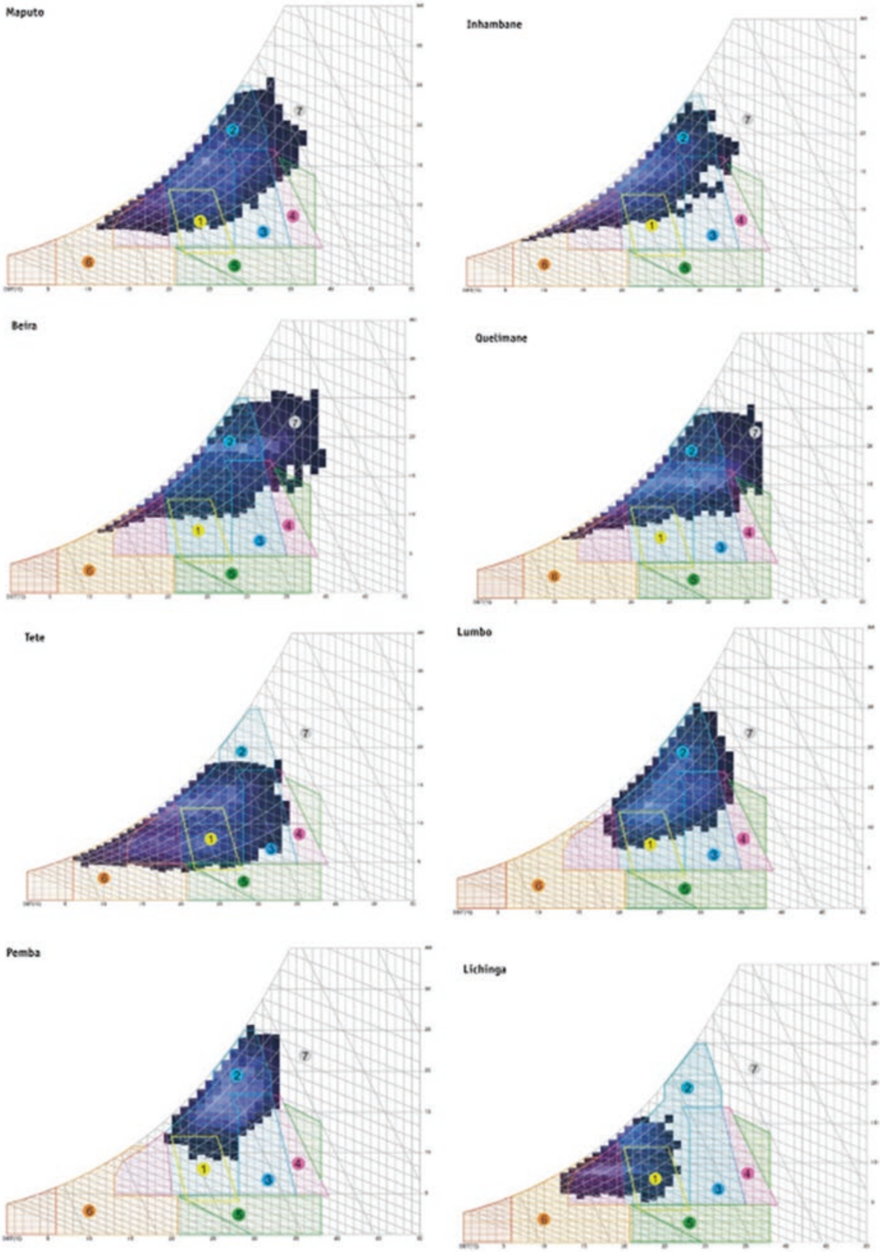


Fig. 3.146 Psychometric diagram – for eight cities in Mozambique, representative of the main climatic zones of the country. The dark blue area illustrates the climatic profile of the region

Fig. 3.147 Luanda, Angola: the use of air conditioning can be avoided through a correct use of passive design, reducing damage to the environment and operation costs

Fig. 3.148 Use of air conditioning devices, city of Praia, Cape Verde

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Chapter 4
Vernacular Architecture in Arid Climates: Adaptation to Climate Change

Nadia Samia Daoudi, Djamel Mestoul, Samia Lamraoui, Aicha Boussoualim, Luc Adolphe, and Rafik Bensalem

People working in the field of vernacular architecture located in arid zones acknowledge that these settlements have developed urban and architectural morphologies well adapted to the extreme physical environment. They identify adaptive features in urban and architectural patterns, cohesive social structure, and finally, adaptive behaviors derived from an indigenous "know-how."

On the other hand, field research in climate change affirms that the human groups most exposed to climate change are those located in developing countries; the Saharan vernacular settlements testify to this assertion. Nevertheless, as regards adaptability to climate change, the indigenous people of the Sahara retain specific knowledge concerning resilient ecosystems. Furthermore, it is recognized that this indigenous knowledge plays a significant role in maintaining local socio-ecologic systems that contribute to socially responsible resilience toward sustainability.

This chapter highlights the role of social cohesion in implementing pro-environmental behavior and adaptive actions to reduce the negative effects of climate change on indigenous communities of the northern Sahara. We base this argument on the results of in situ investigations with the objective of comprehending and evaluating the indigenous knowledge and adaptive capacities of desert oasis dwellers to both ordinary and extreme weather situations stemming from climate change. The case studies are Algerian Saharan vernacular settlements of the M'Zab Valley and of the Gourara region.

International reports and leading conferences corroborate that the most exposed human groups to climate change are those located in developing countries, assuming that these are the most economically disadvantaged areas of the world (IPPC 2007; Moser 2010). Experts explain this regionalization of vulnerability first, by the socio-economic maladjustment of these populations to this phenomenon, especially that

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their livelihoods rely heavily on generally weakened natural ecosystems, and second, by deficiencies in public policy and government, being solely involved in "day-to-day problems," leading to underestimates of the extent and impact of climate change (Swart et al. 2003). Very often, the poor and other at-risk populations occupy environmentally threatened tracts of land, whether in rural or urban areas. Their communities lay under threat of environmental hazards, such as flooding or drought, and are often characterized by environmentally ill-adapted structures. As a result, these communities often become the most negatively impacted by climate change. As a result, we assume that climate change intensifies the vulnerabilities of populations in deprived socioeconomic situations (Speranza et al. 2010). Fortunately, as regards resilience to climate change, leading authors affirm that traditional and indigenous people retain specific knowledge concerning their autonomous resilient ecosystems. Furthermore, it is recognized that these latter play a significant role in maintaining locally resilient socio-ecologic systems (Green and Raygorodetsky 2010).

Several studies have been conducted in the special field of vulnerability due to climate change, either by performing reviews or by dealing with special field studies (Adger 1999; Adger and Kelly 1999; Kelly and Adger 2000). In the scope of this paper, we introduce the concept of vulnerability, as developed by several authors. It is thus defined as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone's life and livelihood is put at risk by a discrete and identifiable event in nature or in society" (Blaikie et al. 1994, p. 9). This definition goes with Smit's et al. definition (Smit et al. 2000, p. 238) that explains vulnerability as "the degree to which a system is susceptible to injury damage or harm, one part – detrimental – of sensitivity." In the research reported here, we agree with the definition of vulnerability developed by Adger and Kelly, as: "the state of individuals, groups, communities, defined in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being" (Adger 1999, p. 254). Moreover, we adopt the importance given to vulnerability as related to "short-term climate hazards and extremes, (flood and drought, cyclone and heatwave)" (Adger 1999, p. 254). These hazards remain the events that occur in the areas of our research, as we will develop later.

Vulnerability as introduced in the former definitions summarizes the state of countries from the developing world that seems to be sadly the remote areas the most at risk. These authors state that one challenge facing at-risk populations to transcend vulnerability is to identify their inherent adaptive capacities to achieve resilience and sustainable development (Adger et al. 2003). In the same scope, Smit (2000, p. 238) defines adaptive capacity as, "the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change." Nevertheless, adaptation to climate change remains of great concern to several authors; we find this in the way they have summarized definitions of adaptation by developing the linkage between climate change variability and the response of the different systems, in terms of the socio-ecological-economical aspects (Klein and Tol 1997; Smit and Pilifosova 2003; Schipper 2007).

However, for the purposes of this paper, we introduce the definition of adaptation as the adjustments an individual or a group perform as a response to any expected environmental natural stimuli or extreme hazard. As a concomitant process, resilience becomes the capacity of a given population to cope with natural hazards, to recover from them, and at last, to adapt and develop innovations from them, (Cutter, 1999; Smit et al. 2000; Cutter et al. 2008, 2009). Again, in terms of resilience, the capacity of a given group to cope with environmental risk depends sometimes on the relationship the group maintains with the variability of climatic characteristics, depending on their structural socioeconomic resources (see Fig. 4.1).

We could consider the first adaptive process as proactive when the group has a reasonable knowledge of the magnitude of the risk, for example, in the case of regular seasonal factors. This type of adaptation reveals a strong ecological framework grounded in structured social cohesion emerging from a supportive organizational structure; it also reflects a strong religious influence. Sustainability is the induced process with a high socially responsible resilience.

The second type of adaptation turns into a reactive form when extreme episodic weather events occur, mainly due to climate change variability, such as heavy rains, floods, sand storms, and so on. Due to their suddenness, magnitude, discontinuity, and irreversibility, they exceed the normal adaptive capacity and disrupt indigenous ecological knowledge, especially when fragile social cohesion and poor economic conditions weaken the general framework. Vulnerability becomes the induced process, highlighting a weak social responsible resilience. However, it is assumed that "anticipating and adapting to such events and their impacts would be much more difficult than responding to smooth change, even if these responses must be made in the face of uncertainty" (IPPC 2007).

These different arguments are summarized in Table 4.1, where types of environmental parameters are related to developing either proactive or reactive types of adaptation.

Again, due to the variability of environmental events, people perform two forms of adaptive actions, one proactive and the other reactive. We can confirm that in these two cases, the degree to which a community is either vulnerable or resilient is strongly dependent upon the strength or weakness of the pre-existing social framework (Daoudi et al. 2011).

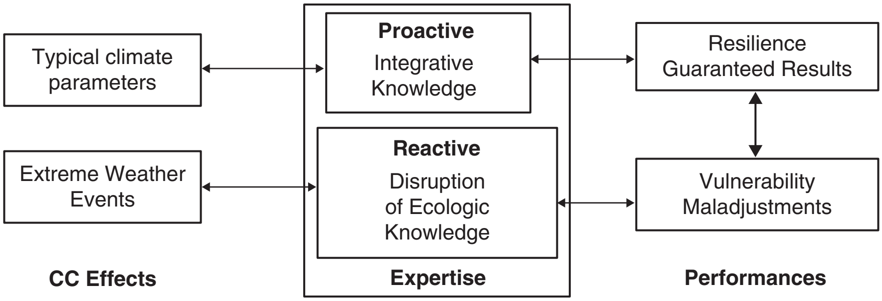

Fig. 4.1 Relationships between type of parameters and adaptation strategies

Table 4.1 Impact of environmental parameters on socioeconomic sustainability

Environmental parameter	Formula	Type of adaptation	Adaptation strategy	Social cohesion influence	Outcome
Weather (regular seasonal)	SRR ↑ SC ↑∝V ↓	Proactive	Intergenerational "know-how"	Strong	Sustainability
Climatic (episodic/ extreme)	SRR ↓ SC ↓∝V ↑	Reactive	Awkward innovation	Weak	Unsustainability

Key: *SRR* socially responsible resilience, *V* vulnerability, *SC* social cohesion, ∝ proportionality

Therefore, regarding the scope of social cohesiveness, distinctively vulnerable populations either experiment using empirical reasoning based on their intergenerational legacy and engage a path to sustainability or, on the contrary, choose dysfunctional strategies (awkward innovation), which put them onto a path of uncertainty and a state of ecological and socioeconomical vulnerability. These assumptions are in phase with the contemporary discourse that finds resilience in the face of climate change draws on survival strategies grounded in traditional social organization (Keim 2008; Chishakwe et al. 2012).

In the same way, authors have also stated that indigenous societies enhance their ability to respond effectively to climate change when they draw upon their traditional ecological knowledge. This latter is "often integral to a traditional community's culture, and is a large part of its repertoire of habits, skills, and styles from which people construct their livelihoods" (Adger et al. 2011, p. 5). To quote Hountondji (1997) "Nobody can nowadays deny that there exists in our oral cultures, corpuses of knowledge sometimes very elaborate, faithfully transmitted from one generation to another and often gaining in quality and substance in the process of such transmission." We shall adopt these arguments as the definition of intergenerational know-how and the quintessence of sustainable, resilient ecological values.

Moreover, confronted with the urgency of making decisions concerning their environmental situation, people living within integrative social structures develop responsible resilience and self-efficacy beliefs, on the basis "of their judgment about what they are able to do as well as on the beliefs about the expected consequences of their actions" (Bandura 1994). The processes engaged in the interest of resilience become tools for the revalorization of traditional and indigenous knowledge. Such people know the empirical mechanisms of their traditional beliefs, and the homogeneity of the group's decision-making strengthens the ecological solutions that they pursue to overcome their vulnerability engendered by climate change.

Following this logic, Adger (2003) puts forward the concept of social capital; this represents for the author "a core of different relations of trust, reciprocity, exchange, common rules," all put together to achieve community resilience. The community's deep understanding of the local ecosystem reveals itself a substantial resource in the objective of coping with, recovering from, and adapting to climate change, as indigenous customs and culture are seen as tools toward sustainability. Engaged in the same debate, Kolawole et al. (2014) affirm that an indigenous population has historically and can still today perform ethno-meteorology to cope with climate variability.

At this point of developing the theoretical background, we can introduce vernacular architecture as the structural framework of an ecological consciousness that is actually under the threat of climate change. Authors refer to vernacular architecture as "an architecture without architects," with a particular "architectural language" of the people with its indigenous, local expressions (Oliver 2006). It is well understood from books dealing with vernacular architecture that these testimonials to the "native science of building" (Oliver 2006) are vivid lessons of environmentally responsive urban and architectural morphologies. Inhabitants of these settlements dealt empirically with their physical surroundings, and they knew how to adapt, as positive as negative congruent experiences, to any evolving environmental conditions. With these experimental solutions to adapt and achieve resilience, they developed an ecologically sustainable discourse and preserved knowledge, transmitted orally or through manuscripts, for future generations.

The above arguments are consistent with the growing trends that link climate change to pro-environmental behavior. This latter is defined as "the behaviour that consciously seeks to minimize the negative impact of one's actions on the natural and built world" (Kollmuss and Agyeman 2002), with a special emphasis on the general actions that are developed to mitigate risk. We have already argued this when we introduced before the two adaptive actions, proactive and reactive, developed according to distinctive physical environmental parameters. Even further, leading research from the field of environmental sociology and environmental psychology have deeply examined the subject of pro-environmental behavior (Sawitri et al. 2015).

However, the theme that is of interest to the general development of this paper is that related to the strong relationship between social values, indigenous knowledge, and pro-environmental behavior, especially when these values transcend individual self-interest and when they focus on the congruent achievement of the welfare of other members of the group.

One pro-environmental activity that settlers from the Saharan desert use to generate resilience is Touiza. We can define Touiza as an altruistic cooperative action realized by the socially cohesive group to achieve individual and group welfare in every aspects of day-to-day life. In the special case of environmental disturbance, this action has proven that group decision-making is organized democratically and with a high sense of equity. Furthermore, it is an intergenerational knowledge that has long proven its utility through the making of vernacular urban and architectural morphologies. When we arrive to the special case of the M'Zab Valley, we will introduce some examples of Touiza in terms of their pro-environmental behavior achievements.

At this point in this brief theoretical overview, two questions arise:

1. Are indigenous groups living in vernacular settlements still aware of their inherent capacities to overcome climate change variability?
2. Will these capacities turn into an integrated expertise by developing pro-environmental behavior aided by a socially cohesive resilience, both driven to achieve sustainability?

We will discuss the answers to these two questions by examining the results of two in situ works that we completed in 2011 in the vernacular settlements located in the Algerian Sahara desert. To do so, we first start by presenting the contextual background of the case studies.

4.1 The Algerian Setting

Algeria is the largest country of Africa (see Fig. 4.2). Due to its large territory, we can identify four climatic zones. The first is the coastal zone, a narrow coastal and humid zone, where we find the major large cities. The second is the Tell Atlas, a chain of mountains between the coast and the desert. Together, these two zones form 20% of Algeria's territory. Third is the Saharan Atlas, a semiarid zone at the frontier of the Sahara. The Sahara forms the fourth arid zone; this latter zone comprises the site of our investigation. The desert region covers 2,000,000 km^2, thus 80% of Algeria's total land area. Because of the ongoing desertification process, the arid zone will increase from 80% today up to 85–88% by the year 2080. We can assume that this huge territory will be dramatically impacted by the process of climate change.

Algeria's Sahara is, from the climatic point of view, generally characterized by the same physical parameters as other warm arid regions. The climate of these regions is characterized in summer time by high air temperatures, low humidity, and little precipitation. Hot winds, called *Sirocco*, bring suffocating dust and airborne particulates, while occasional heavy rains can cause dangerous flash floods. Furthermore, key findings from leading works on climate change testify that these areas will be the scene of potential increase in rainfall volumes and intensity as well as rise in temperatures. However, from our in situ work, we realized that the population identifies extreme climate change events such as flash floods as well as desertification impacts in terms of silting. In this work, we will discuss the scope of regular weather parameters as well as occasional or episodic events, as cited before, and their relation to adaptive actions and sustainability.

Brief Description of the Two Regions

We want to start this part of the paper by quoting Etherton (1978), when he described the Saharan population as follows: "They are the last survivors of a society which has adapted itself over hundreds of years to the rigours of the Sahara." Thus, the settlements found in the M'Zab Valley and the Gourara region reflect this testimonial. The M'Zab Valley, 600 km south of Algiers, the capital city, is located in the desert zone on the rocky Hamada Plateau, whereas Timimoun, in the Gourara region, 1200 km southwest of Algiers, is situated on the Great Western Erg, a vast area characterized by shifting sands and dramatic dunes.

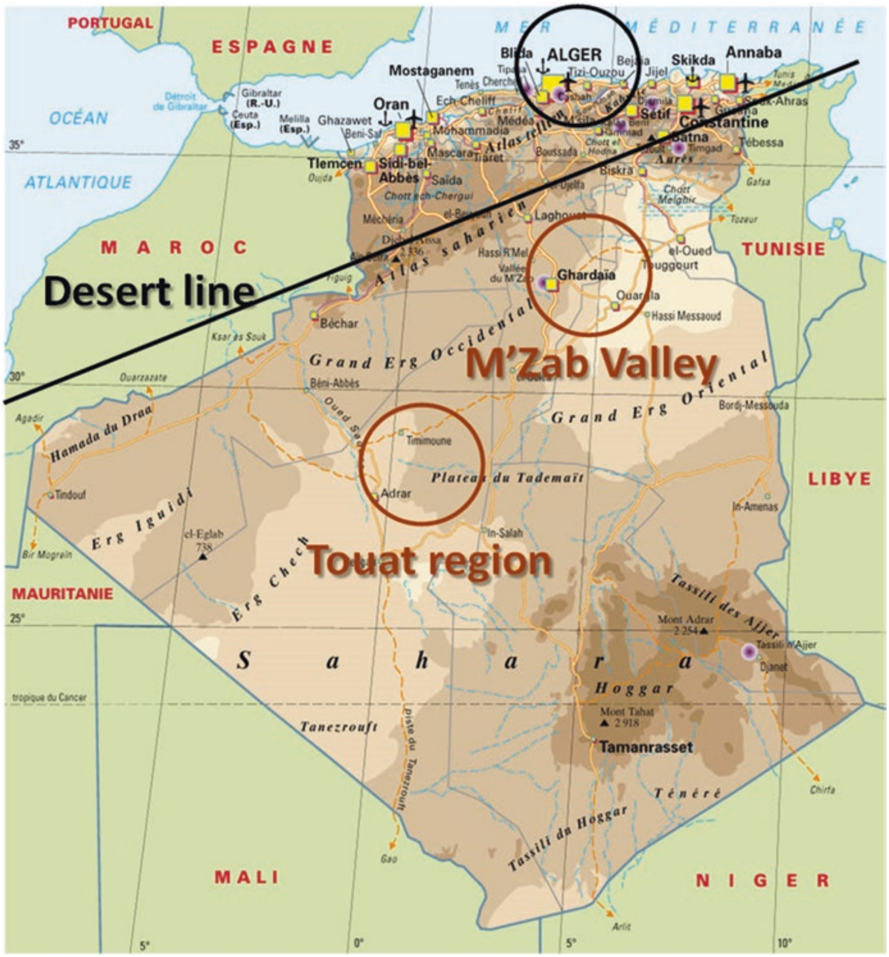

Fig. 4.2 Geographic and political map of Algeria. (Source: http://www.mappery.com/Algeria-Map)

The M'Zab Valley

Due to its patrimonial features, the M'Zab Valley has been recognized as world heritage site since 1982. The Mozabites, or M'Zab Valley inhabitants, are Ibadites, a branch of Sunni Islam, and they explain the coherence of the intricate urban culture by their dramatic history marked by battles and defeats over centuries. Chased from the Arabian Peninsula, they established great settlements in the region of the M'Zab Wadi, the severe environment seen as the ultimate defensible space to encompass their *ksour* to come. The *ksour*, plural noun of *ksar*, are adobe or stone vernacular settlements, built on rocky hills, to preserve the wadi banks as harvestable lands. The process of development of the five *ksour* or the "Pentapole" of the

M'Zab Valley was based on a sequential settlement pattern; when they completed the first *ksar*, the local population expanded to another nearby site to develop another one. They erected five *ksour* in a chronological logic, first El Atteuf (1012), then Bounoura (1046), and Ghardaia (1048); the fourth *ksar* is Beni Izguen (1347), and the fifth *ksar* is Melika (1350). Figure 4.3 presents the five *ksour* and their surrounding developments. We notice that these later developments are organized outside the vicinity of the old settlement, sometimes near the wadi bed, in a floodable zone. This constitutes a vulnerability zone during flash floods.

Writers on the architecture and urban morphologies of the M'Zab valley often described it as a perfect expression of rigor, cohesion, and efficiency. Ravereau (1981) endorsed this argument when he wrote; "The Mozabite rigor is not exercised randomly in appearance or line, but is applied when deeply necessary and is based on an intellectual decision." Morphological coherence illustrated social cohesion ruled over by the strong cultural and ritual power of the mosque, seen sometimes as orthodox. The human settlements started in a heterogeneous process, but it was the adoption of a common religious movement that made the Mozabites more homogeneous.

For the sake of adaptation to an extreme environment and for defensive purposes, the Mozabites developed a culture that combines austerity, equity, democracy, efficiency, rigor, technical expertise, and cooperative work. For centuries, they have deeply preserved their distinctive cultural and ancestral values, in the name of physical and cultural survival.

In presenting the structural features of the M'Zab physical morphology, we start with the *ksar*, or adobe city, a very dense and intricate urban network (see Fig. 4.4). It contains interlaced and narrow lanes and deep canyons, sometimes covered to adapt to environmental extremes, especially during summer (see Fig. 4.5). The *ksar* developed in a concentric process around the mosque and is perfectly adapted to the topography of the hill upon which it is built, with the residential zones spreading

Fig. 4.3 The Pentapole of the M'Zab Valley. (Source: Schmitt 2008)

Fig. 4.4 View of the ksar of Ghardaia

Fig. 4.5 View of a street in Beni Izguen

downward from the mosque to the surrounding town walls. The housing form is introverted, following Sharia precepts issued from the Koran and the Hadith, with a special focus on egalitarianism in the management of the group and the individual's daily life. As an example, we can cite the houses' height, which is limited to permit light and sun to reach the neighboring structures. The second feature of the vernacular settlement is found in the development of palm groves to achieve subsistence agrarian production and allow summer comfort by promoting seasonal transhumance during summer heat.

Of course, nowadays we have moved away from the idyllic image drawn above; the reasons lay on the evolution of the group itself, struggling between preserving traditions and heading to modernity as well as the evolution of the region due to the development of industrial settings near the valley, mostly oil plants. This has led to a growing population and the disturbance of the old structures. The new agglomerations extended between the *ksour* and even into the palm groves. This urban sprawl has resulted in the development of satellite settlements on nearby hills adjacent to the old *ksar* of Beni Izguen. We will come to this point in more details later in the paper.

The Touat-Gourara Region

During our first visit to the Touat-Gourara region, from 20 to 28 November 2009, we investigated several *ksour*, with the objective of completing diagnostic fact sheets on each settlement. In the end, we surveyed ten such settlements, summarizing the strengths and weaknesses of the visited *ksour*. However, for the purpose of this work, we have chosen to present only the results from Timimoun. We choose also to introduce Bedrienne as an example of the environmentally threatening phenomenon of silting, explained as the case of the loss of the "man/nature" ecological pact. First, Timimoun is named the Red Oasis because of the use of the local adobe pigments. It is a weakened vernacular settlement with still strong assets to revive.

Unlike the history of settlement of the M'Zab Valley, *ksour* of the Touat-Gourara region are formed by addition and settlement of nomads of distinctive lineage and origins. We can summarize the different ethnic groups forming Timimoun and other *ksour* of the Gourara region in the following chronology:

First the Jews, second the Zenetes (Berber nomads, settled in different *ksour* of the region), third the Arab-Haratines (according to Etherton 1978, they are the descendants of the original sub-Saharan African slaves, brought from Niger by the Touareg), and then the Mrabtins and Shurfas (Arabs established in the region in thirteenth century). Figure 4.6 below from Bisson (1957) summarizes this ethnic composition.

Despois (1958) established some statistics about the ethnic composition of the Gourara population, with 46.5% of Haratines, 28.8% of Zenetes, and 24.7% of Arabs. This gives an idea of the ethnic heterogeneity of the group. One might speculate that this ethnic diversity has had an inverse influence on the social cohesion of the Gourara community, but for the moment, we do not have enough evidence to make this argument definitively.

When we come to Timimoun urban morphology, we can say that it is the template of any Saharan agglomeration with a *ksar* as the original vernacular

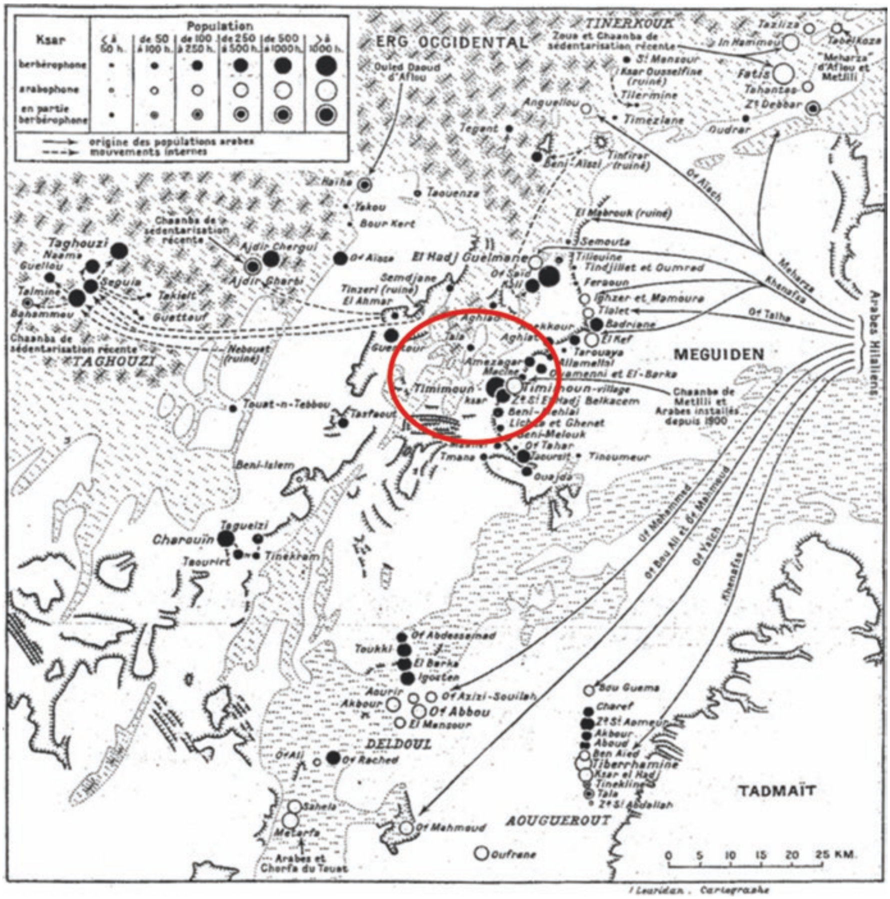

Fig. 4.6 Migration path of the Arabs and Zenetes in the Gourara (Bisson 1957)

settlement, with the palm grove located on the water resource route and the contemporary developments which started in the 1950s, during the colonial era (Figs. 4.7 and 4.8).

We can conclude from this brief introduction to the contextual setting that Ghardaia, Timimoun, and Bedrienne present the morphological characteristics of any given desert vernacular layout, with a hierarchical spatial network, mirroring the formal social structure. The indicators are site integration related to the availability of water resources, environmentally responsive architectural and adapted urban morphologies, a hierarchical socio-spatial structure and the use of local building materials such as *toub* bricks (the name of local man-made clay bricks). However, they all reveal some indicators of vulnerability regarding climate change, as we will develop later. But first, we start by introducing the methodological approach of our research.

Fig. 4.7 Timimoun the urban form. (Source: Google Earth 2011)

Fig. 4.8 Timimoun, street layout

4.2 Research Methodology

This chapter presents results drawn from a comparative study of two chronological research projects, first in the M'Zab Valley (2002–2006) and second in the Gourara Region (2009–2012). The research objectives were to assess the vulnerability and resilience of these desert settlements facing the threat of climate change as well as to examine the relationship established between social cohesion, indigenous knowledge, and the engagements of these populations in the path to sustainability in their day-to-day lives. The in situ work followed three phases, summarized in Fig. 4.9.

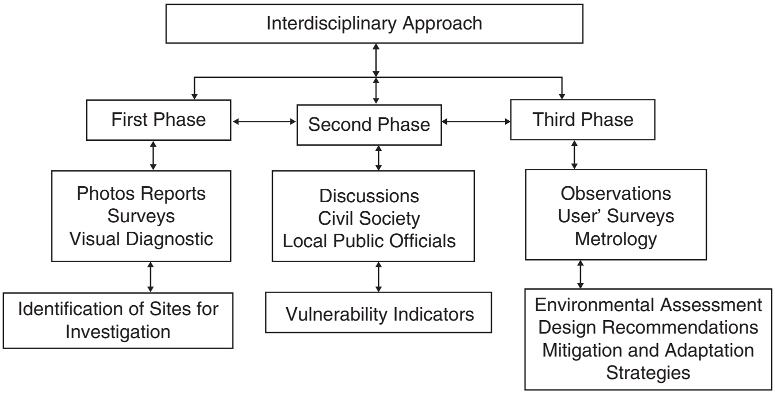

Fig. 4.9 Methodological approach of the two in situ research projects

1. The first phase, the most complicated, was to conduct 15 site visits and produce photoreports to assess the potentialities and weaknesses of the sites under investigation. The purpose was to establish fact sheets for each site in order to match specific research objectives with specific sites, combining surveys and quantitative analysis of physical parameters.
2. The second phase consisted of discussions with civil society representatives and local public officials to identify vulnerability indicators that would help to develop general adaptation strategies on a larger scale.
3. In the third phase, we conducted in-situ research upon three locations using an interdisciplinary approach of quantitative analysis (metrology) and user surveys to evaluate the physical comfort level and the inhabitants sense of well-being during extreme seasons. At the end of this work, we drew up design recommendations for future developments and presented economic and social mitigation and adaptation strategies to cope with the effects of climate change.

In the scope of this paper, we present only the results from the three phases that deal with the human assessment, not the physical one, with an emphasis on the results from the dweller surveys and behavioral observations.

The surveys took place in the different *ksour* of the M'Zab Valley, with a 100-person sample and in 10 *ksour* of the Gourara Region, with a sample of 50 individuals. In the *ksour* from the Gourara region, it was hard to find more subjects to assess, first because of the language barrier, as the local people, especially the women, spoke Berber, an indigenous language that we did not master, and second, because of our engagement at the same time in quantitative analysis of environmental parameters.

Even though the two settlements reveal some similarities in the way indigenous populations reflect adaptive paradigms, the distinctive socioeconomic structures of the two regions influence greatly the responses to climate variability, as will be discussed later. However, before we introduce the results of the second phase, we present our description of vulnerability indicators, based on the phase two surveys.

4.3 Results and Discussion

Primary Results: Vulnerability Indicators

During the two in situ data collection projects, we engaged in multiple discussions with civil society representatives and local rulers. These discussions helped us identify different vulnerability indicators that are summarized in Table 4.2. We have classified them according to two broad parameters:

1. The first category summarizes the tangible domain, where we find the different indicators related to the assessment of the physical system, such as climatic exposure, geographic isolation, socioeconomic development, and the hydraulic system.
2. The second outlines indicators relating to the intangible domain that we have identified as relating to modernity. These are important because of their relation to the principal argument of our paper as regards social cohesion as the path to socially responsible resilience. We have classified them not only in relation to social cohesion at a global scale but also to specific oral transmission of particular indigenous know-how. We have chosen this logic regarding their relation to the field of pro-environmental behaviors to maintain physical comfort levels as well as a general sense of well-being in an extreme environmental setting. Another argument concerns the use of traditional actions to preserve structural assets such as irrigation systems as well as sand silting barriers. Although we found evidence of the erosion of certain traditional strategies grounded in the intangible domain, they nevertheless remain arguments, cited by the surveyed local population.

For the purpose of our paper and in accordance with the theoretical framework, we have developed our arguments based on the close relationship that is found between climate change and socially responsible resilience, the core topic of our paper. We will not develop further all the items summarized in Table 4.2 but solely those that are in relationship with climate change and socially responsive resilience. For each variable, we identified general indictors, with which we connected outcomes, witnessed through our observations and surveys.

Based on our observations and conversations with local residents and community leaders regarding climate change, we realized that climate change impacts are understood locally in terms of the occurrence of extreme events, such as flash floods and droughts. These latter had been predicted in the IPPPC reports. Although these events do not occur very often, they still affect the consciousness of the population. For example, in 2003, the M'Zab Valley respondents cited the influence of flooding in reference to one that occurred in 1998. In 2008, another flood event occurred, leading to deaths and the collapse of housing developments located in the wadi bed. Even though these events occur rarely, once or twice every decade, they still cause substantial damage, because of unregulated developments in the wadi bed, both unauthorized housing developments as well as some public facilities.

Table 4.2 Summary of variables related to indicators and outcomes of vulnerability

Variables	Indicators	Outcomes
Vulnerability assessment: tangible domain		
Climate-related	Increased occurrence/severity of extreme events (drought, flash floods, sand storms) Higher, mean temperatures, lower mean precipitation	Vulnerability at every system: human, natural, and structural Increased desertification: expansion of non aedificandi zone (unbuildable areas) Spread of vulnerable flooding zones to historically protected *ksour*. Increase in silting of *ksour* areas and palm groves Difficulties in the maintenance of infrastructure: roads, runways (heat and silting)
Geographic isolation	Inefficiencies in coordinating and implementing centrally planned actions at the local level Government inattention to isolated areas	Lack of zoning, municipal services in newer high-growth areas Poor maintenance of roads and structures (outside of formal city boundaries) Low-income/high unemployment Inefficiency of public health infrastructure (distance to hospitals, clinics; ambulance service)
Socioeconomic development	Emergence of cash economy Migration to urban settlements (rural migration, nomad settlement, and influx of workers) Natural population increase	Anarchic urban sprawl and building in non aedificandi (uninhabitable) zones Illicit development near wadi beds Housing shortages Loss of palm groves due to urbanization Decrease of subsistence agricultural production
Hydraulic system	Deficiencies in sewage system and servicing Introduction of pumping systems for irrigation and urban water supply	Vulnerability of the traditional system of irrigation, (*foggaras*) Overexploitation of water resources (lowering of water table and diminishment of aquifers) Salinization of palm groves
Vulnerability assessment: intangible domain		
Modernity	Rapid urbanization and rural-urban migration Dilution of social cohesion Loss of the ecologic "man/nature" pact and balance Loss of mitigating traditional know-how (adaptive actions and morphological patterns) Change in social class structure Alienation/lack of trust in government actions	Disengagement in the preservation and restoration of original constructive and hydraulic techniques Abandonment and deterioration of *ksour* Loss of the socially environmental resilience and pro-environmental behavior Loss of traditional "know-how" regarding date palm production Passive resistance to central decisions for management and exploitation of agrarian developments

When we come to the intangible domain, we want to point out that issues relating to poor economic development, urban sprawl and migration also lead to the loss of social cohesion. We observed these relationships in the new developments but not in the old *ksour*. Even though the *ksour* are often run down in appearance, they still are the scenes of a cohesive social life, especially during religious festivities, such as *Ziarets*, that take place to celebrate a local holy man or a religious event.

As a logical result to the loss of social cohesion, we find the disengagement in the preservation and restoration of local patrimonial amenities as well as the loss of the traditional know-how. A key example is the loss of *foggaras*, elaborate traditional irrigation systems which draw water from deep underground aquifers.

An Illustration of Vulnerability or When the Ecological Pact Is Lost

Although we acknowledge that the phenomenon of silting is a consequence of desertification, from our conversations with local informants, especially from the *ksar* of Bedrienne, we discovered that there was awareness that silting effect was due to the loss of the "man/nature" ecological pact and balance. Furthermore, silting as an ongoing phenomenon causes several disturbing effects both on the local scale of the *ksar* and at a larger scale when it comes to damages caused to infrastructure such as roads. It is an aggravating factor at the social level with high migration from the derelict *ksour* to new unequipped areas, often endangered by silting in the long term and from poor socioeconomic conditions. Local populations recognize that a pact is drawn to establish a balance between the dune territory and the built environment (man territory). When this pact is broken due to anthropogenic developments, the result is a dramatic vision of an abandoned and buried *ksar* (Fig. 4.10).

To illustrate this phenomenon, we present in Fig. 4.11 the development of the *ksar* of Bedrienne. According to Bisson (1990), between 1952 and 1987, the number of houses in this *ksar* increased from 298 to 707. This development took place in the land interval meant to be a gathering place and a boundary/transition territory between the dune and the *ksar* (Fig. 4.12). There is traditional local know-how regarding mitigation of dune encroachment in the creation and maintenance of *afreg*, or vegetation barriers, which perform the critical role of obstacle to silting and to any sand movement in transit on the erg (Fig. 4.12). These barriers are planted in a way that allows the dune, developed from the accumulation of sand, to occupy its "territory" (Fig. 4.13). When the local people lose their traditional know-how, such as the maintenance and restoration of the *afreg*, the aggravating problem of silting and dune expansion endangers local vernacular settlements, with Bedrienne presenting a vivid example of extreme vulnerability to silting in the Gourara region.

One Assessment: Distinctive Findings

The title above is not meant to be judgmental of either the M'Zab Valley or the Gourara region as regards socially responsible resilience. Both are as reflect socially cohesive resilience. The former has retained its traditional systems intact (cultural

Fig. 4.10 Bedrienne, view of a buried part of the ksar

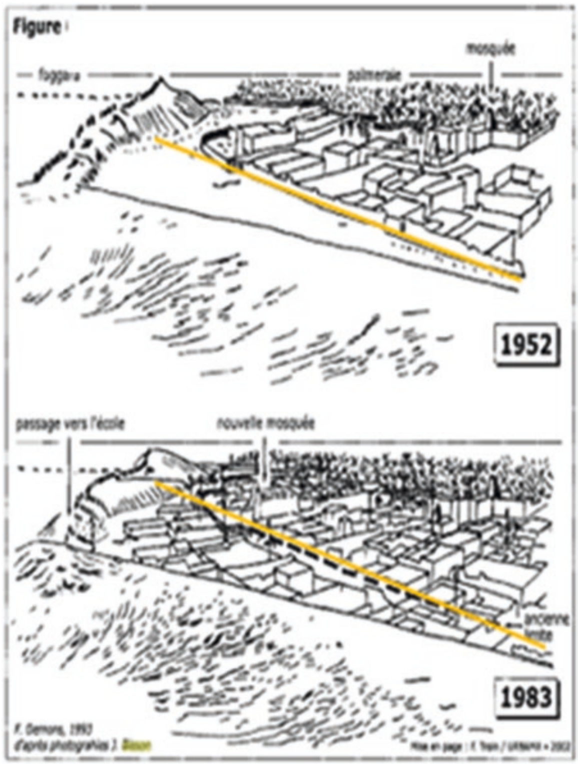

Fig. 4.11 Development of the ksar of Bedrienne, between 1952 and 1983. (Source: Bisson 1990)

Fig. 4.12 Bedrienne, view of the old ksar

Fig. 4.13 View of the afreg

and socioeconomic) and has even enhanced them, through the transfer of historical knowledge. However, in the case of the Gourara region, it was difficult to discern elements of traditional knowledge transfer from our observations and interviews with the population itself. In Gourara it appears that the channels for transmitting traditional knowledge have been eroded as a result of the vulnerability variables and outcomes outlined in Table 4.2. Nevertheless, there are still social cohesion assets to revive and aspects that we will reveal in the conclusion of this paper. We first start with the M'Zab Valley assessment.

The M'Zab Valley: An Introduction to Socially Cohesive Resilience

We have already suggested the inhabitants of this region encompass strong cohesive systems, at every level, social, religious, cultural, and economic. The local population explained this status by referencing their dramatic historical background, characterized by alternating periods of peace and war. Furthermore, they acknowledge that they rely on their traditional sustainable adaptive practices, which we term skills, when confronted with particular environmental or defensive problems. We refer here to "skills" by referencing the definition elaborated by Ericson and Oliver (1995): "The performance of an act acquired through extended practice and training," in other words, the retention and practice of empirical indigenous intergenerational know-how.

On the environmental side, sustainable attitudes and behaviors were developed and are still implemented to ensure well-being for the individual and the group. They seek to develop pro-environmental behavior in the way Karp (1996) has defined it, as "the promotion of collectively beneficial decision-making." They are not only witnessed on the urban scale, when the original adobe settlement (*ksar*) was integrated on the hill slope with the palm trees settled logically in the valley near the wadi bed but also with the architectural layout where space distribution followed strict cultural and human demands as well as environmental adaptation. It is important to say that throughout our in situ investigations, some interviewed persons proudly declaimed these environmental aspects.

The survey results, conducted in 2004, validated the perceived impacts of some climatic events. We asked respondents to rank environmental threats according to their perceived negative impact. Table 4.3 shows how 35% of surveyed people classified floods as their number 1 environmental threat. We later realized that this was in large measure due to the impact of the 1998 flood of the wadi M'Zab (Fig. 4.14). A decade later, in 2008, the same environmental scenario occurred again and flash floods led to the deaths of 31 persons and the destruction of 500 houses (Fig. 4.15). This illustrates that although we assumed that the M'Zab Valley represents the virtue of cohesive responsible resilience, it, nevertheless, experiences the same devastating effects of climate change.

Nowadays, to avoid the risky anarchic urban development near the wadi bed, some pro-environmental actions have been launched to develop satellites urban extensions to the ancient *ksour* on nearby hills; these initiatives promote mutual aid that responds to community needs. Figures 4.16 and 4.17 show the sustainable examples of Tinemirine and Tafilalt, developed in the same scheme and values as the ancient *ksar* of Beni Izguen. The contemporary need for car access has led to the widening of the streets, but the designers have preserved the basic physical structure as well as the distribution of communal tasks, revealing a sustainable planning scheme.

To realize the benefit of these proactive adaptive actions, a group of leaders, acting in the manner of the original *djemaa*, or group of "wise persons" in charge of the organization of the original *ksar*, developed what was at the beginning a planning vision. To develop the two urban schemes, they identified favorable

Table 4.3 Ranking of climatic events according to perceptions of environmental threat

Parameters	Flood	Wind/sand	T°↑/summer comfort	T°↓/winter comfort
Rank	First	Second	Third	Fourth
Scores	35%	28%	22%	15%
				Total = 100%

Fig. 4.14 1998 flood of the M'Zab Wadi

Fig. 4.15 2008 floods and destruction of the wadi banks in lower part of Ghardaia ksar

Fig. 4.16 Street of Tinemirine

Fig. 4.17 View from Tafilalt

contextual conditions, aided by the group's own high expectations to achieve the challenging environmental and social goals they set for themselves. Here they validate what some research in pro-environmental behavior attaches to the concept of self-efficacy, defined as "the belief in the individual's own capacity to manage and control the courses of action required to handle certain-situations in the immediate future" (Bandura 1989).

The *Touiza*, as the structure of the altruistic cooperative group's actions, produces a synergy between different driving forces, social, economic, and ecological. To achieve their goals, the group demonstrates obedience to the will of the group transcending individual egoism. This confirms Adger's (2003) theory when he links social capital to sustainability, through the testing of "relations of trust…and common rules." Strict fundamental and common rules and norms were applied in accordance with the strong pre-existing social structure. These fundamental concepts are summarized in Table 4.4:

However, interestingly, we found that attachment to traditional values varies according to gender, as demonstrated by the scores in Table 4.5. Due to strict religious principles, women in this area are confined to indoor activities. Thus, we find that 85% of women identify their community with traditional values compared to only 45% of men. Men, on the other hand, when asked to characterize their community, responded by citing environmental parameters relating to climate change 55% of the time, compared to only 15% of women. We refer here to traditions, as the "respect, commitment, and acceptance of the customs and ideas that one's culture or religion impose on the individual," developed by Swartz in 1992 (Karp 1996). Even when they are educated, women remain the guardians of intergenerational know-how.

Another example of the M'Zab Valley population's demonstration of its deep attachment to tradition is embodied by the indigenous intergenerational adaptive actions they perform to achieve seasonal comfort. Regarding the architectural features, people from the M'Zab Valley demonstrated their attachment to the

Table 4.4 Fundamental rules of the new developments, Tinemirine and Tafilalt

Tinemirine (1992–2000)	Tafilalt Tajdit (2000–2006)
Self-reliance as regards the creation of the new community Explicit rejection of the general feeling of the "welfare state" (*l'état providence*) Conscious adoption of ancestral adaptive behaviors to achieve sustainability in new developments Preservation of the palm grove from mineralization and development in floods areas Promotion of *Touiza* as a guiding spiritual device, with socioeconomical dimensions Residents must each contribute 150 work hours of *Touiza* in total: 60 work hours allow him the choice of the house; at 120 hours, he may settle in the new house; the remaining 30 work hours are meant to help develop the settlement	Conscious adoption of ancestral adaptive behaviors to achieve sustainability in new developments Preservation of the palm grove from mineralization and development in floods areas Promotion of *Touiza* as a guided spiritual device, civic, and economic dimensions Apply fundamental design of the old *ksar*, cohesive morphology with the integration of elements of modernity Communal upkeep of the residential areas, (maintenance, cleaning, planting) – each family is responsible to perform 1 week of collective work Integrate each dweller in the making of the space

Table 4.5 Traditional values versus climate impact by gender

Survey question: how do you characterize the M'Zab Valley?	Traditions values (%)	Climate impact (%)	Total (%)
Women	85	15	100
Men	45	55	100

traditional patio house with its special features such as the courtyard of proved thermal comfort and social response to the need for an introverted gathering space for women.

By integrating pro-environmental behavior, the new developments' designers have updated this architectural pattern to meet the needs of the new dwellers. Figure 4.18 shows the evolved house pattern from the original layout drawn by Didillon et al. 1977 to the actual layouts found in Tafilalt and Tinemirine. The indigenous way of life is preserved; furthermore, dwellers recommend the space as the fulfillment of a consciously sustainable objective.

From the survey, we learned of additional proactive actions promoted to provide winter and summer comforts. Furthermore, the surveyed persons cited spontaneously these actions, praising their environmental achievements. Proactive actions are identified in Table 4.6. Concerning winter comfort, they take either the form of a translucent lid put on the courtyard grid with 27% of respondents citing this practice or a heavy woven hanging on the entrance door with 26% (Fig. 4.19) or, lastly, woven coverings on the bottom part of the wall with 22% (Fig. 4.20). Interviewed persons also cited spatial transhumance, with night sleep in the cellar of the *ksar* house, reported by 25% of respondents.

Concerning summer comfort, surveyed persons also cited proactive actions, which we also witnessed and experienced their impact upon our comfort during our stay for the duration for our in situ campaigns. These actions take the forms of

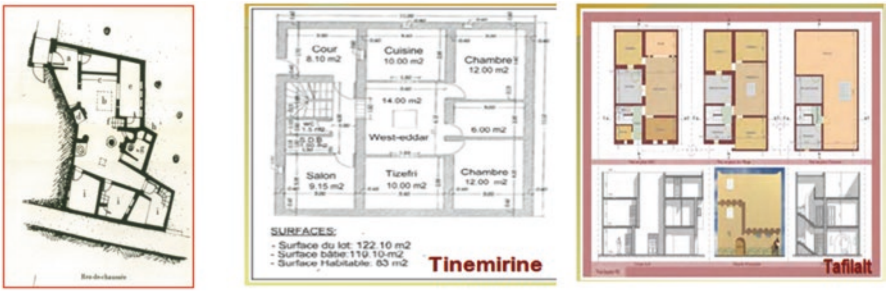

Fig. 4.18 Layout of three different houses, old ksar and new developments. Traditional House, tenth century. (Source: Didillon et al. 1977). The Tinemirine House, year 2000. (Source: Association Touiza). The Tafilalt House, year 2006. (Source: web)

Table 4.6 Scores of sustainable adaptive actions, winter comfort

Actions	Objectives	Scores (%)
Translucent lid on the courtyard grid	Maintain warmth and allow natural light inside	27
Screen at the door entrance	Stop cold cross ventilation	26
Woven hangings on the bottom parts of the wall	Provide thermal insulation, depending on the capacity of the material	22
Night sleep in the cellar, *ksar* house	Promote thermal inertia of the buried space	25
		Total = 100

Fig. 4.19 Woven hanging at the entrance door

Fig. 4.20 Woven hangings at the lower parts of the wall in the cellar

Table 4.7 Scores of sustainable adaptive actions, summer comfort

Actions	Objectives	Scores (%)
Heavy lid on the *chebek* (grid)	Keep cool by reducing sunlight inside	35
Day sleep in the cellar	Thermal inertia	25
Night sleep on the terrace	Night cooling	22
Summer migration to palm trees	Cooling effects of vegetation	18
		Total = 100

putting a heavy woven lid on the courtyard grid with 35% acknowledging performing this adaptation, to avoid heating sunlight into the inner space. Another proactive action takes place in the spatial transhumance between spaces of the courtyard house, such as day sleep in the cellar cited by 25% and night sleep on the terrace with 22% (Table 4.7).

The results discussed above validate our argument that a socially cohesive group with a strong sense of identity is the most successful tool to achieve cohesive responsible resilience toward sustainability. Of course, the population develops some reactive adaptive actions such as relying on air conditioners, especially in newly built areas and wealthy socioeconomic situations, but nevertheless, the majority is still using these adaptive actions among others issued from intergenerational know-how. At last an indicator of the influence of the cohesive social structure is revealed by the fact that all *ksour* in the M'Zab Valley are still inhabited, facts that are not found in most *ksour* of the Touat region, as we will discover below.

The Gourara Region: Structural Assets to Revive

We will discuss results from the Touat-Gourara region through the findings of the survey and observations we conducted in the *ksar* of Timimoun, as the leading vernacular settlement in the region. Even though some morphological features of patrimonial assets remain, especially in the urban development of the *ksar* (Figs. 4.21 and 4.22), most of its urban areas have undergone the effects of environmental

Fig. 4.21 Timimoun, street pattern adapted to desert environment

Fig. 4.22 Timimoun, use of desert architecture and local adobe material

threats and loss of population. These latter have led to a state of derelict appearance. Furthermore, the palm grove is under the threat of desiccation due to the decrease of the water resources and the salinization of the land.

The local population is aware of the climatic change effects and identifies floods and droughts as episodic events that lead to extreme vulnerability. Because of its impact in the collective consciousness, 2004, a year of devastating flash floods, is often cited as a special climatic event, with 78% of respondents between 25 and 49 years old doing so in response to our query (Table 4.8).

Table 4.8 Scores of perceived episodic events

Episodic climatic risks/age	18–24 (%)	25–49 (%)	50+ (%)	Total scores (%)
Flash floods	15	50	35	100
2004 flash floods	0	78	22	100
Droughts	11	56	33	100

Table 4.9 Scores of identified vulnerability indicators

Vulnerability indicators/age	18–24 (%)	25–49 (%)	50+ (%)	Total scores (%)
Collapsed houses due to flash floods	20	60	20	100
Dried palm grove and derelict *foggaras*	9	73	18	100

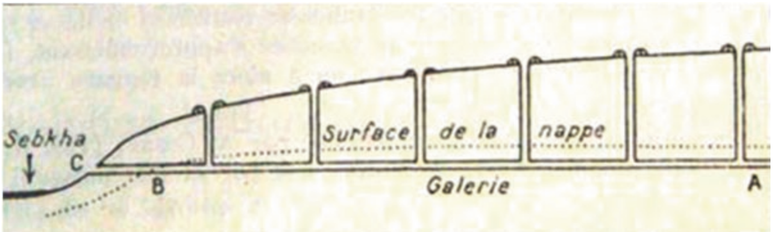

Fig. 4.23 Scheme of a foggara, drawn by A. Cornet. (Source: Bisson 1957)

Interviewed people identified vulnerability indicators, such as the ongoing process of derelict *ksour* and collapsed houses due to flash floods as well as the loss of the traditional water systems (*foggaras*), leading to dried palm groves; the scores are found in Table 4.9. These indicators of vulnerability exacerbate the weakening of the socioeconomic structures and the sustaining ecosystems that lead to heavy out-migration of local population and concomitant loss of traditional knowledge.

One indicator is the loss of the *foggaras* leading to the state of dried palm groves with the highest score of 73% for persons aged between 25 and 49 years old. The *foggaras* are the traditional irrigation systems. They are described as a slightly inclined underground tunnel, draining the water from the aquifer upstream, toward the palm grove. This method utilizes a sloping tunnel system of a length of up to 20 km; equipped with a series of spaced ventilation shafts of 5–22 m. In Fig. 4.23, we can see a scheme of a *foggara*.

The *foggara* is a technique related to the traditional social system and is an expression of collective work. A committee of "wise persons," called *djemaa*, conducted the construction work of the *foggara*; their role was to direct and oversee the maintenance of the irrigating system and the fair distribution of the water (Remini et al. 2010). By 1996, only 650 *foggaras* were still in function, compared to the 900 recorded in the early twentieth century (Kessah 1998). The collapse of the galleries, their gradual silting, and the intensive use of water pumps are the physical factors that accompany the slow degradation of the infrastructure. On the other hand, it is very difficult to maintain a *foggara*; it is physically demanding,

Fig. 4.24 View of a foggara. (Source: Bisson 1999)

Fig. 4.25 View of the derelict state of a foggara in Timimoun

and there is a lack of skilled labor to do so, reflecting and reinforcing the loss of traditional know-how. When we learn that "it took four men one year to tunnel one kilometer and there are four thousand kilometers of *foggara* in the Sahara" (Etherton 1978), we can easily understand the current difficulties to maintain this traditional irrigation and urban water supply system. This situation is even more complicated because historically *foggaras* were built and maintained by *Haratines* (former African slaves). In Figs. 4.24 and 4.25, we present two contrasting states of the *foggara* system, one in good condition (1999) and the second in an advanced state of disrepair, year 2011.

Concerning the theme of perception of climate change effects, the interviewed population has agreed that climate change affects their day-to-day activities and comfort. Table 4.10 shows the total scores regarding the perception of climate

Table 4.10 Scores of the perception of climate change effects

Climate change awareness/age	18–24 (%)	25–49 (%)	50+ (%)
Perception of climate change	13	43	25
No perception of climate change	0	19	0
			Total = 100

Fig. 4.26 Cement blocks as trusted building material

change effects, with 81% of respondents of all age groups recognizing the impact of climate change on their lives. Again, most of our respondents were men between the ages of 25 and 50. They were the most engaged with our in situ work, as they are among persons that it was easy to approach in public spaces. This group works outside the home, either in public institutions, in the building sector, or as peasants.

However, even if they are conscious about climate change effects, the population of the Gourara helplessly adopts mostly reactive adaptive actions, resulting in at best "vulnerable" sustainability. Although they acknowledge that the *ksar* morphology is sensibly adapted to the desert environment, they admit that in the face of unpredictable heavy rains, they engage in reactive actions such as deserting the *ksar* and the collapsed houses and settling in new developments outside the *ksar* vicinity, rather than repairing them and remaining there. While they tend to abandon their damaged houses in the short term, many also return eventually to their traditional homes in the *ksar*, but they prefer to use nonresponsive cement blocks to restore the houses (Fig. 4.26) or erect new "solid" shelters near the old traditional house (Fig. 4.27) just in case another climatic event occurs.

Scores from Table 4.11 demonstrate this argument, especially that young people between 18 and 24 express the highest score of 53% acknowledging the use of cement blocks to build/rebuild traditional adobe houses. They lean easily to the use of cement blocks, believing that adobe houses are more vulnerable to environmental threat than the cement block ones. However, what they don't realize is that the cement block houses are not well adapted to the desert climate. They end up living in poorly insulated homes that are maladapted to summer and winter comfort. Another interesting score concerns the restoration of older houses, with 90% of

Fig. 4.27 Development using cement blocks

Table 4.11 Scores of reactive and proactive adaptive actions to climate change

Age	18–24 (%)	25–49 (%)	50+ (%)	Total (%)
Proactive actions				
House restoration/return to *ksar*	10	50	40	100
Reactive actions				
Desertion of *ksar*/damaged house	33	50	17	100
Re/construction using cement blocks	53	30	17	100

people aged 25 and overreporting that they have at some point restored their homes in the *ksar* in response to climatic events such as flash floods. This is an indicator that nevertheless, proactive adaptive actions are still being performed, revealing remains of pro-environmental behavior and a deep knowledge of the adobe house adaptive capacities. Interviewed people affirmed that although new developments provide new amenities, they all revealed that they keep the *ksar* house to return to after the environmental event, to reconnect with the social life and social cohesion that only the *ksar* can provide.

It is true that in the popular consciousness, the reactive actions (short-term abandonment of the *ksar* house and medium-term rebuilding using cement blocks) are not only viewed as marks of modernity but also as survival adaptations in the face of extreme climatic events. One cannot blame them for such attitudes, bearing in mind that they have low incomes and they do not have a great faith in local government to protect them from climatic threats. When government does intervene, its aid takes the form of a small financial compensation and new development locations. It is also government that encourages local homeowners to rebuild using cement blocks, arguing that the skills to build in adobe are effectively lost. Perhaps also we might speculate that the owners of cement block factories have unduly influenced local government officials in this area.

Table 4.12 Scores of the perception of the value of cultural heritage

Perception of the value of cultural heritage/age	18–24 (%)	25–49 (%)	50+ (%)
Some perception of the value of cultural heritage	8	42	17
No perception of the value of cultural heritage	8	17	8
			Total = 100

Whereas the old *ksour* were located in settings protected from silting and sandstorms, the new developments often are situated on a plateau that accentuates the silting effect. Nevertheless, the Gourara population is aware of the economic value of their region, as it is a great destination for cultural and environmental tourism. They agree that their settlements encompass patrimonial features that are worth preserving and reviving. Table 4.12 summarizes scores of local population's perceptions regarding the value of the region' sculptural heritage. Forty-two percent of the 25–49 years old cohort affirms this view. They are also aware of the danger of losing their local legacy, from the ecological and socioeconomic points of view. They only need to recover their lost traditional know-how and social cohesion and find the right organizational structures to support local economic growth aided by sensible local governance in sync with traditional community values.

An important example of a publicly supported governmental initiative to restore and promote the cultural heritage of the region is Capterre, a training institute based in Timimoun dedicated to the revival of vernacular assets such as the restoration of adobe architecture and the involvement of the local population through civic associations in the restoration of old *ksour* and *foggaras* (Fig. 4.28). Another vibrant example of the value that the community places on its strong cultural heritage is in ancient handwritten manuscripts which are preserved today in private libraries (Fig. 4.29). These documents have the potential to serve as an intergenerational tool for economic development and cultural survival, through the promotion of tourism and by scientific study for their historic and religious value. One other intangible aspect of cultural heritage as a tool of community revitalization is in the recognition and subsequent restoration of *Ahallil*, a religious tradition of musical performances typical of the Gourara region. *Ahallil* was designated as a UNESCO-recognized universal heritage in 2008 (Fig. 4.30). Not only does the revival of such musical traditions promotes economic growth through cultural tourism, but it primarily serves to re-energize social cohesion and pride in local cultural patrimony. Finally, we witnessed that the original vernacular settlements are still the scenes of a cohesive social life especially during local cultural events, such as the *Ziarets*, or religious festivities that take place to celebrate a local holy man or a religious event.

These actions restore self-respect and promote social cohesion. In addition, we believe that it is through such actions that deal with aspects of the intangible domain that indigenous people from vernacular settlements can recover the pro-environmental behaviors that will provide the needed framework to achieve socially responsible resilience.

Fig. 4.28 Capterre as a center of adobe architecture renewal. (Source: web)

Fig. 4.29 Example of a manuscript. (Source: web)

Mitigation and Adaption Strategies

Because of the threats of climate change, the local populations of the M'Zab Valley and Gourara appeared to us at times to be reduced to helplessness in the face of extreme ecological events. It felt as though they had lost faith in their traditional capacities to react and cope with threatening ecological situations such as floods and silting, especially in the more heterogeneous communities of the Gourara region. However, to cite Berrang-Ford, we all know that in the case of climate change, "adaptation is unavoidable" (Berrang-Ford et al. 2011, p. 25). Therefore, one of the objectives of the second phase of our research work was to compile a list

Fig. 4.30 Musical performance of Ahallil. (Source: web)

of strategies for adaptation and mitigation grounded in the community's own wealth of knowledge. These recommendations were then presented the local leaders as well civil society for discussion and adoption. We did not want to come as "experts" but rather, we wanted to highlight the structural resources embodied within the group as a whole. Our goal was for them to reestablish faith in their inherent capacities and gain self-confidence in order press ahead to socially responsible resilience.

We have classified the different strategies into two categories of intangible and tangible domains, as reflected in the identification of vulnerability indicators and outcomes above. Moreover, we recognized that the strategies that fall within the intangible domain have the advantage of actually being actionable strategies for local populations. Unlike the tangible strategies, which rely on government and other large institutions to implement, the intangible strategies derive from inner-directed, local, communal, and traditional know-how. If people can recapture their traditional ways of knowing and doing, they can adapt in pro-social, pro-environmental ways that result in sustainable communities rather than the vulnerable and unsustainable ones we see today. We summarize these arguments in Table 4.13.

4.4 Conclusion

Authors have identified humans as the most adaptable mammals that have survived in regions of either abundant or restricted resources (Oliver 2006). Furthermore, it is by the means of "their culture and traditions that they are well adapted" (IPPC 2007, p. 935), developing settlements that achieve congruent balance between built morphologies, environmental characteristics, and human needs for comfort and well-being. These arguments go along with the findings which we gathered through our in situ work. We can affirm that the people living in the Saharan vernacular

Table 4.13 Mitigation and adaptation strategies

Systems	Intangible domain	Tangible domain
Ecological	Support traditional democratic institutions which promote a spirit of solidarity to enhance social cohesion toward sustainability (*djemaa*, *azeba*) Encourage a culture of self-confidence and pride in traditional culture – leads to social cohesion and faith in traditional know-how Reestablish ancestral resilient practices and pro-environmental behaviors, issued from intergenerational knowledge (*foggaras*, adobe construction, *afreg*) Reinitiate cooperative group action (*Touiza)* Build bridges between academia, government, and civil society to promote adaptation of traditional knowledge to modern challenges (Capterre, Tinemirine and Tafilalt) Regain the sense of the ecological dimension	Institute zoning regulations that limit growth to environmentally safe areas (away from sensitive transition zones and palm groves) Regulate expansion of power-driven pumps and deep well water extraction Rebuild traditional *foggaras* to maintain healthy irrigation and water transportation networks Limit use of cement blocks and other maladapted construction materials
Geographic	Mitigate the sense of isolation Work toward the awareness of local eco-socioeconomic opportunities to be developed Enhance the ecological specificity of the desert landscape	Reduce distances by maintaining the different means of communication, land, and aerial Reorganize local economic systems, (private and public)
Economic development	Divorce from the assistantship of the "the welfare state" Develop restoration projects of local vernacular forms to sustain social cohesion and indigenous architectural and urban patterns Support the social and economic values of manual works	Sensitize to the merits of socioeconomic decisions at central and local scales Adopt integrative actions to achieve territorial opening up and equity from different urban developments Integrate civil society in the decision-making Inject public funds to restore existing systems (agricultural and hydraulic) to mitigate the impact of floods and silting
Education and training	Promote the influence of original circles of religious and social powers (*Zawya*, *Azzaba*, *Djamaa*) Sensitize to the value of intangible heritage, (manuscripts, oral transmissions, cultural ceremonies, music, and dances) Discuss objectively about preserving authenticity and leading modernity dynamics	Strengthen existing educational structures, (private and public) Encourage the development of professional training centers under the leadership of local experts, skilled workers, and professionals (building, restoration, learning of adobe and stucco works)

settlements illustrate this vision, of a group that settled in a region of limited resources, and through contrivance and empirical experimentation, they were able to adapt and build community resilience to climate threats. Furthermore, they were able in most cases to involve their community-based structures to achieve endogenous environmental risk reduction strategies.

The results presented above have proved the theory we wanted to test that climate change is a global phenomenon that threatens locally vulnerable populations, especially those located in third world countries. Moreover, we have also found that social cohesion permits such groups to achieve high resilience, which places them on the path to sustainability. A cohesive group with strong capabilities can perform sustainable adaptive actions, proactive or reactive, aided by the framework of its traditional practices.

Through our research, we have been able to analyze, assess, and understand the different local situations in both the M'Zab Valley and the Gourara region and compare their variable responses to climate threats. By assessing the indicators of vulnerability, acutely stressed in both intangible and tangible domains, we can achieve the recognition of the intrinsic values of vernacular architecture and the human richness that made these urban and architectural morphologies survive over centuries of extreme weather and climatic threats. Furthermore, these indicators point to the identification of the tools for the revalorization of vernacular architecture and urban forms. Given the opportunity, emerging from the revitalization of indigenous institutions and through responsible local governance, such communities can act autonomously to develop integrative actions and tools that will mitigate against environmentally induced vulnerability.

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Chapter 5
Vegetation and Environmental Comfort

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Deviation from nature is deviation from happiness.

Samuel Johnson

It is the aim of this section to contribute with information on the potential of vegetation to provide outdoor microclimates thermally more comfortable than in unvegetated places. It introduces the subject of vegetation and its relation to mankind. In a first stage, it shows the integration of man and nature in different moments in time. By looking at past examples, it is the intent to show how man once needed, eventually worked with, and then appreciated being linked to environment. These lessons which have been forgotten are still valuable today. Our fantasies, our hopes, our inspiration and appreciation of art, and our image of paradise are all linked to nature. Landscape and climate are two broad terms with indefinite connotations used by artists, poets, ecologists, and architects, among others. All have acclaimed nature in their own interpretations. Nevertheless, architecture is the form of art with most impact on people and their perceptions. "Architecture reflects, materializes and eternalizes ideas and images of ideal life. Buildings and towns enable us to structure, understand and remember the shapeless flow of reality and, ultimately, to recognise and remember who we are" (Pallasmaa 1996). Our living environment "strengthens the existential experience, one's sense of being in the world, essentially giving rise to a strengthened experience of self" (Pallasmaa 1996). The closer we bring nature to our dwellings, the better use we can make of it, gaining in physiological and psychological aspects.

Trees and landscape are not only scenery but linked with physical, biological, and cultural features. They include the entire community of all living and lifeless things and depend on the relationships and forces of both the biotic and abiotic world. Man being an inseparable part of this system is in a position to modify it, to exclude, introduce, or change natural and unnatural elements in his surroundings. The quality of interference will define the extension and quality of sustainability.

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A theoretical account and an overview of the effects of vegetation on microclimates of the built environment are presented in this section. Trees and plants were initially valued for their productivity. They were food for us, their fibres clothed us, and they provided shelter. Eventually we learned to benefit from its medicinal powers and adore its beauty. The objective of this section is to show the potential of a new façade of vegetation, one of urban landscaping, even with a tree alone, which offers a strategy for natural cooling, with reference to the hot African regions, and, at the same time, enriches the environment. It can bring year-round physical comfort into our habitats and aesthetic pleasures into our lives. A theoretical account and an overview of the effects of vegetation on microclimates of the built environment are here presented.

In the same way that there is no better light than natural sunlight and there is no better breeze than the wind breeze, there is also no better shade than that of a tree. The benefits which are to be profited from microclimates with trees are described further along in this section. A part is devoted to the microclimatic effects of vegetation and another to its effects on helping sustainable development. Emphasis is given to the use of trees and their effect in diminishing temperatures and rising relative humidity levels through the blocking of sun and leaf transpiration, better known as evapotranspiration.

5.1 Landscape and Man

Since the existence of man, its environment has always dictated its life. What he ate, what he wore, how he lived, and where he sheltered were all linked and associated to the climatic conditions of its surroundings. "The problem of controlling his environment and creating conditions favourable to his aims and activities is as old as man himself" (Olgyay 1960). Throughout history, from Aristotle to contemporary scholars, intellectuals have expressed that climate possess effects, both physiologically and psychologically on the human being, and that adequate climatic conditions are a necessity for the evolution and development of society. It has been studied that a person's productivity may well be affected negatively in situations of uncomfortable heat as well as cold (Kaplan et al. 1993; Rivero 1986; Rowe 1994).

In modern times, man distanced himself from his natural roots and instincts, to be found impressed in a materialistic, power-seeking world. It has become the will of the "modern" man to be independent and dominant. In the quest for being autonomous, all common sense seems to be secondary, and man not only seeks to dominate one another but also nature. Through this obsession, living is now possible anywhere on earth, from the Arctic and Antarctica to the middle of the Sahara. Through technological innovations, man has separated outdoor climate from indoor climate. It is possible to watch TV only in shorts in a base camp in Antarctica, although the external temperature is −50 °C. With the aid of artificial air conditioning, it is said that a comfortable living space is possible. This concept would be very much interesting if taken into consideration only when needed, in rare cases. Unfortunately it has become a rule, a natural way of thinking and building.

Many building typologies are operated by artificial cooling or heating systems. Independent of city, country, or continent, they will be constructed the same way. This obsession for artificial air conditioning is turning comfortable places to uncomfortable spaces. These range from shops to restaurants and from banks to offices. Most of the new residential blocks are also air-conditioned. Therefore many times a common external and comfortable temperature of 28 °C is transformed into an unpleasant 18 °C due to air conditioning. Bigger problems such as overloading energy peaks and sick building syndrome (Rowe 1994) come into question. The use of artificial cooling mechanisms create a vicious circle where waste heat results from the use of air-conditioning units to cool buildings, drying up the city temperature which then requires a larger cooling load for the buildings (Takakura et al. 2000).

Furthermore, Ryd (1991) states that not only sealed buildings can be subjected to the sick building syndrome but also our homes. It is manifested as diffuse reactions to airborne compounds, aerosols, and other particulates. “The reactions can be itchy eyes, dry mucous membranes, abnormal fatigue, headache, or other psychosomatic reactions”. The air quality not only in the building, or home, but also that surrounding it is of great importance.

The increasing urbanisation of cities in the developing countries has brought modifications to the local urban climate. The most known manifestation of this urbanisation process is the heat island effect. Studies by Jauregui (1990) with large urban parks, has confirmed that temperature differences are likely to be more visible, among other factors, in cities where green areas are scarce. Obviously, there is a very high cost to all of this, and just now is man becoming aware of the problems he has created and those, environmental, for example, which are still to come. With the oil crisis of 1973 and the increasing energy concern, environmental issues have become increasingly objects of studies in all the world, as seen and discussed since the Kyoto pact. The awareness of the threat that the exaggerated energetic use in the present may pose to the future, has led to a new way of thinking, a mentality of responsibility and of sustainability.

The first thing to be aware is that natural resources are limited, especially in a world of fast increasing population. Man-made fuels and electricity are costly, inaccessible to poorer nations. Energy systems cannot cope with the exaggerated demands. The more we use today, the less future generations can also rely on them. This opposes any logical idea of sustainability. Sustainable development, as stated before, was defined by the World Commission on Environment and Development (1987) lead by Mrs. Gro Harlem Brundtland as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Generally, design is not taught in most places in the context of its social and ecological impact. Mackenzie (1991) in his approach to green design suggests the approach of “eco-efficiency which means the delivery of the maximum benefit to the user, with the minimum use of resources and the least possible environment damage”.

Nevertheless, everything taken from nature has a reaction somewhere else. This is the equilibrium law of nature itself. As Lavoisier said: “nothing can be created or destroyed, only transformed". If forests are destroyed, soil will erode. If soil erodes, minerals will be washed away. If minerals are washed away, an infertile land will be the result. The burning of fossil fuels and the destruction of trees and forests contribute to an increase of the greenhouse gases, especially carbon dioxide. To reduce the rate of build-up of the greenhouse effect, it is essential the preservation and expansion of the forests. What we many times call things such as tidal waves, avalanches, and acid rain as natural disasters, it is mostly nature seeking equilibrium. As the second law of thermodynamics says, the entropy of the universe always increases; there is a universal tendency to chaos and disorder. All matter has a natural process to move towards entropy and chaos, tending to revert to the simple molecular level. Newton's law of motion and equilibrium states that for every action, there is always an opposed equal reaction. Therefore nature acts on us in the same way we act on nature, and through this organised chaos, it reaches balance.

Rather than seeking to dominate, control, and confront nature, man has to search for a peaceful and integrated coexistence. The smaller the scale, the higher the probability of creating successfully a pleasant and comfortable living environment. On the other hand, the inverse is also true. The larger the scale, the higher the probability of failure. This is to say that it is easier to understand and manipulate a microclimate, as in the outdoors of a house, than to manipulate a climate as in a whole city and region.

Primitive Dwellings and Nature: Past Examples

Man has always been linked to nature, seeking shelter and comfortable spaces. Throughout the history of mankind, examples can be found to illustrate this relationship, sometimes instinctive, other times rational. Although there is much to be learned from past examples of our ancestral and their bond to nature, we frequently disregard them as cliché, passé, and démodé. Most of the times, they are ingenious and indigenous solutions. As soon as man appeared on earth, it exercised its phenomenal duty of adjusting itself to the environment and vice versa. The Palaeolithic man sought refuge in caves and canopies of trees as can be seen in cave arts. A new concept was introduced to the Neolithic man, that of changing from a hunter to an agriculturist, and with the discovery of metallurgy in the Bronze Age, man started to take control of his own environment. He no longer had to depend and move from place to place to eat and sleep. The natural scenery was changing to man-made scenarios. Forests began to be cleared, and developed centres of civilisations started to appear in ancient Greece, China, Japan, and Persia, where the idea of designing a garden in order to give aesthetic has a long history. From this point on, two opposing trends were always to exist. One tendency is the materialistic, concerned with greed and money, exploiting natural resources to exhaustion, interested in immediate profits. It leads to deforestation, erosions, water and air pollution, as well as the oppression of minority native groups. The contrasting current is worried about not unbalancing the ecosystems, working through symbiosis, mutual profit, and concerned about sustainability by being concerned with future generation's welfare.

Trees are indispensable to human life. Accordingly we must ensure to relate to it. In ancient times, people were much more exposed to the forces and manifestations of nature than what we are nowadays (Bernatzky 1978a). Fortunately, imaginative examples of the integration of people and the environment have been secured in archaeology, books, and even legends. This enchantment of man and nature is responsible for some of the most extraordinary architecture, paintings, literature, and poetry as the Mahabharata epic poem, which describes charming gardens with abundant trees. It has written some of the most inspiring pages in the history of humankind. Man has always been fascinated by the biblical reference of paradise, the Garden of Eden, where trees are essence of life. In the book of Genesis 2:9 of the Bible, it is written: "God planted a garden in the east, in Eden, and there he put the man whom he had formed. Out of the ground the Lord made trees of every kind to grow, both those that are pleasant to the eye and those that are good for food. In the middle of the garden he planted the tree of life, and the tree of knowledge of good and evil".

With the evolution of the hunting man to agriculturist, the garden concept was soon discovered and contemplated as Jellicoe (1995) illustrates:

> The first designed garden emerged from the contemplation of the miraculous effect of irrigation on a dead world. A rich green oasis, patterned solely according to the science of agriculture, spread like a vast carpet between the Tigris and Euphrates. All gardens were an idealisation of this scene. They were laid out geometrically within protecting walls and their primary contents were channels of irrigation and trees which to recline.

"The tree was always an object of veneration"

During the Babylon period, considered by Jellicoe (1995) as "the mother-city of the manufactured landscape as well as of gardens", one of the seven wonders of the ancient world was built, the Hanging Gardens. In Western Asia, the Ziggurat of the city of Ur was a monument, which towered above the city dedicated to the moon god Nanna. Also known as a Hill of Heaven, its grassed terraces were planted with trees, accentuating its distinctive beauty (Corbishley 1995). Muslim architecture was continuously integrating gardens with houses, interiors with exteriors. Baghdad at the time of Harun al-Raschid was renowned in descriptions for its gardens and palaces. The clear combination of nature and man-made is illustrated by the Moorish architecture in Alhambra, where the gardens are a mere extension of the house, providing coolness, comfort, and peace. Further initiatives in landscaping were incorporated in other great cities and empires of the time as the Byzantine and Persian with its gardens (Hoag 1963).

A mystical relationship between man and his environment originated in early Chinese landscape design. The Chinese, later formalised by Confucius and Taoism, believed that man came from earth as any plant, tree, hill, and mountain and consequently in spirit was one of them. The utter respect towards nature is part of the Chinese philosophy. Through Taoism, they seek "the way" towards peace and harmony not only in their lives but also in the relations between the buildings and society (Graham 1938). All cosmic forces of nature are characterised as the female yin and the male force yang. Gardens were and still are planned to achieve the desired mood and harmony between these forces (Keswick 1986). An indispensable space for a healthy, sane life.

During the Renaissance, the evolution of gardens and homes virtually began. Man within himself found the conflicting duality of good and ignoble. Dante questioned the world system in the *Divine Comedy*, and Machiavelli philosophised on morals. This discovery encouraged the arts and sciences. The mind was being valued, and man was now regarding himself as the centre of universe. The relationship with nature was more direct, having the garden made for him and being dignified by it. The interior of the house blended with the outwards. Sites were conquering the hillsides and mingling with the climate. The garden design was no longer to be a mere extension of the house; it became part of a larger composition. Versailles is probably the most magnificent example of landscape architecture ambition and an affirmation of not only an art or domestic design but a contemporary concept of thorough planning (Tacker 1979).

By the eighteenth century, man was returning to its roots throughout the world by the use of landscape design. An example of an attitude towards green open spaces and trees are the Boulevards of Paris which allowed the circulation of air, light, as well as troops and had trees planted along them to attract the eye and give a sense of scale to the pedestrian**.** Rousseau through his philosophy clearly advocated a return to nature. Laugier represented the ideal habitat by the symbol of the primitive hut (Fig. 5.1). His *Essai Sur L'Architecture* examined the elements involved in architecture and attached importance to nature as an indispensable part of the project: "this is what pleases us in nature: (1) the shade of the woods, the green of the meadows, the murmur of the brooks; (2) pretty viewpoints, pleasant landscapes; (3) the happy extravagance of nature's arrangement and that beautiful carelessness which bars from its adornment any appearance of studied affectation. The task is to combine all these favourable features in an arrangement which allows us to sense more keenly the contrasts and harmony yet does not efface the natural and the graceful" (Laugier 1977).

The transition into romanticism inspired many authors to write great works favouring a world in which the relation of man with nature was to be one of partnership rather than subordination. Thoreau (1992) in his book *Walden* openly acclaims us to reunite to the environment and advises of the necessity of it by writing: "We can never have enough of nature".

The history of man has always been and continues to be written by art, whether it is literature, painting, sculpture, crafts, or, the mother of them all, architecture. "Man is the maker and moulder of himself. In that process, architecture has been one of the chief means … of transforming and making visible to later generations his ideal self" (Mumford 1975). Art is the only means to record the habits and lives of our ancestors. During the second half of the eighteenth century, the impressionists started modern art. By transporting light and colour to their paintings, they searched for a new meaning to all things part of life. This would innovate an

Fig. 5.1 The Primitive Hut (Laugier 1977)

approach towards reality and cast new intentions on arts including environmental design and landscape architecture. Fascination and involvement with nature was also confessed by Van Gogh in a letter to his brother Theo where he wrote: "In all nature, for instance in trees, I see expression and soul so to speak" (Jellicoe 1995).

A concrete example of the evolution of a new and pioneer concept linking environment and lower classes was presented by Robert Owen, one of the most influential utopian socialists of the early nineteenth century. In his ideas for New Lanark, a self-sufficient community, he was convinced that a person's character is formed by the effects of their environment. He idealised the perfect settlement where each person had an obligation but all had the right to entertainment and above all a healthy life with great contact with nature. Owen was convinced that if he created the right environment, he could produce rational, good, and humane people. Unfortunately his ideas were not universally recognised although they are a foundation for the conception of human ecology. Later Vernadsky (1945) suggested that we think of the "noosphere (from Greek noos, mind) or the work dominated by the mind of man, as gradually replacing the biosphere, the naturally evolving world which has existed for billions of years". The assumption that mankind is now wise enough to understand the results of his actions is a dangerous philosophy.

Contemporary Society and Environment

After a period of great technological growth which started with the industrial revolution, man has overlooked the fragility of nature, its limited natural resources, its potentials, and fundamentally its dependency to maintain its own existence. Later, with the oil crisis in the 1970s, the threat to our species led to the "green revolution", theme of the Stockholm Conference on Human Environment in 1972. It has been perceived that scientific innovations have been shading indigenous and more sensible solutions. Scars of stripped land have become larger and manifesting more frequently. Cities have grown beyond regional and environmental support. The industrialised man now lives in a globalised society, where problems, made by a few of him, must now be solved by all.

As countries changed from agriculture to manufacture and the capitalist system continued to be the basis for the western world, it was left for the knowledgeable middle-class individuals to arise and express creative ways of living towards the progress of civilisation although preserving traditional values. Throughout the twentieth century, examples where architecture and science no longer conflict, having landscape to amalgamate between the universal and the particular, are seen individually and scarcely. Gunnar Asplund agreed with views of Aristotle that the city should be seen as a whole. In his philosophy he proclaims that: "Nature does nothing without purpose or uselessly". The architecture of Antonio Gaudi in Spain was blended with nature-like forms and colour. Le Corbusier envisioned in his plan for Ville Radieuse where light, air, and especially green, which he considered essential, were abundant. He stated that: "Sun, space and trees are the fundamental materials of city planning, the bearers of the 'essential joys'" (Le Corbusier 1947). Brasilia eventually reflected some of his ideas with its green belts, open spaces, and low buildings. In England, plans for a Garden City were pioneered by Ebenezer Howard as seen in Fig. 5.2 (Howard 1902).

The design of the Fallingwater house by Frank Lloyd Wright was definitely a milestone. It was a fine example of merging architecture and the environment. In his words "Nature is my manifestation of God. I go to nature everyday for inspiration in the day's work. I follow in building the principles which nature has used in its domain" (in Owsley 2012). His organic architecture inspired many other projects. The Brazilian Roberto Burle Marx was one of the greatest artist landscapers in the world. He revered nature so much that it seemed more than pleased to look beautiful in his projects. His passion spread and was a turning point in discovering the richness of the wild and native Brazilian flora and blending it to different kinds of sites and projects as can be seen in the palaces and central park of Brasilia. Rio de Janeiro, his home place and where much of his work can be appreciated, is a beautiful city where man's relation to landscape is blessed and determined by mountains, beaches, and the Atlantic forest. Many places in Africa are also rewarded with unique trees and landscapes which should definitely be part of the design process.

Growing cities, like African capitals, are entering a new century with similar problems that other big cities had 100 years ago. The population is rising at worrying speed. Consequently, road networks are expanding, suburbs spreading incessantly,

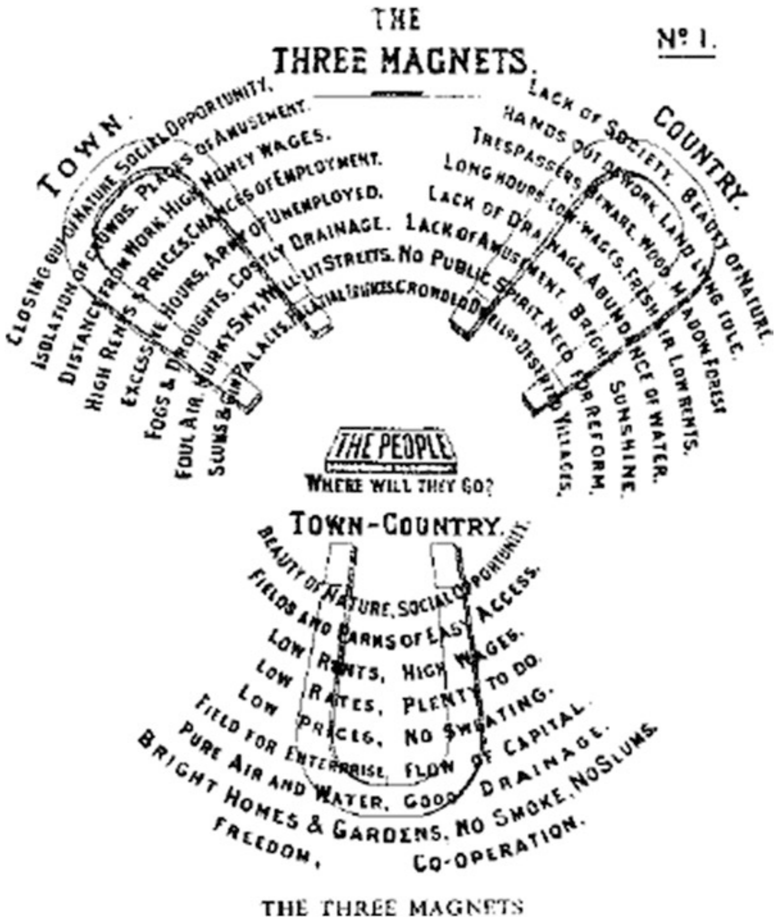

Fig. 5.2 The three magnets diagram. Representation of Howard's reformist ideas. (Cities of tomorrow, Ebenezer Howard)

numbers of vehicles and pollution increasing, and great areas being abused, harming plants and man's life. The environment and human pride is being destroyed, leaving the city in a shameful state of landscape decomposition. The rural society has been overwhelmed by the urban, obfuscating cultural values and confusing collective instincts. Huxley (1984) described the uncontrollable urban colonisation as chaotic 30 years ago. Since then it has not gone any better. "Man is at last pressing hard on his spatial environment. There is little leeway left for his colonisation of new areas of the world surface. He is pressing hard on his resources, notably non-renewable resources. In fact, we are well on our way to ruining our material habitat. But we are beginning to ruin our spiritual and mental habitat also. Not content with destroying or squandering our resources of true enjoyment – spiritual, aesthetic, intellectual, and emotional. We are spreading great masses of human habitation over the face of the land, neither cities nor suburbs nor towns nor villages, just a vast mass of urban sprawl or sub utopia. And to escape this, people are spilling out farther and farther into the wilder parts and so destroying them. And we are making our cities so big as to be monstrous, so big that they are becoming impossible to live in". The survival of the urban areas depends on the city and nature being a single design.

The private garden, although an individual expression, makes up a large part of a total area of a humanised landscape. Its relation with the house and site is variable as the typology of a tree can also vary to relate to visual pleasure, creativity, and comfort. No matter the scale of a private garden, it is an important, responsible, and intricate piece of design. The connection, which involves human perception and reaction, of the inhabitant with the landscape will determine its quality. In places with a lack of greenery and exposed to harsh climatic conditions, the private garden is a recommended solution. The tree, house, garden, and neighbour relationship is being lost in detriment to the epidemic concrete jungles. It is not the vegetation or the individual who is the essence of the landscape design but their association and the resulting benefit. This exchange will be further explored.

It has always been part of advanced civilisations to bring nature into the city and therefore be linked to it. The difference today is that other than only instinct, we now have a scientific knowledge to benefit from. Greenery in all its forms of plants and vegetation attract and appeal to us as beautiful because they provide and enhance our welfare. The thermal benefits that vegetation supply to our comfort deal primarily with aspects of temperature, humidity, and radiation.

5.2 Psychological Benefits from Vegetation in Urban Areas

Thermal adaptation to an outdoor environment can be attributed to physiological adaptation and psychological habituation or expectation. Psychological adaptation "encompasses the effects of cognitive and cultural variables and describes the extent to which habituation and expectation alter one's perception of and reaction to sensory information" (Brager and Dear 1998).

A comfortable body is no guarantee of a comfortable mind. Psychological comfort is many times overlooked, but it is nevertheless of equal importance. Goromosove (in Saini 1973) states that "any environmental factor which normally does not affect the human organism can, under appropriate conditions, act upon it through the central nervous system and its receptors". The emotional state of the individual is affected by the stimulation received through the sensory receptors and through the action of the different nervous pathways, triggering either stimulation or inhibition of the nervous activity (Canter 1977). Spaces with determined sizes, proportions, surroundings, and even specific views have emotional significance and affect our stimuli. A great psychological effect is the combination of sunlight, fresh air, and greenery. Saini (1973) states that "greenery impinges on man's nervous activity providing favourable sense impressions during periods of physical activity and rest". Colours also have a psychological effect, being able to soothe or stimulate. The colours commonly found in nature such as greens and yellows have a soothing effect on the visual system by reducing eye fatigue as well as strengthening the chromatic and achromatic vision (Hill 1995). In insipid and arid climates, this is of clear importance. Furthermore, Birren (1982) writing about colour and human response states that "green is symbolic of nature, balance, normality… invariably people are socially adjusted, civilized, conventional". The greenery of vegetation together with the blue of skies "tend to have a relaxing effect both physiologically and psychologically. The rate of body functions may be lowered and there may be greater ability to concentrate inwardly, with less distraction from the environment". They help soothe the harshness of the dryness.

Psychological benefits linked with trees and a more pleasant space listed by Dwyer et al. (1982) include improvements in the aesthetic environment as in sights, sounds, and smells; improvements in physical health from the relief of stress; greater enjoyment of daily life; "enhanced" feelings and moods; and a significant feeling of connection of the inhabitants with the environment.

Significant emotional and spiritual experiences provided by trees and forests have been reported by park and arboretum visitors as reported in studies by Schroeder (1991). A deep feeling of attachment to certain places and trees can result from these experiences and are very important in people's lives. They provide memories, emotional and symbolic meanings, and settings that contribute to a significant and satisfying sense of place in the urban environment.

City inhabitants hold very personal and strong ties to urban trees. These ties are associated with traditions and symbolism. Trees fulfil psychological, social, and cultural needs of people. In "The Significance of Urban Trees and Forests: Toward a Deeper Understanding of Values", Dwyer et al. (1991) observe through a series of interviews and studies the deep emotional bonds between trees and the city dwellers. It is thought that our image is reflected on them, as "the sheltering nature of trees suggests a parental nature" and as it was also observed that "old trees look wise, and young saplings are fresh and growing". The abundant diversity of tree species also mirrors our own cultural and ethnic diversity, with different traditions, customs, and appearances. In some beliefs, trees are religious symbols of health, wisdom, and enlightenment. "Trees stand as a symbolic link between the human and divine, and are the means by which humans come into contact with their deepest spiritual values" (Dwyer et al. 1991). They are a constant reminder of a natural world as well as our past. Public support for tree planting and preservation is strongly rooted in Chinese culture and tradition (Profous 1992). It can be traced back to the thirteenth century when Kublai Khan required trees to be planted along both sides of public roads for shade during summer and as road markers during winter. They are now religious symbols. During World War II, trees only survived in and around Buddhist and Taoist temples. Nowadays they still are concentrated in temples, gardens, monasteries, palaces, and parks, protected by cultural and religious traditions, which the government now realises can promote positive conservation values.

Studies by Talbot and Kaplan (1984) assessed the preferences of residents of low- and moderate-income areas in Detroit. Interviews were conducted, and results indicated that these inhabitants placed a very high value on their opportunities to enjoy the outdoors. A large majority saw nature as enjoyable and important to one's lives. Responses suggested the need for more contact with the natural environment and a satisfying and fulfilling response towards nature.

Among the most meaningful features contributing to the quality of residential streets and houses are trees. They introduce perceptions of satisfaction and personal safety. In popular urban settlements, a monotonous environment is inevitable, causing considerable mental stress and boredom. Experiments by Heron (in Saini 1973) on the effects of sensory deprivation on the human behaviour showed that people subjected to complete monotony presented clear signs of impairment in thinking. The subjects in completely monotonous environment and tedious isolation were also found to be more irritable and developed childish manners. It is suggested furthermore that bare, insipid, dull, and unattractive places could have a link with juvenile delinquency. The building environment with the simple use of trees and plants can provide the perceptual stimulation needed, visual, tactile, and aural, ensuring diversification and avoiding monotony. This achievement would probably lead to a community spirit with pride, a sense of enjoyment, and integration.

Physiological adaptation includes "all of the changes in the physiological responses which result from exposure to thermal environmental factors and which lead to a gradual diminution in the strain induced by such exposure" (Brager and Dear 1998). Genetic adaptation and acclimatisation are two subcategories which lead to physiological adaptation.

Extreme heat and dryness are the main causes of physiological uncomfortable conditions in arid climates. Bernatzky (1978b) states that "overheating causes disturbances of health: congestion of blood to the head, headache, nausea, and fatigue". Landscape design is directly related and affects thermal comfort of people. Connection of the man-made world and the natural world creates diverse microclimates, not always salubrious. Some landscape elements such as trees and water affect the microclimate. There is no doubt that within a single site, city, or landscape, there are many different microclimates all around. When walking down a street with no protection of the intense heat and suddenly passing under the shade of a nice green canopy, the feeling is different. The best and easiest way to perceive these differences is with our body themselves. We perceive different sensations even before we think about them. Our body's feelings tell us when we are put under stress or strain. Pallasmaa (1996) writes: "I experience myself in the city, and the city exists through my embodied experience. The city and my body supplement and define each other. Psychoanalytic theory has introduced the notion of body-image or body-schema as the centre of integration. Our bodies and movements are in constant interaction with the environment; the world and they self inform and redefine each other constantly. The perception of the body and the image of the world turn into one single continuous existential experience – there is no body separate from its domicile in space, and there is no space unrelated to the unconscious image of the perceiving self".

As not all elements, which influence microclimates, can be anticipated or predicted, it is wise to think about the worse situation and try to overcome those problems through microclimatic design. In overheated places like most places in Africa, both summer and winter present hot diurnal temperatures. But the winter presents more problems for it is also drastically dry. In such cases, design should mainly concentrate on solar radiation control and maximise the gain of evaporation. Evaporation can be a cooling element with significant potential, due to the fact that for water to change into a vapour phase, it needs a lot of energy. Evaporation is more likely to occur in conditions of high temperature and low humidity, because the hotter it is, the more water vapour will be held in the air.

5.3 Microclimatic Effects of Vegetation

Microclimate is the essentially uniform climate of a small outdoor space. Its condition includes solar and terrestrial radiation, wind velocity, humidity, air temperature, and precipitation. The subcanopy microclimate is the thermal space under the crown foliage which is determined by the tree's characteristics related to its surrounding environmental conditions (Figs. 5.3 and 5.4).

Objects in the landscape interact with the prevailing climate creating microclimates. Microclimatic design, by determining the location of objects in the landscape, as a tree in the site, can influence the thermal comfort of people, as well as reduce the heating or cooling energy load required for a building in that site (Fig. 5.5).

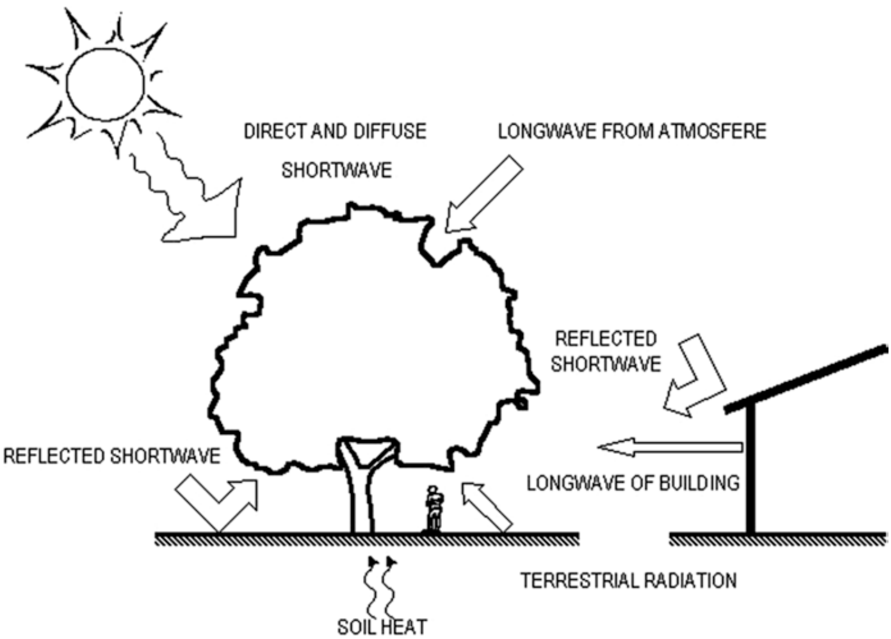

Fig. 5.3 Incoming radiation

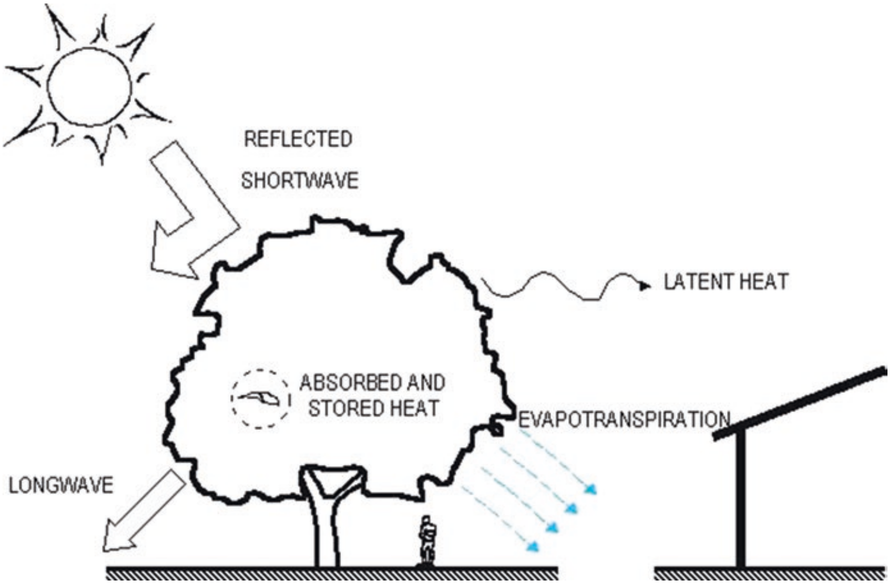

Fig. 5.4 Outcoming radiation

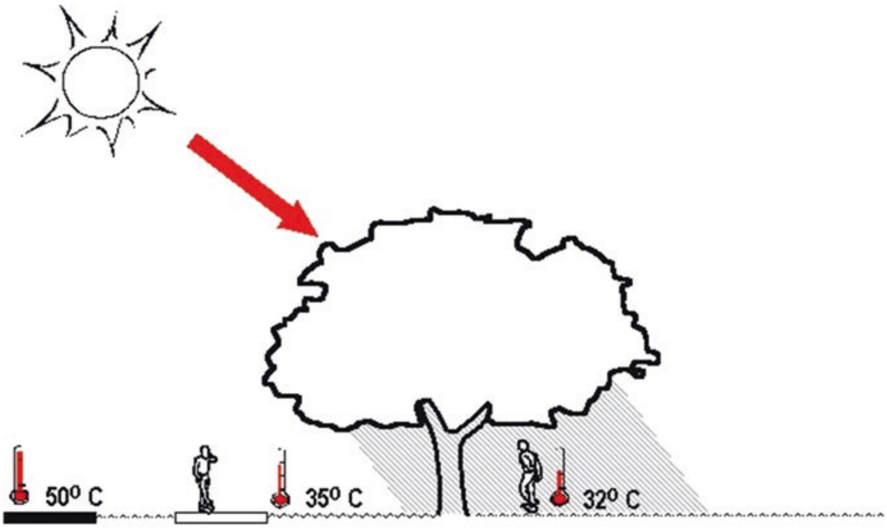

Fig. 5.5 Microclimatic differences. (After Robinette 1983)

To answer the question of what constitutes comfort, MacFarlane (1958) defines it "as certain thermal conditions in which over 50% of the people are unaware of their climatic environment, that is, they do not feel the need to adjust to it" (Fig. 5.6). Human thermal comfort is generally considered when the mean skin temperature is maintained by various means below 33.9 °C and above 31.1 °C.

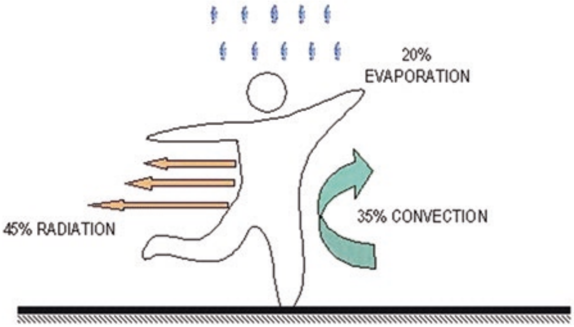

Fig. 5.6 Thermal equilibrium of the body (Cantuaria 2001)

In general, the careful sitting of vegetation on and around buildings has long been recognised as a means of cooling. Vegetation influences heat gain on external surfaces, consequently indoors too, through processes which include shading, shielding from air, infiltration, and the creation of cooler microclimates around the building through evapotranspiration, therefore reducing wind speed, regulating humidity, and reducing temperature. As complimentary aspects, it also absorbs dust particles, uses carbon, and produces oxygen.

Geiger in *The Climate Near the Ground* (1950) expresses the conspicuous effects of the relationship between vegetation and the environment by stating that: "Vegetation occupies the space between the earth's surface and the atmosphere. A continuous plant cover not only takes up space but by virtue of its properties forms a transition zone, because the individual organs of the plants, such as leaves, needles, twigs, and branches, behave like solid ground, absorbing and emitting radiation, evaporating, and playing their part in the exchange of heat with the surrounding air. However, the air is still able to circulate within the plant cover more or less freely. Thus vegetation forms a new component part of the air layer near the ground".

Vegetation is an ideal element for solar radiation obstruction for it has low, almost insignificant transmittance; does not reflect much radiation to adjacent spaces; allows the hot air to evacuate; and does not overheat above air temperature due to its self-regulating capacity. In general, it is considered that of the incoming radiation on a leaf, around 50% is absorbed, 30% is reflected, and 20% is transmitted (Robinette 1983) (Fig. 5.7). As most canopies are multilayered, the radiation being transmitted from one layer is then simmered and transmitted to the next layer in succession, consequently resulting in an insignificant transmittance by the time it reaches the bottom part of the canopy (Fig. 5.8). Much of the reflected radiation is also reflected to other leaves, therefore reducing the amount which is reflected to adjacent spaces. Most of the absorbed radiation by trees and plants is lost by evaporation of the moisture which is being transpired by the leaves or absorbed by the ground and released slowly.

Green shading upon a building envelope reduces direct solar gain and diffuses light reflected from the sky and surrounding surfaces. Exchange of long-wave radiation cooling is reduced by trees for they block the amount of night sky visible from the walls and roof. As a result, the surfaces take longer to cool from the accumulated

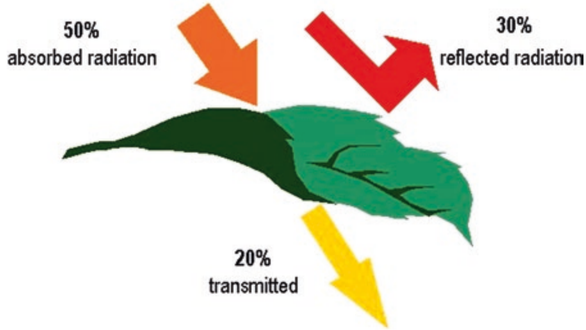

Fig. 5.7 Leaf properties

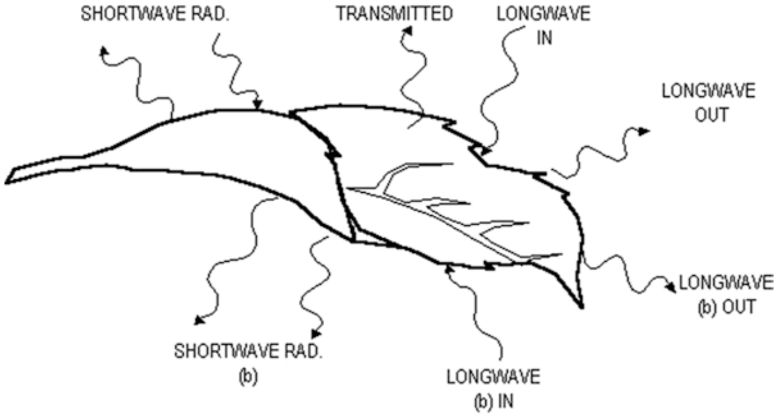

Fig. 5.8 Leaf thermal exchange; b is for bottom of leaf. (After Oke 1990)

diurnal heat, which is desirable in arid climates, such as in many African countries, because the nights may become too cool. Studies by Cantuaria (2001) have confirmed that trees, even a single one, mainly through processes of shading and evapotranspiration, may modify a microclimate's temperature and relative humidity and transform it into a more comfortable space.

The microclimate is created when the regional climate interacts with a specific landscape or site. The amount of solar energy, the main source of energy, which is to be consumed as evaporation, as convection by the air or by heating any object located within this site, will define the microclimate. As known by the laws of physics, no energy can be destroyed, even if not desired and excessive. Nevertheless it can be manipulated to be blocked, transformed, transmitted as radiant energy, and distributed to certain objects of the site. Energy and radiation are subject of most changes. Differences in these could lead to changes in temperature and humidity values because they are linked together.

Vegetation is significant in establishing microclimates. Fitch (1971) analysing the studies by Rudolph Geiger indicates that in the Northern Hemisphere, a forest of oaks and alamos reduces in 69% the incident solar radiation, making the forests cooler in the summer and warmer in the winter. It is also stated that a row of trees can reduce the wind velocity by 63%. Izzard and Guyot (1980) comment on the effect produced by the foliage of a tree on the surface right below it, under the canopy. They state that this foliage "creates a type of 'sky' and its radiant temperature is higher than that of the sky dome, which allows a decrease in the emissivity of longwave radiation from the ground surface". The vegetation together with the topography and the soil surface are local climatic factors, factors which determine the microclimate.

Photosynthesis

When discussing vegetation it is necessary to talk about photosynthesis. The word means to synthesise food from light and is the only natural process by which solar energy is used to manufacture food (chemical energy which is stored in the carbohydrates). The amount of food produced seldom is fully appreciated. "The total energy converted and stored by plants in photosynthesis is about 100 times greater than that in all the coal mines in the entire world during a year" (Kramer and Kozlowsky 1960). It is estimated that 25–45% of the total product of photosynthesis is converted into usable wood. On the other hand, the quantity of energy that plants use in the process of photosynthesis is very small, not more than 5%, and therefore may be dismissed from its energy budget. Energy in light drives the conversion of atmospheric carbon dioxide into organic materials.

The general representation of photosynthesis is:

$$6CO_2 + 12H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Internal and external factors were identified by Devlin and Barker (1971) as affecting the rate of photosynthesis. External factors include light quality, intensity, and duration; water; temperature; CO_2 concentration; oxygen; and mineral nutrients. The internal factors include morphology, stomatal behaviour, age, anatomy, and carboxylation mechanism.

Overall, the process of photosynthesis is considered to be temperature dependent. Most diurnal changes in photosynthesis appear to be fairly well correlated with light intensity, except for the midday dip (Fig. 5.9). The slowing down of photosynthesis around noon is often attributed to stomata closure caused by high transpiration (Kramer and Kozlowsky 1960). Temperatures around 30–35 °C allow maximum rate of photosynthesis. At 50–60 °C, no photosynthesis occurs. Beyond 60 °C and 0 °C, the destruction of plants occurs.

Vegetation with the highest rates of photosynthesis also has the highest rates of transpiration. Pearson (1994) concludes that the efficiency of plants to modify the environment depended on the amount of light they receive. In his studies, increasing light intensity led to greater reductions in temperatures and increases in relative humidity. The effect of evapotranspiration in most places in Africa would be

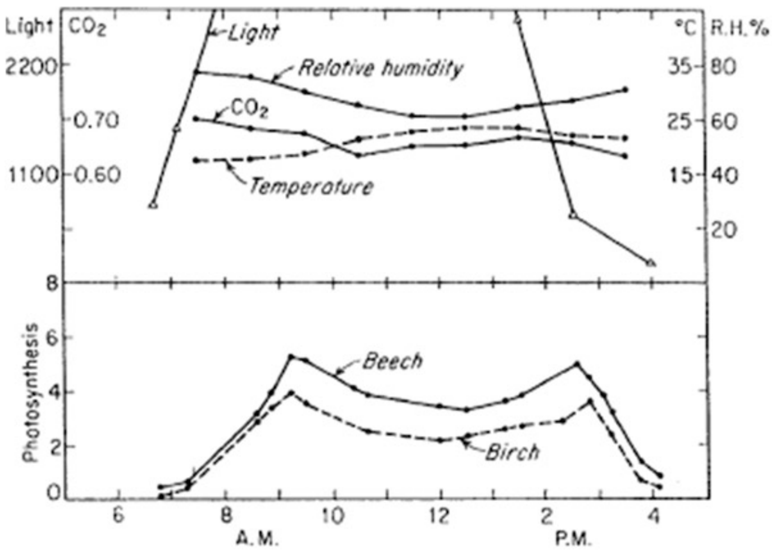

Fig. 5.9 Midday reduction in photosynthesis of beech and birch (Kramer and Kozlowsky 1960)

maximised and very beneficial. Research by Kramer and Kozlowsky (1960) state that expanding foliage and maturing of flower parts increase transpiration, and indicate that efficacy also depends on the number and size of species used. Furthermore, the authors affirm that temperatures decrease and humidity increases too around leaves with a healthy, dark-green colour.

Respiration in plants, being the oxidation of food in living cells which releases the energy for processes such as mineral absorption and assimilation, has a higher optimum temperature than photosynthesis. At high temperatures, the rate of photosynthesis will probably be lower than the rate of respiration (Fig. 5.10). The lower temperatures at night also lower the respiration rates and balance with photosynthesis which does not occur at night, helping to maintain a normal growth, which otherwise could lead to the starvation and death of the plant since it would be consuming more than it can produce (Sutcliffe 1977).

Evapotranspiration

> While the pyramid of life is dependent upon sunlight captured by chloroplast, the great work performed by the sun- a gigantic multiple of that employed in photosynthesis- is the evaporative phase in the hydrologic cycle in which H_2O is transmuted into vapour, and elevated, and then precipitated as rain or snow, sustaining those terrestrial creatures who have escaped from the sea but who are still dependent upon it. (McHarg 1992)

A tree has been described as a “water system”, and “large trees have been known to evaporate as much as 3000 gallons per day through the leaf system” (Zion 1995). Evapotranspiration is a major natural process of plant biochemistry which has the

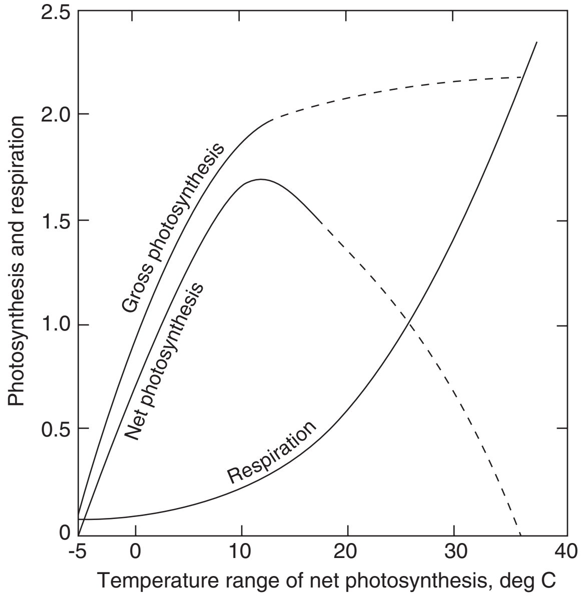

Fig. 5.10 Effects of temperature on photosynthesis, respiration (Kramer and Kozlowsky 1960)

effect of influencing cooling. During this process, trees take in water through their roots and pass it through their trunk, and by the transpiration of leaves, they slowly introduce water into the surrounding air. Therefore the air near green spaces tends to be more humid. During summer it reduces conductive and convective heat gain by lowering dry-bulb temperatures and increases latent cooling loads by adding moisture to the air. Trees cool spaces by evapotranspiration. Ambient heat is actually removed by the act of evaporating water into the air. The Boyle's law effect is a key process of cooling: one calorie of heat is removed from the air temperature for each gram of water which is converted from liquid into vapour. Air conditioning cost reductions estimated from 10% to 50% result from such cooling (Willeke 1989).

Evapotranspiration of urban vegetation plays an important role in urban cooling. The higher heat capacity and conductivity of buildings and paving materials and the reduced evaporation area are the main elements in making cities to be a few degrees warmer than the surrounding rural areas (Landsberg 1981). In arid climates, where it is desirable to increase humidity, trees can be a valuable mechanism for moderating microclimates. In the process of evapotranspiration, energy is absorbed, resulting in heat loss in the atmosphere. The microclimate of outdoor spaces in kibbutz settlements was considerably improved by tree planting. After a couple of decades, due to microclimatic changes, subtropical and even tropical plants have been now growing. Ruth Enis (1984) writes that a transpiring isolated tree may create a cooling effect of 2500 kcal/h which is equivalent to five average room air conditioners running 20 h/day. Federer (1976) also states that the shade of an isolated tall urban tree of 20 m can provide as much cooling as five room air conditioners working 20 h/day. Therefore evapotranspiration can provide local amelioration from urban heat island influences and reduce energy required for space cooling of residential buildings. Studies by McPherson et al. (1989) of vaporisation of moisture from well-irrigated turf see a reduction of air temperature at 2 m of up to 7 °C compared to a dry soil surface.

In the water taken from the soil are minerals that are converted into starches and sugars by means of chlorophyll in the leaves, which traps and utilises the sunlight as energy to manufacture its food. The leaves are the lungs and stomach of the tree. The leaf also contains tiny breathing pores or stomata (Fig. 5.11) that evaporate moisture during the manufacturing process and take carbon dioxide from the air using it, together with sunlight and the minerals absorbed by the roots, in the creation of the starches and sugars that the tree needs for growth. Heat influences the amount of evaporation from the leaves and therefore determines water requirements of the tree (Devlin 1975). The excess heat and light which we avoid are usually welcomed by vegetation.

Research by Grimmond and Oke (1991) measured evapotranspiration from urban areas over a wide range of meteorological conditions through a model. Because it is necessary to cope with the changing water availability on a surface, during or following rainfall or irrigation, an evapotranspiration-interception approach was used. The model developed can be applied to areas, which range from

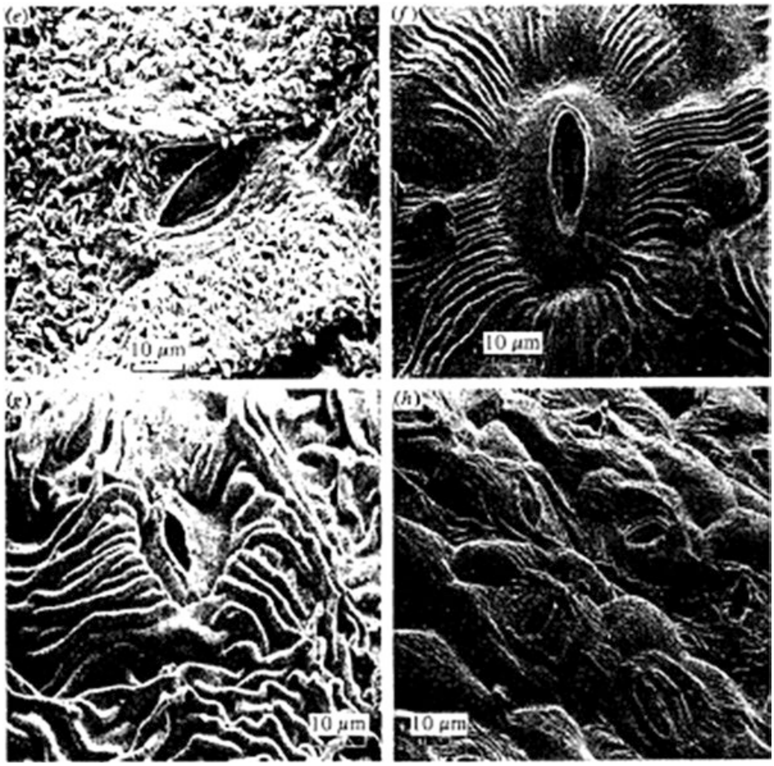

Fig. 5.11 Opened stomata from the leaves of different species (Jones 1992)

city block size to zones of land use, as well as time periods from 1 h onwards. Evapotranspiration modelled was confronted with micrometeorological measurements. Modelled urban evapotranspiration results showed realistic estimates, both hourly and daily, of the real averages of latent heat flux and surface water state. It was seen that the mass equivalent of the latent energy flux, evapotranspiration, is the element which connects the water and the energy balances.

5.4 Vegetation and Passive Cooling

The major source of energy in a microclimate or any site is solar radiation. The amount of radiation received and kept in a microclimate will depend on its characteristics, the size, location, and orientation of the site and objects within that site; the surface characteristics; the size and type of vegetation; and the size of any water body.

Everything in a site affects solar radiation. One main object would be a tree. Thin, light canopies may intercept 60–80% of sunlight, and dense canopies may intercept up to 99% (Fig. 5.12). Different tree and leaf morphologies will have variations. In the UK, for example, beech intercepts from 90% to 99%, and birch may intercept up to 60%. Twigs and branches also help to block solar radiation. In deciduous trees, about one quarter is still blocked during the winter (Dodd 1989). The average value of irradiance reduction by a "typical" deciduous non-species-specific tree according to Thayer and Maeda (1985) is about 35% during winter and 85% during summer.

Vegetation uses shortwave radiation in its metabolic process of photosynthesis. Longwave radiation cannot be used for this purpose by the leaves and therefore is rejected mainly through transmission and reflection. Vegetation overall has a low albedo. It varies from 5% of woods and coniferous forests up to 30% of grasslands (Johnston and Newton 1991). In contrast, evaporative cooling from water albeit effective has a high albedo of up to 95% when reflecting low sun angles. Overall, evaporation has been shown to constitute 38% of the annual external water balance and 81% of the losses of the summer water balance (Oke 1990).

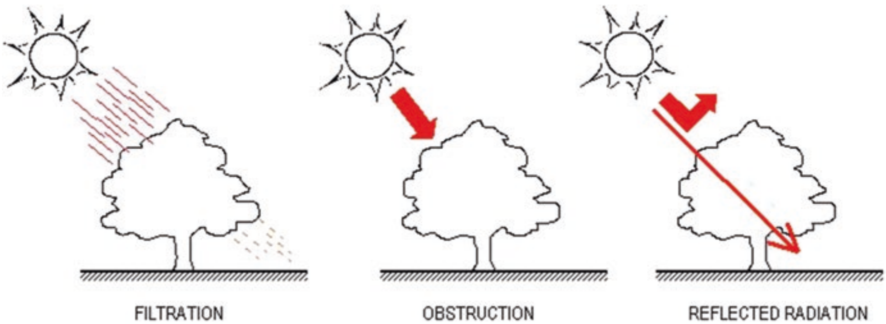

Fig. 5.12 Solar radiation control

Tree shading can change the total radiation reaching a space, surface, or being absorbed by an element. Although there would be an increase in longwave radiation received if the canopy of a tree was used for shade, due to the fact that trees are better emitters than the sky, overall it would be well reduced because of the significant decrease of solar radiation obstructed by the canopy itself (Kramer and Kozlowsky 1960).

Solar Radiation and Trees

In a microclimate, radiation is the element that can most significantly affect the environment and human comfort. It too can be modified and manipulated through the use of trees and landscape design. The balance between the amount emitted by a person or building and the amount received by their surrounding environment is the key issue. All objects in a landscape either absorb, reflect, or transmit radiation, but woody plants and solid structures are the ones with the most influence. Their characteristics such as size, capacity to store heat, transmissivity, and foliage are important issues to determine their effectiveness on solar radiation. Their location and orientation are also determinants (Ferri 1985).

Intercepting radiation before it reaches a surface, reflecting it by changes of the material and colour of the object, and modifying the amount to be absorbed by the object are all ways to mitigate radiation, which can be done by the proper use of trees. Landscape elements have different albedos, and different tree species will intercept radiation at different rates, also according to the time of year. Their height, canopy transmissivity, seasonability, foliation, and defoliation are some ways that trees differ in their ability to influence shortwave radiation.

Direct solar radiation impacting on walls and windows is the primary source of heat gain, but two other factors are also important: heat from ambient air and indirect longwave radiation from the immediate surroundings. All three of these factors can be moderated by planting trees close to the residence. Trees especially help in shading roofs and walls acting as insulation. Figure 5.13 describes the effect.

Influences of two street tree systems, deciduous and mixed conifers/deciduous tree system, on the microclimate in Nanjing City, China, were examined by Mao et al. (1993). The summer microclimates in streets of deciduous trees were up to 7 °C lower than those in streets with mixed trees and on average 4 °C. The relative humidity was higher in streets with deciduous trees on an average of 10% and up to 20% during the warmest hours of the day. The greater evapotranspiration of the lush deciduous trees in summer, resulted largely in lower temperatures. It was accounted that on average street tree, evapotranspiration contributed 62% of the street cooling, and therefore temperature difference in two different streets was primarily due to different evapotranspiration by different tree typologies, although the shading effects of the trees were also important. Tree species therefore have a greater influence on humidity than on temperature. Typologies with a high transpiration potential in the urban areas, with a deep, strong root system, compensate for the loss of evapotranspiration area due to concrete replacement.

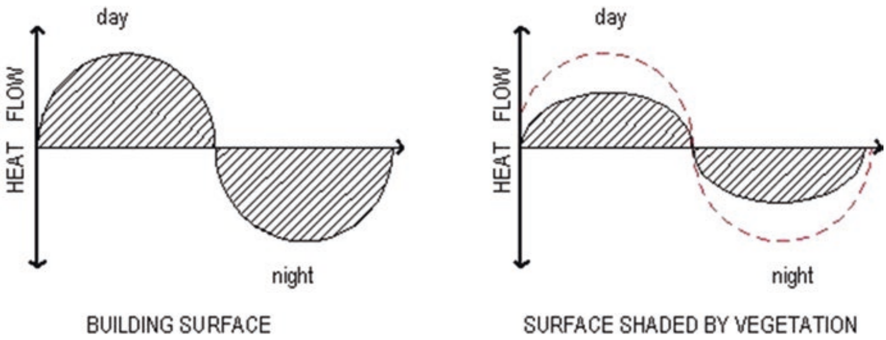

Fig. 5.13 Effects of vegetation on a surface. (After Oke 1990)

The impact of trees in urban areas on the microscale, below-canopy climate, has been the subject to a few studies. Preliminary measurements from Taha (1997) in neighbourhoods from suburban Sacramento with mature canopies indicate daytime air temperature differences of 1.7–3.3 °C than in areas with no trees. Souch and Souch (1993) compared street trees with trees planted on grass in Bloomington, Indiana. All trees showed a consistent effect with temperatures being reduced and humidities elevated under the canopies. A cooling effect of around 1.3 °C was registered in early afternoon, but street trees proved significantly less effective than those planted on grass due to the colour and properties of asphalt.

The cooling effect of small urban green wooded sites of various geometric configurations was the object of study of Sashua-Bar and Hoffman (2000). The cooling effect estimated in this study is perceivable up to 100 m in the streets which branch out from the site (two to four times the width of small green sites with widths ranging from 20 to 60 m). The average temperature difference in all sites was about 5 °C, ranging from around 2 to 7.5 °C. It was noticed that cooling potential of the green sites depended, among other things, on the outside temperature. The higher the temperature was, the higher also was its potential. The site-specific effects such as the tree characteristics were not appointed. It is important to stress, however, that in all cases, no matter how small the green area, the shading coverage more than offsets the heating effects especially of the heavy traffic. Therefore its use is suggested for alleviating the urban heat island effect.

Home cooling by tree shading was also studied by Rudie and Dewers (1984), where a sample of 113 homes of similar setting and design in Texas was used. The effect of tree shade on homes in a setting of native and planted trees was the object of study. Mature oaks measuring 50–60 ft in height were used to shade the 113 homes. The shade was evaluated by a system which rated each home on shaded roof. The amount of shade on the roof perimeter and wall space determined the shade score for each roof. In this case, class 1 shade (the best classified) was determined by the oak tree with a depth of shade of 5.5 m or more cast on the roof at 15:00 on July 21. The study adequately demonstrates the value of shade trees in the home landscape in reducing cooling energy costs and illustrates the optimum position for trees in relation to a home setting.

Trees have multiple effects on the potential utilisation of passive design strategies from the point of view of building and urban microclimate. There would be a reduction of the urban heat island effect as a result of lower heat flows absorbed and released by pavements, roofs, and walls due to the shading provided by tree canopies and consequently a reduction of the air temperature also due to evapotranspiration. The reduced incident radiation on building surfaces, as roofs, glazings, and walls, would also lower the cooling loads and the overheating of outdoor spaces as seen in studies by Canton et al. (1994).

It has been reported by Landsberg (1981) that the humidity distribution in urban areas is related to both land use and surface materials. As the increment of the use of vegetation in the urbanised areas can moderate unfavourable climates, it is desirable to increase vegetated spaces. Vegetation can be used in three ways to protect the building from solar radiation, namely, adjacent to the building, on the building, and independent to the building (Fig. 5.14).

Rooftops with vegetation can decrease the heat flux through the rooftop slab. In urbanised areas during the summer, the vegetation system can be successfully applied to reduce the thermal load on buildings and to moderate hotter and drier climates. Studies by Harazono et al. (1990) indicate that the absolute humidity in the surrounding air increased and the air temperature in the room below decreased with the rooftop vegetation in summer. Investigations show that changes in plant activities cause seasonal variations in the effects of vegetation. During the summer, for example, the transpiration of plants is more vigorous, and plants and deciduous trees have leaves which interrupt solar radiation and then shade building surfaces. Harazono states that: “If we were able to grow plants and trees on unused surfaces

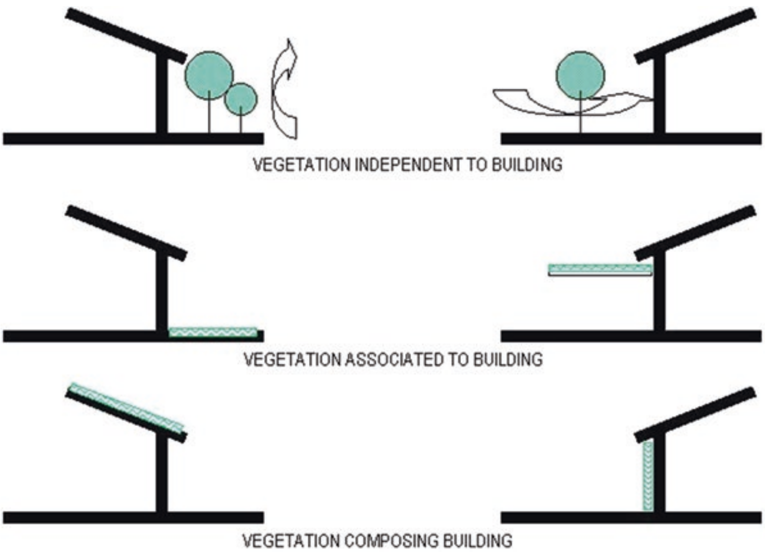

Fig. 5.14 Use of vegetation in relation to a building

without the need for any additional reinforcement, for example, rooftops or other open spaces, then we could obtain a more beautiful neighbourhood, a moderate microclimate, and a decrement in the thermal load on the air-conditioning of buildings".

Increases in population and an expanding urban scale are gradually decreasing the green areas in an urban region; therefore air temperature rises in cities, aggravating the heat island effect. Studies by Honjo and Takakura (1990), Saito et al. (1990), Jauregui (1990), and Harazono et al. (1990) investigated urban green areas such as parks as useful means of improving the thermal environment. All studies showed that green areas have a cooling effect influence on their surrounding built-up area, thus reducing the stress produced by the heat island. In Mexico City, for example, the Chapultepec Park with a green area of around 500 ha is 3 °C cooler than its boundaries and reaches a distance about the same as its width of 2 km (Jauregui 1990). An influence area extending to a distance of 1 km in the northwest direction was also found by Ca et al. (1998) in Tama New Town's Central Park in Japan. The relatively lower albedo of the park canopy as compared with the urban fabric is perhaps responsible for the temperature contrast, with the available energy being used for evapotranspiration.

A 3 °C difference was also found between downtown and the greener suburbs of Kumamoto city (Saito et al. 1990). The cooling area moved with the wind direction. A low-temperature zone may be formed around an urban green area, particularly in its downwind area. Honjo and Takakura (1990) defines the intensity of the effect by the temperature difference between the maximum of the urban area and the minimum of the green area. The range of the effect is defined by the distance from the downwind end edge of the green area to the point of the urban area where the decreased temperature by the green area recovers to the level of the upwind urban area. Even though it is indicated that small green areas could also have a cooling effect, all these examples dealt with big urban green areas and climatological differences. Small green areas in cities, as trees, provide shade, and as Landsberg (1981) points out, their effect is limited to the microclimate; nevertheless they are significant.

Tree Shading

Shading is the most important contribution of vegetation to the microclimate. The presence and permanence of foliage, and also of the distribution of filtering elements within the crown's structure, are functions of the permeability of tree crowns to solar radiation. Trees not only provide the best shade but are also the most economical. Studies by McPherson and Biendenbender (1991) compared the cost-effectiveness of shade provided by metal shelter versus trees at 64 bus stops in Tucson, Arizona. The estimate was based on present value and projected for 40 years' time. Costs were over 50% greater for shelters than to trees. These findings suggest that shade from trees can be an economic substitute for shade provided by metallic shelter in hot climate cities.

Studies by Makzhoumi (1983) looked at the use of trees to control direct solar radiation and provide a more acceptable microclimate for a hot-arid climate with specific reference to Baghdad. Shading efficiency varied among different typologies. Despite the height of the palm tree, it had the smallest area of ground shade and therefore was less effective. The shading efficiency increased when a row of trees formed a rectangular enclosure made by the rows of trees with the longer sides facing an east/west orientation.

Bernatzky (1982) investigated the contribution of trees and green spaces for the climate of a town. Aided by measuring devices, it was observed that a beech forest evaporates around 83% of its incoming radiation, while in a town, 60% of the incoming radiation is warming the air. Deciduous trees still remain efficient even during winter. Branches and twigs can still retain up to 60% of the filtering capabilities. Another study by Bernatzky (1978b) shows that a small green area in Frankfurt may lower the temperature by 3–3.5 °C and intensify RH% by 5–10%.

Results from meteorological simulations by Taha (1997) suggest that increasing albedo and vegetation cover can be effective in reducing the surface and air temperature near the ground and therefore can feasibly reverse heat islands and offset their impact on energy use. It was estimated that under favourable meteorological conditions, with potential evaporating circumstances, increases in vegetation in urban areas can result in some 2–4 °C in air temperatures. Profous (1992) states that for every 10% increase in green cover, the temperature may decrease 1 °C. Studies for Beijing show the heat island intensity has been calculated to 4–5 °C and postulated that it may be possible to control it by increasing green space cover by 50%.

Vegetation and Energy Budget

Microclimates are all centred on the concept of energy budget. The site will always adjust to find equilibrium between the energy being consumed and the energy being supplied. As part of the microclimatic design, trees as energy consumers are of great importance because not only may the energy supplied be partitioned among them but also because they can be manipulated.

The composition, form, and structure of a leaf determine the amount of solar radiation which will be absorbed or dissipated to the environment. It is logical to express a plant or tree canopy as a uniform volume of leaves since the major energy exchanges of vegetation happen through them. Although the leaf arrangement of a certain typology is not homogenous, they usually follow a certain distribution and form which tends to benefit from maximum sunlight. Secondary energy exchanges of solar radiation between the environment and trunks, roots, and branches may be mainly disregarded.

An energy budget may be used to balance the flow of energy into a tree against the amount of energy flowing out and stored by the tree. Nevertheless, accurate modelling of the thermal behaviour of vegetation is very complex. All types of greenery are living forms which respond and react to its surrounding environment uniquely. Although there is no way to simulate the self-regulating temperature of vegetation, we know it exists and has a very important role in the microclimate and its energy mechanisms. While site characteristics can be vaguely estimated, it is hard and unreliable to foresee microclimatic change, especially because they are different for every location. Different equations are also needed for different tree species and tree dispositions, as, for example, a single or various trees are to be considered. Effects also differ over time as a tree grows, changes morphology, and dies. Furthermore, the characteristics of the leaves, as in size, form, texture, and colour, affect and relate to the thermal performance. Therefore many times only a single leaf is considered as means of comparison.

Due to its biological complexity, the thermal modelling of the properties of leaves has an unreliable percentage of error. Although quantifiable, the thermal effect of trees is usually ignored in investigations involving vegetation. On the other hand, more precise accuracy of the thermal effects and the reliability of the repetition of certain patterns are possible within the constraints of a certain context. It is not the objective to model and simulate the thermal effects of different trees due to the complexity of the metabolic processes stated before. However, it is the interest to consider the significance of these processes and compare the potential outcome of different microclimates for reference.

Energy Savings by Tree Planting

Environmental concern about global warming, heat island effects, and air pollution has brought attention to the potential of trees in ameliorating climate and conserving energy. As stated earlier, climate and human comfort benefit from trees basically through shading, which reduces the amount of radiant energy absorbed and stored as well as that radiated surrounding surfaces, and evapotranspiration, which converts radiant energy into latent energy, consequently reducing the heat that warms the air. Airflow modification may also affect the diffusion of energy.

Greater canopy density leads to an increase in wind speed, standard deviation of wind speed, and direction. Average daily air temperatures in new and intermediate canopy densities are higher than in mature densities. An inverse behaviour happens for relative humidity, therefore reducing below younger canopies.

Reducing urban summertime air temperatures and saving cooling energy in buildings by increasing urban vegetation hold great potential. Findings from simulations by suggest that a single tree around 7.5 m tall can reduce annual cooling and heating costs of a typical residence by 8–12%. In warm climate cities, reduced solar gains from tree shade were responsible for most of the cooling savings. Evapotranspiration also had an important role in cooling with an increased potential in regions with more cloud cover.

Studies by McPherson et al. (1989) reviewed a range of experimental designs, building types, and landscaping and found that measured air-conditioning savings ranged from 25% to 80%. Larger savings were associated with more dense and extensive shading, by large compact canopies.

Studies by Holm (1989) investigated the use of creepers instead of trees. Best results were obtained in low-mass building in hot-arid climates with equator-facing walls of high radiation absorbance in winter but covered by vegetation during summer, which all other outside walls were covered with evergreens. A constant of 2.5 °C cooling effect in the room temperature facing the equator was found. Indoor temperature was reduced from a 17 to 33 °C range to a 18–28 °C range in an ambient temperature range of 21–31 °C dry bulb. The thickness of the foliage acts as a canopy where the outer layer filters and reflects the solar radiation, while deeper layers act like insulation material.

Soil characteristics include its thickness, its apparent density, and moisture content. They determine the soil thermal diffusivity, which will augment with the apparent density and diminish with the soil moisture content. Thermal conductivity and weight are also reduced with lighter soils. Therefore the garden roof acts better as insulation than a cooling element, mainly by reducing the heat flux through the roof. Evapotranspiration has a secondary effect as a green cooling device. Nevertheless the air exchange rate between tree canopies and the surrounding free air is more important and effective to the microclimate.

Furthermore the cooling effect increases with the increase in leaf area per unit roof or leaf area index (LAI), and the same consideration can be applied to trees. Canopies which have greater foliage area have larger effective areas for evapotranspiration than areas with smaller leaf area.

Trees and Wind

Landscaping has a great influence on wind. It can redirect the airflow and make it blow faster or slower. Winds are unpredictable and vary much, but generalities may be considered for understanding its effects as seen in Fig. 5.15. Prevailing winds may actually increase the energy used for air conditioning by increasing the infiltration of warm air into the residence. Trees and shrubs can act as barriers. The scattered pattern of built forms opens up more wind paths, unless there is sufficient tree planting to add compensating roughness. “Tree shelter reduce both wind speed and homogeneity, as well as retaining local air pockets in place” (Dodd 1988). The

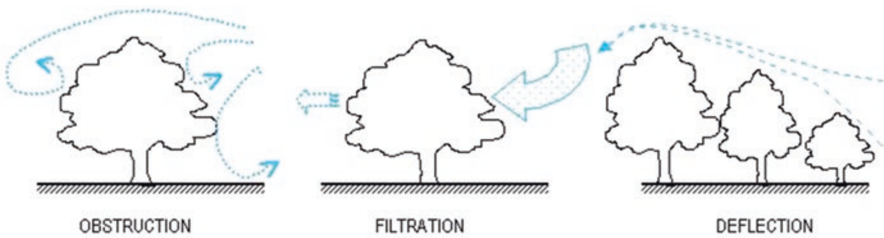

Fig. 5.15 Wind control

convective heat transfer between the outside air and the house, or from the macro- to the microclimate, and the infiltration rate of outside air into the conditioned space are reduced by decreasing the wind speed. This is desirable in hot-dry places.

Differences in temperature and humidity are said to be harder to achieve because of the constant mixing of air by the atmosphere; therefore temperature and humidity differences are quite rapidly and easily dissipated**.** However, there is a chance of obtaining important effects and significant changes by isolating and disconnecting the microclimate considered from the main atmospheric system. Separating from the system and consequently having low wind velocity by obstructions such of walls and above by tree canopies can create an interesting setting worth exploiting, leading to significant temperature and humidity changes.

Trees and Air Quality

Pollution can be considered as substances which cause damage to targets in the environment. The pollutants can be diluted or transformed into harmless substance before reaching their targets which can be plant, animal, human being, or inanimate structure. Trees and vegetation can act as an effective sink for airborne pollutants. They may intercept or absorb pollutants which are then combined with plant tissue and are effectively removed from their pathway. Carbon dioxide is an essential part of the food-making process of plants, photosynthesis. They absorb this pollution, and it is then assimilated as carbon within the vegetation, with the by-product oxygen released into the atmosphere. Carbon dioxide is absorbed by the leaf surface through stomata. Once the pollutants are absorbed, they are diffused into intercellular spaces or dissipated by water films.

Healthy mature trees may remove up to 70 times much pollution than a small tree. Among the tree species with broad leaves, the most effective in capturing pollutants are those with rough leaf surfaces.

Young, healthy, and fast-growing trees are better for eliminating CO_2. Urban trees are also more efficient than rural trees and "are up to 15 times as valuable as identical rural trees in limiting CO_2 build up: one time for the CO_2 they lock up in biomass; and fourteen times because of the fossil fuel they save by reducing needs for air conditioning in summer and heating in winter" (Willeke 1989).

Trees are capable of absorbing large quantities of dust from the atmosphere. Dust and other forms of pollution can be trapped by leaves of certain species, like evergreens. Although the residue is washed off during rainy seasons, the space beneath the canopy benefits during long dry periods. The air beneath a tree canopy contains only a fraction of the pollution found above and around the wooded area. The vegetation acts as a filter, the rate of pollutant removal being controlled by its physicochemical nature, the species, height of the vegetation, and the prevailing climatic conditions. In a city without trees and green areas, the wind will continuously pick up pollution particles. On the other hand, trees and greenery interrupt the flow of warm, polluted air to the urban centre, and "the homogenous air stream of the field wind splits up into several smaller circulations" (Bernatzky 1978b). Up to 70% of the airborne dirt can be retained by well-planted streets (Sanchotene 1994). A mature urban tree can intercept up to 50 lbs of particulates per year (Dwyer et al. 1982).

Trees exchange gases with the atmosphere and capture particulates that can be harmful to people. The amount of foliage, number and condition of the stomata, and metabolic characteristics primarily determine the rate at which trees remove gaseous pollutants such as ozone, carbon monoxide, and sulphur dioxide. Increase in ambient temperatures increases urban ozone concentration. Therefore by reducing summertime temperatures, urban trees provide another means of improving air quality; therefore urban trees act as sinks for gaseous and particulate pollutants and can very effectively add to pollution control. They can be seen as components of an overall strategy to restore air quality into cities. Improved air quality will enhance physical and mental health, leading to reinforced well-being. It also results in substantial savings for health care and reduces the costs of repairing damage to buildings caused by poor air quality.

5.5 Complementary Aspects About Vegetation

Trees provide contrasts of colour, texture, and form in a built environment, introducing the shapes, colours, and feelings for nature into the man-made geometric patterns of roads and buildings. With fresh greenery, blossoms, ripening fruit, and dancing shades on brick walls, pavements, or silhouettes against the sky, trees provide endless variety and delight. Species selection, planting location, and cultural practices all have an impact on the visual quality site and health of the inhabitants (Cantuaria 2000c).

Lawrence Halprin (in Jellicoe 1995, p. 333) emphasises the visual importance of nature by believing that "…not only does form equal process in nature, but we derive our sense of aesthetic from nature… I view the earth and all its life processes as a model for the creative processes". Trees have more than visual appeal. The wind rustling through leaves is a sound evocative of the countryside and a welcome diversion from city noises. The smell of their flowers and fruit associate with nature and temper with the artificial appearance of the town dweller in replacing oxygen and improving the soil.

Ecological stability is promoted by urban trees by providing habitat for wildlife, enhancing biodiversity, and conserving soil. These benefits are very unlikely to be quantified and valued but are important to many urban inhabitants and the long-term stability of a city's ecosystems. These ecological benefits such as the preservation of valuable existing natural areas, the restoring of degraded lands, and habitat creation attracting and increasing biodiversity will become more and more significant with the growing environmental awareness and concern for quality of life in cities.

Trees have a beneficial influence on health. The presence of trees in cities has been associated with reducing mental and physical stress of its inhabitants. Landscapes with trees and vegetation "produce more relaxed physiological states in humans than landscapes that lack natural features" (Ulrich 1984). Studies by Ulrich indicated that hospital patients with window views of trees and green recovered significantly faster and with less complications in comparison with patients who had no access to views with greenery. Cleaner air is also expected to improve health.

Glare problems can also be mitigated by planting trees. By reflecting most of the solar radiation, it aids in controlling where glare would be excessive. Jeremy Dodd (1988) in his writing about *Energy Saving Through Landscape Planning* also suggests that even the attraction of other small life forms is a way of upgrading the microclimate. "The growth of trees and plants and the diversity of insects like butterflies are useful visual indicators of microclimatic improvements and may overcome human tendency to underrate the comfort of low wind speeds".

Vegetation through root network and hydrological effects substantially affect slope stability and prevent erosion. Trees also function like retention and detention structures when reducing runoff, which is essential in many communities such as popular urban settlements where drainage piping is not a priority. Storm water treatment cost in settlements can be lowered by reducing the runoff due to rainfall interception. Therefore by reducing the rate and volume of storm water runoff, flooding damage, storm water treatment costs, and water quality problems, urban trees can play an important role in urban hydrologic processes Dwyer et al. (1982).

In the urban environment, noise pollution is another common problem, influencing human comfort and health and in extreme cases causing medical or psychological symptoms. Human behaviour is also influenced by noise condition. Properly designed plantings of trees and shrubs can significantly reduce noise. Trees may act as sound buffers. The leaves absorb the sound and reduce the reverberation time. Reductions of 50% or more can be achieved in the apparent loudness by wide belts of tall dense trees combined with soft ground surfaces.

However noise attenuation studies by Mao et al. (1993) showed significant higher noise attenuation efficiency in streets with a mixed use of trees and shrubs, although the use of trees only also showed noise reduction. A greenbelt of 25 m of deciduous trees during summer showed a net noise attenuation of up to 6 dB and an efficiency of 0.24 dB/m, while a 22 m greenbelt of mixed trees and shrubs had a net noise attenuation of up to 8 dB and an efficiency of 0.36 dB/m. Therefore, with the same green space, the mixed use of trees and shrubs could diminish noise by 2–3 dB more than the use of only deciduous trees and had on average a noise attenuation efficiency of 0.33 against 0.17 dB/m. The use of dense tree rows, shrubs, and species with large leaf size and shape is attributed to the higher noise reduction.

Without a doubt, architecture plays an essential role in human ecology. As shelter, its most elementary sense, architecture has enabled man to adapt to natural and environmental conditions radically different from those in which he first evolved. Nevertheless, it is admitted that the place where a person lives, his shelter and environment, dictates habits and values. Being a living organism, man is a bearer of specific cultural characteristics and an owner of individual consciousness. Among the practical problems of humanity today, our relation to the immediate space is of critical importance. Our applications of science have been restricted. In our present view of the environment and microclimate, "much that the anthropologist recognises as 'cultural' has to be defined as serving also an 'environmental' function" (Dansereau 1966). Dansereau also suggests that the interaction of man with its vegetated external surroundings not only provides thermal microclimatic benefits but also provides environmental education, and much can be learnt from their presence. He says: "As plants and trees are highly selective to environmental factors by identifying physiographic climatic zones and soils we can perceive order and predictability in the distribution of constituent plant communities. Indeed the plant communities are more perceptive to environmental variables than we can be with available data, and we can thus infer environmental factors from the presence of plants. McHarg (1992) outlines our environmental method in landscape architecture as "the prerequisite for intelligent intervention and adaptation".

5.6 Vegetation and Sustainable Development

> Sustainability has to do with environmental aspects as well as economical and social issues.
> Nigel Howards

Relations between users and the symbolic quality of environment suggest that individuals define, reinforce, and extend their sense of self through the direct relation and communication with the environmental object. In this context, trees can be seen as "social tools", or symbols representing one's values and status, and, as such, inform others of one's identity as well as reinforce one's own sense of self. Social symbols consequently function as a significant reference and a means of communication. Trees may operate as symbols by reason of association, relationship, convention, or accident. In all ways, it has a shared meaning between all people with whom communication is desirable. Through perception and cognition of this order should social learning occur and ultimately affect culture and communication between groups in society and individuals.

Trees are of social importance and contribute to the vitality of a city or neighbourhood. They can dominate the urban landscape and contribute to its character and image of a progressive and liveable environment. Urban landscaping brings an environmental responsibility, ethics, and a stronger sense of community, empowerment, to the residents. Tree planting improves neighbourhood conditions and enhances a community's sense of social identity, self-esteem, and territoriality and promotes environmental education and awareness.

Stuart Arden (1980) sees the use of greenery as part of the environmental coding which not only upgrades the urban landscape but also upgrades the social structure. He defends that a tree is a medium of environmental communication and may be considered artistic and aesthetic because it fulfils one or all of the following propositions:

- It communicates to the onlooker; it elicits some response, negative or positive.
- It changes the onlookers' perception of the world or human experience.
- It has a discernible form or style.

- It exhibits uniqueness; it derives from a creative source.
- It transcends pure emotion and gives dominance over our feelings.
- It speaks to a sense of mystery in life and world experience.

> If we accept landscape architecture as an art; accept art as the manifestation of the collective cultural, historical and philosophical identity of a community (the genius loci); and accept that art is not only a sign of a unified society, but also a contributory factor in its creation, then landscape architecture becomes truly significant. (Birksted 1999)

Vegetation is part of popular culture because it embraces all phenomena in artistic and social regimes. As such, it reflects the taste and understanding of the public; expresses the patterns of values, thoughts, and feelings; validates familiar experiences; produces what is expected; and is not complicated, requiring no special skill for appreciation.

The lack of trees and vegetation in an area can lead to a cultural gap, an absence of values. The provision of greenery is also the provision of a wiser man, a more responsible society, and a more human and sustainable horizon (Bernatzky 1978b; Saini 1980; Pearson 1994). The interference of vegetation and other objects in one's culture as explained by Boulding (1968) is that "Culture is a body of coded information which is passed on from generation to generation, suffering mutation and selections, just as the coded information in the gene is passed on, except that cultural evolution is much more subject to mutation and proceeds at a much more rapid rate than the evolution of genetic structure. It is new inputs of information into a culture that constitute mutation in social evolution and these inputs can affect either the image of the world or the value-systems, according to which decisions are made".

5.7 Conclusions

The use of greenery as a means of passive cooling and environmental comfort in buildings and cities in Africa is very promising. A tree's cooling potential will vary according to its size, form, morphology, and maturity. Trees not only help in energy-related issues but also in creating better living conditions by providing less straining spaces, less dust, and less illness-related issues, playing space for children, fruits, and neighbour interaction. These complimentary aspects are related to better life quality and the concept of sustainability.

A single tree has the cooling potential through shading and evapotranspiration to ameliorate a hot and dry outdoor microclimate by decreasing temperatures and increasing humidity. Provided an adequate typology of mature tree, it should be possible to shield excess solar radiation from under the tree canopy, hence diminishing the temperature of the shaded microclimate. Relative humidity levels should also be able to increase provided the foliage canopy is large and green. The canopy with most leaf area is bound to be the most effective.

Urban trees can strongly influence the physical and biological environment and mitigate many impacts of urban development by soothing microclimates with more comfortable temperatures and humidity levels. They also help conserving energy, carbon dioxide, and water, lowering noise levels and wind, controlling rainfall runoff and flooding, improving air quality, harbouring wildlife, stimulating biodiversity, and enhancing the city's beauty and scenic quality. Each of these has a meaningful implication and influences the well-being of the dwellers. Benefits extend beyond individuals to society by strengthening the community, improving neighbourhood conditions, and promoting social and environmental responsibility. Green environments provide an increased enjoyment of daily life, aesthetic surroundings, and a sense of significant connection between people and the natural environment. Trees can be seen as a vital element of the urban infrastructure that helps to create and maintain a healthy environment for the inhabitants. It is a living technology.

This section suggests an architecture that roots in its cultural and regional soil. "It must become more primitive and more, refined at the same time: more primitive in terms of meeting the most fundamental human needs with an economy of expression and mediating man's relation to the world in an equally fundamental and literal way, and more sophisticated in the sense of adapting to the cyclic systems of nature in terms of both matter and energy" (Pallasmaa 1991).

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Chapter 6
Shading in Architecture and its Relation with Natural Cooling: Learning from Maputo, Mozambique

Rui Nogueira Simões and Pedro Ressano Garcia

Shaded areas around built structures is an effective strategy in reducing direct sunlight inside buildings located in countries with hot climates. In regions of hot humid climate, shade has the effect of reducing the air temperature of the surrounding area and enhancing natural cooling. This is increasingly relevant in times of climate change because buildings are requested to lower CO_2 emissions. This chapter aims to give an overview of twentieth century architecture in Mozambique and provide information to architects of the twenty first century that intend to continue this tradition and expand bioclimatic solutions that succeed in lowering the consumption of energy. The focus on Pancho is due to the excellence of his work in the panorama of modern architecture, the diversity of his design merging local traditions and new technologies, and the cultural impact of his work in Maputo, Mozambique.

Architecture solutions of shading, cross ventilation and thermal control have been refined in recent years, improving performance by developing a bioclimatic quality, which is influenced by the exchange of best practices from around the world. In Mozambique, and mainly Maputo, there are several examples of architecture that adapt and interact with the tropical climate. Throughout the twentieth century, with population growth, Maputo experienced an unprecedented urban development, where a number of bioclimatic strategies were tested, namely, the extension of roofs, the use of balconies that bring shade to façades, ventilation of ceilings, roof covers, vertical and horizontal shade blades to induce ventilation, shade grill façades (cobogós), division of windows in areas of lighting and ventilation, semicircular frameworks with brise-soleil shades and façade elements realised as closets or joists to increase the cooling of buildings. All of these elements are present among the solutions used by modernist architects and were particularly well illustrated in the works of architect Pancho Guedes, a member of Team 10 (often referred to as Team X), who lived and designed many buildings in Maputo.

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Climate of Africa

The continent of Africa presents a uniform climate, making it unique compared to other continents. Its particular location, with the crossing of the Equator and the two tropics, allows the whole territory to be considered a low latitude climate zone, according to the classification of A. N. Strahler (González and Javier 2004, p. 21). The low latitude zones form the part of the world where the sun's rays focus more perpendicular to the surface of the Earth and in a very uniform way throughout the year (González and Javier 2004, p. 13). Most of the territory is covered by a warm climate, divided into humid equatorial climate, wet dry tropical climate and hot dry desert climate (Fig. 6.1). These climates are characterised by high temperatures and humidity variation between very dry and very wet. The equatorial climate, between 10° N and 10° S, is the one in which the temperature and humidity are more constant throughout the year. The wet dry tropical climate lies between latitudes 5° and 25° both north and south of Ecuador, benefits from the presence of tropical forests and has different levels of humidity at different times of the year, with wet summers and dry winters. The desert climate that lies between the latitudes of 15 and 30° N and 15° and 30° S is characterised by being extremely hot and dry, with few temperature variations during the year.

The dry subhumid tropical climate region is the main climate zone in the Portuguese-speaking countries of Africa, covering most of the area of Angola and Mozambique. However, São Tomé and Príncipe and Guinea-Bissau are in the equatorial climate zone. Cape Verde, which is the northernmost Portuguese-speaking country, is already in a hot and dry desert climate zone. So, with the exception of Cape Verde, the climatic characterisation of Portuguese-speaking areas in Africa is hot and humid. The architecture designs for these countries value shading solutions to achieve an efficient improvement of the feeling of thermal comfort, associated with the ambient temperature and air humidity concentration. The replacement of blind façades for shading systems enhances natural ventilation, which is essential in order to reduce the levels of humidity in buildings.

Climate of Maputo

Maputo is located in southern Mozambique on the southwest coast of Africa, between parallels 25° 40′and 26° 30′ south and meridians 32° 35′and 33° 10′ east. Summer is a hot season with precipitation; the dry season presents high winds and no clouds. Throughout the year, the weather is warm and the variation in temperature is between 16 °C and 29 °C, and is rarely less than 14 °C or more than 33 °C. The rainy season lasts for approximately 5 months, from November to March. The dry season lasts for almost 7 months, from April to October. The duration of the day in Maputo ranges between the shortest day on the 21 June, with 10 h 30 m of sunlight and the longest day on the 22 December, with 13 h 46 m of sunlight.

The annual relative humidity ranges from 65% in summer, where February and March are the wettest months, and 45% in winter, where August and September are the least humid. The average wind speed in Maputo undergoes significant seasonal variations throughout the year. The season with higher levels of wind during the year lasts for 4 months, from August to December, with average wind speeds of up to 17 Km/h. The strongest winds usually occur in September, with an hourly average wind speed greater than 19 Km/h. The calmer season of the year lasts about 8

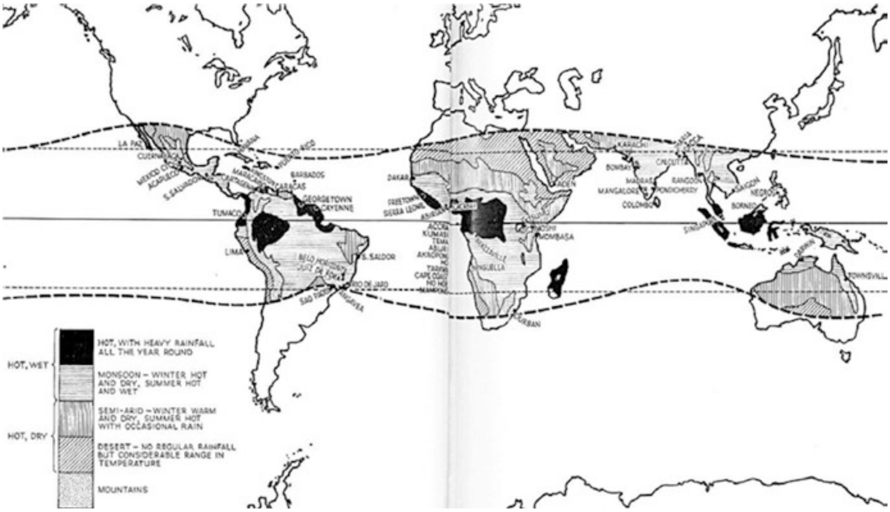

Fig. 6.1 Intertropical area of planet Earth: tropical architecture in the dry and humid zones (Source: Fry and Drew, 1964)

months, from December to August. The lowest average wind speed occurs in May, being about 15 Km/h, which is not actually considered to be wind. The most frequent wind comes from the east for most of the year. It may blow predominantly from the southwest with a proportion of 15% (weatherspark.com).

The city of Maputo is located on a plateau with a coastline, has a constant topography, with slopes to the south and east, and ending in coastal shallows. This orography ensures good sun exposure but mainly good ventilation in the area of the plateau and slopes, oriented in the direction of the prevailing winds to the east, taking advantage of the presence of the Indian Ocean (Morais 2001, p. 52). The city has evolved from the initial core area, located in the south. This area was initially an island that was then later attached to the coast by landfill, developing gradually by soft slopes located southwest of the plateau, first extending to the east and later to the north. The city's density is very low, which, along with the design of the urban plan, ensures good urban ventilation.

The initial plan of the city of Maputo, the Araújo plan, dated from 1900, is characterised by the design of large blocks and wide avenues organised in an orthogonal mesh. This grid was oriented with a rotation of about 28° to the north–south axis, which allows for the implementation of buildings close to the ideal in the north and south sides of the blocks, since the windows are mostly to the north façade.

6.1 Shading Typologies in the Architecture of Maputo

In hot and humid climates, there are fundamental requirements for temperature control of the built environment: avoid direct sun impact on windows, enhance the concept of opaque envelope, reduce the air temperature surrounding the building and promote cross ventilation to reduce the internal temperature and humidity levels. The thermal inertia of the materials associated with appropriately designed shade ensures an effective feeling of thermal comfort. For this, shade systems are critical and various types of devices can be used according to the situation or orientation of the building. In hot regions, a well-shaded building can be between 4 °C and 12 °C cooler than one without shade (Guedes 2011, p.40). Shading systems should block the incidence of the sun's rays before they pass through the glass, thus avoiding the greenhouse effect. Some distance should also be kept between the shading element and the glazed area, so that thermal radiation captured by the device does not heat the interior of the building. The shading of the outside world that envelopes the building can be done through fixed or adjustable devices, by vegetation or surrounding shaded areas. Another technique that helps to lower internal temperatures is the creation of cooler environments around the building, which can include solar protection of balconies, patios or atriums.

The efficiency of fixed devices varies according to the solar orientation. They can be: horizontal blades, ideal for the protection of glazed surfaces in façades oriented to the north; vertical blades, ideal for protecting windows from solar radiation in façades oriented to the east and west, due to the low angle of the sun in the early morning and late afternoon; or combined horizontal and vertical shades, such as the projecting frames of windows. Fixed grids are effective for enhancing indoor ventilation. Fixed shades are prominent elements of façades, such as beams, eaves, wardrobes etc.

Mobile devices include adjustable vertical and horizontal blades or blinds, or even mobile grills, shutters and lattices, which are used mainly in façades oriented towards the east and west, hiding the entire glazed surface. Mobile devices change the visual appearance of buildings and are managed by users to keep the temperature at a comfortable level. Without them, it would easily lead to overheating of the building.

Neighbouring buildings can promote shade on façades, mainly on the lower floors, but cause, as a side effect, a reduction of natural light in the rooms. Vegetation also promotes a better environment around the buildings, having a dual purpose of shade and reduction of temperature through an evaporative cooling effect. In hot climates, the use of evergreen trees constitutes a preferred solution.

The creation of cooler surrounding intermediate spaces also allow lower temperatures inside the building. This could be achieved by verandas, patios, sheds, roofing over floor extensions and galleries or arcades. This is the traditional method to cool buildings, by casting shadows over the exterior areas around it, thus constructing a sort of thermal envelope. In Portuguese-speaking countries with tropical climate, in the architecture of the nineteenth and early twentieth centuries, this process was often used, as can be seen in the "Roças" architecture in São Tomé and Príncipe or in downtown Maputo.

The island at the mouth of the Espírito Santo River is where the settlement of Maputo was initially established in 1544 as being a Dutch, English and Austrian trading post successively, until it was taken by a Portuguese expedition originating from Goa in 1781. In this place, a Portuguese presidium (establishment of military colonisation) was settled, under the command of Joaquim de Araújo. After 1902, because of the railroad connection and the pacification of the interior of South

Africa, the city of Lourenço Marques later became known as Maputo and evolved into an important business centre, mainly due to its role in importing and exporting goods from South Africa. The urban expansion of the city developed during the transition of the centuries, on one hand from a plan of 1887 by the engineer António Araújo, to the slope to the north of the downtown, and simultaneously in the "Ponta Vermelha", from a plan by MacMurdo. This plan was initially separated and later became integrated in the urban design of the city (Fernandes, p. 59). The great urban expansion took place in the 1920s and 1930s, based on the plan, designed in 1903, "Insurance Plan of Lourenço Marques, Delagoa Bay", in which the urban grid extends to the north, to the current Av. Mao Tse Tung and the circumvallation, which was already included in the plan, thought to be built only later on.

Architecture of the late nineteenth and early twentieth centuries

Downtown Maputo and the central area are the places where it is still possible to find buildings from this period. Unlike the capitals of other Portuguese colonies, where the influence of Portuguese architecture has a greater presence, here, we find colonial buildings of the late nineteenth century influenced by South Africa. Large balconies made from wood and wrought iron characterised these buildings, with covers suspended by columns in metal or wood and, later, concrete. Prefabricated wrought iron pieces such as pillars, porch grills and stairs were imported in order to quickly assemble buildings, built in traditional British colonial style or Victorian style (Schauer 2016, p. 12).The colonial style is visible, for example, in the building of the old offices of Delagoa Bay in the street Rua Do Bagamoyo (Fig. 6.2) or in the residence of the director of the central hospital in Av. Eduardo Mondlane. Some commercial buildings in the downtown area feature long galleries with neoclassical columns and concrete slabs. Some of these galleries were added later, as in the case for the commercial building of Tobler's house built at the beginning of the century but with a gallery of neoclassical columns from 1929 (Fig. 6.3). This period of iron-based architecture produced two important buildings: the central railway station (Fig. 6.4) of 1908/1910 from a project by Alfredo Augusto Lisboa de Lima and José Cristiano de Paula Ferreira da Costa with a central turret and two lateral arches surmounted by balconies, an element that allows it to adapt to the climate, and also Vila Jóia (Fig. 6.5) from 1890, with a design by the architect of Pretoria, F. A. Bodde, which has a metallic structure with Hindu-inspired staircases and classic arcade (Fernandes, p. 149). This building, one of the oldest in the city, belonged to Gerard Pott, Consul of the Transvaal in Lourenço Marques, and is a great representative of the Dutch colonial architecture (Lima 1966, p. 56) of neoclassical style. Two works in the Polana area from the early twentieth century represent the first uses of reinforced concrete and utilised the same morphology as the large galleries of colonial architecture. These are the Nautical Guild (currently the Naval Club), artwork between art nouveau and art deco, and the Tea Pavilion, a typical concrete architecture on balconies and consoles" (HPIP - Heritage of Portuguese Influence, HPIP.org).

Art deco architecture and "Português suave" style

As with the "Victorian" style of balconies and iron pillars, imported from England, which was used in several colonies, art deco was also imported from Europe and the

Fig. 6.2 Former offices of Delagoa Bay

Fig. 6.3 Tobler's house

USA and became popular in the African colonies (Schauer 2016, p. 12). Some cities like Asmara in Eritrea or Casablanca in Morocco are known for this architecture. In the case of Maputo, the art deco is of British origin and will have come via South Africa. This style, together with the first modernism, still has a significant presence in the city of Maputo today, due to the population expansion in the city in the 1930s and 1940s. However, while in the metropolis and in other Portuguese colonies the

Fig. 6.4 Central railway station

Fig. 6.5 Vila Jóia

"Português suave" style was of greater importance, in Maputo, the English influence was stronger. According to the opinion of José Manuel Fernandes, *"Maybe we can even say that the more dynamic modernizadora? (...) along with a cosmopolitan internationalism, powered in direct relationship with the Anglo-Saxon neighbour, have led to a smaller dimension of the architecture phase neotradicionalista?"* (Fernandes and Janeiro 2006, p. 165).

We can find some of these examples in Maputo, namely in two types of art deco: one of more volumetric character, with vertical bodies of pure geometry (Fig. 6.6) more connected with the English art deco, and a later one marked by the cantilever slabs and blades of reinforced concrete (Fig. 6.7), influenced by the American art deco. Although it became a truly popular style, even among the builders, many architects of this time are not known, as most of the buildings had designs sometimes coming directly from South Africa (Schauer 2016, p. 13). In single-family

Fig. 6.6 Villa art deco

Fig. 6.7 Villa art deco

Fig. 6.8 Villa art deco

dwellings, this style was characterised by high ceilings and small openings to control solar radiation. For the purpose of ventilation, most of the dwellings had small grates next to the ceiling in order to expel the warm air. The adaptation to a tropical climate is recognised in some dwellings with deep balconies, designed as a negative of the volume (Fig. 6.8) or balanced in cases in which the construction already used reinforced concrete. In the first phase of art deco, the blades of shade on the windows, when they existed, are still small due to the difficulty in construction and because they are mostly constructions built before the use of reinforced concrete. In the second phase, we found a greater volumetric freedom, lower wall surface and larger openings, although covered with blades of shade. The characteristics of this style, sometimes called "streamline modern", are the use of curved shapes, protruding volumes and rounded corners, elongated horizontal lines and surfaces, and, sometimes, nautical decorative elements, such as round windows and protection rails in metal tubes (Fig. 6.9).

Some of the most notable equipment buildings in Maputo are from this time in an art deco style or from early modernism: the Scala cinema and the Scala café building, built side by side in 1931, are joined by galleries covered with a reinforced concrete cantilever slab, which extends over the two streets (Fig. 6.10), probably the first to be built in Maputo. The Cathedral of Maputo was built between 1936 and 1944 (Fig. 6.11) following the design of engineer Freitas da Costa "recalling churches by Auguste Perret and Pardal Monteiro" (Fernandes, p. 165), namely the Church of "Notre-Dame du Raincy" and the Church of "Nossa Senhora de Fátima" in Lisbon. Constructed entirely of reinforced concrete, it presents with horizontal blades in the central tower that accentuate its tropicality. The "Casa Hillman" (Fig. 6.12) on Av. 25 de Setembro, built in the 1940s as a building materials store on the ground floor and an English club on the upper floors, is now the ministry of

Fig. 6.9 Villa art deco

Fig. 6.10 The Scala cinema

energy. In an art deco language, it is "formally almost a reduced version of the headquarters of the newspaper 'Diário de Notícias' in Lisbon" (Fernandes, p. 167), presenting, however, recessed windows in order to create deep shading galleries on the main façade. Also, the bay windows in the main tower are transformed into small horizontal slots. The Hotel Cardoso built in 1938 (Fig. 6.13) by the Italian architect

Fig. 6.11 The Cathedral of Maputo

Fig. 6.12 The “Casa Hillman”

Paolo Gadini, located on Av. Martires de Moeda, presents, on the façade facing the bay, cantilever balconies and recessed windows recessed for shade. However, because it is oriented to the west, vegetation is also used to enhance temperature control. But it is the blades of concrete to the west and the grilles to the east, both of which fulfil the purpose of ventilation, that characterise this building. The 1948

Fig. 6.13 The Hotel Cardoso

Cine África (Fig. 6.14), at Av. 24 de Julho, is a building from the end of the art deco period and shows the same type of blades on the main façade, with the double function of shading and ventilation, as well as a gallery on the first floor. The Radio Palace of 1949 (Fig. 6.15), also by the architect Paolo Gadini and engineer Pardal Monteiro[1] (Schauer 2016, p. 44), already built during the transition to modernism, is made up of three different bodies: the first apparently cubic with a shading grid consisting of squares, the second a vertical tower with vertical blades and the third is lower with horizontal blades, form an imposing ensemble. Other buildings in Maputo during this transition period between art deco and modernism show other types of vertical, horizontal or combined blades of shade, such as an office building on East Timor Street (Fig. 6.16), which has vertical blades but oblique in relation to the façade plan, which protect it from direct solar radiation.

Modern architecture between 1950 and 1974

In this period, there was a significant population growth in Maputo, from nearly 100,000 inhabitants in 1950 to 350,000 in 1970, which resulted in expansion of the city and increase in construction activities. Many architects from mainland Portugal were attracted to the colonies, seeking more opportunities, on one hand more commissions and on the other more creative freedom. Although in mainland Portugal

[1] By the dates referred, the engineer Pardal Monteiro is likely the son of Porfírio Pardal Monteiro, the very known Portuguese architect Pedro Kopke Pardal Monteiro (1920–1984), who finished the course in civil engineering at Instituto Superior Técnico in 1944 and may possibly have spent a period in Mozambique before returning to Lisbon to work in his father's workshop. Due to the fact of being from this period, it may not be a coincidence that two important buildings in Maputo are clearly influenced by the architecture of Pardal Monteiro, the Cathedral of Maputo and the Casa Hillman.

Fig. 6.14 The Cine África

Fig. 6.15 The Radio Palace

there was great development in the post-war period, architects were pressured by the conservative government to practice a restrictive architectural style widely known as "Português Suave", which means smooth Portuguese. In Angola and Mozambique, the distant central government did not have as much control as in the metropolis. Therefore, the architects in Mozambique allowed themselves to experiment with the principles of the Modern Movement with much more freedom,

Fig. 6.16 Office building on East Timor Street

adapting them to the tropical climate, similar to what had already happened in Brazil since the 1940s. The exhibition by MoMA in 1943, followed by the catalogue edition that same year under the name "Brazil Builds: Architecture New Old 1652–1942" by Philip L. Goodwin and G. E. Kidder Smith, showed modern architecture works of recent years, but also a whole historiography of Brazilian colonial architecture since 1652. In Portugal, as in the rest of the world, the showcases of the Brazilian architectural scene triggered a critical reflection among architects that questioned how to follow the international language. At the 1st Portuguese National Congress of Architecture in 1948 in Portugal, a radical message had emerged against the traditionalist political regime "Estado Novo". Following this, in the 1950s, though mainly in the 1960s and 1970s, the colonies emerged as a privileged location for architectural experimentation with a production of Portuguese architecture of great quality, mainly in Mozambique and especially in Maputo. The influence of modern Brazilian tropical architecture increased the size of windows, often using the entire façade, increasing all types of shading elements, with brise-soleils built in concrete with vertical, horizontal or grid-like blades. Buildings rose from the ground, releasing the ground floor, with services or garages on the lower floors and housing on the higher floors, being able to take advantage of cross ventilation (Fig. 6.17). The windows have a projecting concrete frame to avoid direct radiation and the floors and balconies extend beyond the façades of buildings, to shade them. Open and shadowed galleries are created to access the various spaces, especially in public buildings, such as schools. Stairwells are either opened outwards or with blades to allow vertical ventilation through the entire interior of the building. The number of available examples is so vast that their exhaustive study becomes difficult. However, some buildings from this period stand out in the city of Maputo.

Fig. 6.17 Residential building in Maputo

The headquarters of the Bank of Mozambique, the former Banco Nacional Ultramarino from 1956 to 1960, with the project managed by José Gomes Bastos and follow-up work by Marcos Miranda Guedes, is one of the most sumptuous buildings in the Portuguese colonies, not only for its architecture but also for the quantity of works of art, which includes the ceramic panel of Querubim Lapa next to the entrance on Av. 25 de Setembro (Fig. 6.18). The building is inserted in the discourse of the Modern Movement, referring to the paradigmatic building of Brazilian modernism, the Ministry of Education and Health in Rio de Janeiro by Lúcio Costa, with Affonso Reidy, Carlos Leão, Ernâni Vasconcelos, Jorge Moreira and Oscar Niemeyer, who had Le Corbusier as a consultant. In Maputo, the brise-soleils are inserted on the inside of windows, this method being more discreet than in Rio, where they are the main element of the façade, hiding the pavement slabs, in contrast to what happens at the Banco Nacional Ultramarino building, where the slabs, oriented to the north, contribute to the shading of the main façade. The TAP-Montepio building of 1960 (Fig. 6.19) by Alberto Soeiro is a corollary of the current elements of modern buildings in Maputo: an elevated ground floor with parking under the building, two service floors with façades of vertical blades and ceramic grills (cobogós), elevated floors of housing; south façade more open with galleries to access the apartments and the façade to the north more closed, with kitchens and WCs, facing away from the sun and facing the river. The east façade facing Av. Samora Machel is a huge and colourful tile panel, presenting a strong image of this building.

Not only did the private commission promote architecture of the Modern Movement in Maputo, but also public works, especially in the areas of education

Fig. 6.18 The Bank of Mozambique, former Banco Nacional Ultramarino

Fig. 6.19 TAP-Montepio building

and health, where experimentation with modern precepts had very fruitful results, are still visible today throughout the city. The block of Maputo Central Hospital has several buildings that date back to its foundation in 1900, having a series of buildings in art deco style from the 1930s that still exist. However, the building of the general hospital north of the plot, constructed in 1958 (Fig. 6.20) in a project by

Fig. 6.20 Maputo Central Hospital

Luis de Vasconcelos and Francisco Assis, is a modern building of generous size that contains several wings organised in a symmetrical, classicist and monumental base structure, implanted in order to configure four pleasant interior patios, for ventilation and shading. This building uses the lexicon of Brazilian modernism in its architectural composition (Ferreira 2008, p. 198), with elements such as access ramps in glazed volumes, blades indicating accesses and brise-soleils of various types. The current maternity wing that began as the European pavilion, designed in 1940 by Antonio Rosas in an art deco style, was expanded in 1966 (Fig. 6.21) by Fernando Mesquita to a hospital school. With the addition of two floors, the building now has continuous galleries on the first and second floors, and large blades with grid shades on the third and fourth floors. These blades that accompany the design of the art deco plant, including the cylindrical body, overshadow the north-facing façade and contribute to the strong image of this building. The current Ministry of Health, built in 1971 for the provincial health department in a project by the architect Francisco Assis, stands out for its creative design of the access tower, its natural ventilation devices and the galleries that it forms on Av. Eduardo Mondlane, in the south of the building.

In the architecture of educational buildings, Mozambique is a success story in the colonial landscape, mainly due to the actions of Fernando Mesquita and the type of projects of the schools he designed in the "Secção de Estudos e Projetos dos Serviços de Obras Públicas", starting in 1955, "receiving like no other functional program, the influence of its architectural ideas, based on the ideological principles of the Modern Movement" (Ferreira 2008, p. 170). The type model of Mesquita's schools was characterised by the north–south orientation (circulation gallery), contrary to

Fig. 6.21 Maputo Central Hospital: maternity wing

the orientation of most of the urban plans where the schools were inserted, thus occupying the centre of the wooded blocks, with a design of exterior spaces adapted to each specific case. The southern façades contain large glazing, protected by vertical protruding planes on the north side, and access to the rooms is protected by covered galleries. Environmental control is ensured by the long inclined roofs covered with fibre cement, which protect all spaces from the sun and by the continuous circulation of air inside the rooms and in the playground (Ferreira 2008, p. 171). In 1959, Fernando Mesquita would use these models in his most important school project: the Governador Joaquim Araújo Elementary Technical School (currently Red Star Secondary School). Cardoso Alves, who designed many of the projects of Fernando Mesquita in several type schools for the province, stands out as a designer from the 1970s on the development of school programmes, starting from Fernando Mesquita's appointed head of the Studies and Projects Division. Its most important project was the Dr. Azevedo e Silva Commercial School (now Maputo Commercial School) in 1972 (Fig. 6.22), on Av. 24 de Julho, characterised by a design of great functionalist simplicity, with raised stairs in the gables of the pavilions and exterior galleries on large consoles.

In the set of administrative buildings also stands the headquarters of Cambios, Statistic County and Historical Archives of Lourenço Marques (currently National Direction of Geology), with its original construction in 1939 in art deco style, which underwent profound change and enlargement in 1970 (Fig. 6.23) in a project by the architect Marcos Miranda Guedes. This enlargement was characterised by the replacement of the original cylindrical body containing the entrance and the vertical circulations by a new one, divided into two volumes: the corner volume with six floors and a bigger volume built in the centre of the set with 12 floors. This second

Fig. 6.22 Maputo Commercial School

Fig. 6.23 National Direction of Geology

volume is rectangular in shape and, from the sixth floor standing outwards, is made up of a parallelepiped in a reinforced concrete structure and glass clearly inspired by the principles of the Modern Movement, as is recognised in some of its elements, such as sculptural coverage in the terrace, the rear façade protected by brise-soleil and the free plan. On the east façade, clearly unprotected from solar radiation, the architect opted for large glazed surfaces, offset by large openings that allow cross ventilation. The western façade consists of vertical brise-soleil with reduced spacing between them for window shading. The south and north façades are mostly blind, although there is a ventilation grid that runs vertically throughout the building.

6.2 The Architecture of Pancho Guedes

For most researchers, Pancho Guedes is not only one of the most important architects of the modern tropical climate in Maputo, but he is one of the Portuguese architects that stand out internationally. According to architect Ana Milheiro, "In the colonial authors (Portuguese and international), Pancho's work remains unique" (Milheiro 2012, p. 81). According to Nuno Grande, curator of the exhibit *Os Universalistas* that celebrates the excellence of Portuguese architects of the twentieth century, Pancho is described as the most universal architect of his generation and "this singular character Amâncio Guedes, with his unique work, wrote an unpublished page in the history of Portuguese architecture" (Grande 2016, p. 15). His architecture is beyond the adaptation of the Modern Movement to the tropical climate, though it has remarkable solutions of natural cooling while absorbing the African culture and local tropical climate. While most authors at present agree that Pancho's work is highly relevant and among the most influential of the modern generation, the quality of his design solutions cover technical and efficient patterns of thermal behaviour, while reaching a higher level of complexity. The strength of his architecture relies on his ability to dissolve the borders between architecture, design and sculpture.

Biographical data
In 1953, Pancho Guedes received his degree in architecture and in 1954, travels to Europe request the validation/recognition of his diploma in Portugal. He took this opportunity to visit several European cities, which allowed him to learn about post-war architectural production before returning to Lourenço Marques. From 1955 onwards and in the years that followed Mozambique's independence, it had a vast production, mainly on the capital, drawing nearly seven hundred projects among dwellings, housing, facilities and tourism, and commercial buildings (Revista Construir 14/5/2010).

Along with the intense professional activity, he developed relations with other architects and artists that he met during his college years in Johannesburg and travelled extensively, namely, several trips to Europe. In 1961, he participated in the 6th

Bienal de São Paulo, where his work was exhibited, and took the opportunity to visit modern Brazilian architecture, namely Niemeyer's works. Following his publication in the Architectural Review of London in 1961, his work was widely published all over the world.

In 1962, he participated in the first Team 10 encounter with Christopher Alexander, Jaap Bakema, Georges Candilis, José Antonio Coderch, Christopher Dean, Giancarlo De Carlo, Ralph Erskine and Aldo van Eyck, among others. Also in 1962, he participated in the First International Congress of African Culture in Rhodesia, where he met several personalities linked to culture. It is in the 1960s that he became a prominent figure in the architecture and cultural scene and emerged, as Nuno Grande argues, the most universal among the generation of universalists.

In 1975, after the independence of Mozambique, he left the country and moved to South Africa, where he took on the position of Head of Department of Architecture at the University of the Witwatersrand. In 1988, he and his wife Dori moved to Europe and took residence in Lisbon. It is during this period that he received honours: Doctor Honoris Causa (Pretoria, Johannesburg, Lisbon) invitations; second participation in the Biennale for Architecture in Venice, 2006; and retrospective exhibitions: Swiss Architecture Museum. He died at the age of 90 years old at his daughter's home in South Africa.

In 1985, the Portuguese journal "Arquitetura Portuguesa" dedicated an entire magazine to Pancho Guedes, where his autobiography "Vitrúvus Mozambicanus" was published. Here, his architectural production is organised into 25 books, with 25 groups of works divided by styles or programmes. The publication presents the theoretical basis that supports the architectural solutions he pursued during his lifetime.

These biographical data were collected in the thesis of Miguel Santiago titled "Pancho Guedes Spatial Metamorphoses", which is a fundamental text for the understanding of the work of this author.

Shading devices in the work of Pancho Guedes

The first projects of architecture present systems for overshadowing and ventilation of the façades. From the early stages, Pancho introduced these strategies in his designs to further explore his own interpretation, turning them into singular objects with strong artistic expression. An example is the series of buildings implemented in the downtown of Lourenço Marques, which he named "temporary towers, blocks and slices of front run". The first project of this group is the Joosub building constructed in 1951, where the Tamariz Hotel operates (Fig. 6.24). Here, there are a series of devices typical in modern tropical architecture that we will often find in his works. The main façade, oriented to the south, is in line with the street Rua Consiglieri Pedroso. It has generous glazed spans that are overshadowed by vertical blades, with small spaces between them. This type of shadow prevents direct radiation on the glazing. On the west façade, the ceramic shading grids, common in modern tropical architecture, are located in front of the balconies of the rooms. The arrangement of the two volumes on top of the commercial floors, and the separation between them, reinforce the shading system of the windows. At the Mann George

Fig. 6.24 Joosub building: Tamariz Hotel

Fig. 6.25 Mann George building

building dated in the same period (Fig. 6.25), the vertical shades use marble stone plates fixed to the building structure with bronze pieces. The Octávio Lobo building, constructed in 1967 and located in the same area of the city, used a similar solution on its south façade, proving that good thermal solutions are repeated in his work. The Mann George building still has a cantilever shading blade on the ground floor of the street Rua Bagamoyo with a polychromatic geometric decoration, which

Fig. 6.26 Abreu, Santos e Rocha building

contributes to making this building one of the most relevant in the city. The Abreu, Santos e Rocha building in MacMahon Square, built in 1953 (Fig. 6.26), consists of two blocks of eight stories high, one with a north–south orientation and the other with an east–west orientation. In the Joosub building, the volume on the north side provides shade for the volume the southern façade, which holds a vertical concrete shading, while the west has a grid system that closes the circulation galleries and features a decorative panel of rolled pebbles. This building presents inventive solutions for solar protection, interior temperature control and natural light. Across Rua Consiglieri Pedroso, the 1957 Spence e Lemos building (Fig. 6.27) presents a different solution: the retreat of narrow and high gaps in the northwest and northeast façades in order to reduce direct radiation. Together, they reveal a systematic and simultaneously creative group of solutions to design shading devices.

According to Miguel Santiago, the "Dragon House" building from 1951 (Fig. 6.28) follows the precepts of the Modern Movement, but with a new grammar in the use of materials, textures and themes of the murals (Santiago 2007, p. 74). This building, the first of the group "habitable boxes and shelves for many people", presents a system of double pilotis and a wall that runs along a mural, which gives the building its name. The wall divides the public area from the private area, generating a shadowed zone where the stairs of the building begin. The building has the main façade to the east, where the living rooms and bedrooms are oriented. This elevation with the recessed spans alternates between open balconies and balconies enclosed by ceramic grids of geometric design, systems that ensure good protection from sun exposure and maintenance of temperature stability. The stairs to the apartments are ventilated with vertical blades in the same façade to promote natural ventilation. The building reached international awareness for its uniqueness, though its main features encompass a variety of efficient solutions to enhance shading

Fig. 6.27 Spence e Lemos building

Fig. 6.28 Dragon House building

devices and natural cooling. The combination of different systems and building technologies were exposed during the meetings of Team X, where Pancho's buildings were cherished and published, becoming important references to twentieth century architecture.

The building for housing dockers, dated from 1953, located near Maputo's downtown, on Av. Josina Machel (Fig. 6.29), stands out due to its large cantilever

Fig. 6.29 The building for housing dockers

Fig. 6.30 Tonelli building

flap that provides shade to the ground floor and the ventilation grills that overshadow the central staircase, made from concrete pipes of various sections and lengths. The Tonelli building, dated from 1954 (Fig. 6.30) and located on Av. Patrice Lumumba, belongs to modernist architecture. On the western façade, the few narrow openings are framed by systematic concrete frames, elements commonly used to ensure control of solar heating and thermal stability of the interior. The 1963

Fig. 6.31 Police orphans and widows building

Police orphans and widows private building (Fig. 6.31) presents a simple composition of volumes, in which the main one is a concrete box with workshops and shops on the first several floors and dwellings in the remainder. It uses two types of balconies fronting the bays: either by adding concrete volumes that frame the windows but also serve as balconies or subtraction to the main volume creates deep balconies in the living rooms of the apartments. The open staircase is overshadowed by horizontal blades. As Pancho himself puts it, the building had only basic finishes, which reduced the cost of its construction (Guedes 2009, p. 209), though the complexity of the architectural elements assembled to control heat and provide thermal comfort emerged from years of research and building practice, where he had the opportunity to test his ideas and continuously challenged his architecture to attain better results.

In the book "pieces of village, to remember other villages far away in my land", Pancho presents several sets of row houses, most from the 1950s, where influences of Portuguese vernacular architecture became tropicalised. In the 12 houses for COOP of 1954/1956, the windows feature concrete frames, some of which are inserted into perforated moulded concrete walls, which function as ventilation grilles (Fig. 6.32). In another project, the house of Judge Camara (Fig. 6.33), completely enclosed balconies with wooden mashrabiya were designed. The use of sheds, reinforced concrete pergolas or advanced volumes on the upper floors to create shaded areas on the ground floor are solutions implemented in these small single-family dwellings. Similar features can also be found in larger dwellings, such as the house of the three giraffes (Fig. 6.34), whose name is given by the three generous chimneys. Designed in 1953, it follows the principles of the Modern Movement but in an alternative way. It consists of two volumes: the living rooms on the ground floor and the bedrooms raised on stone planes, creating shady areas. The volumes

Fig. 6.32 Twelve houses for COOP

Fig. 6.33 House of Judge Camara

are crowned by gable roofs that refer to the Mozambican vernacular architecture. Local, primitive and vernacular elements are combined with the rational elements brought forward by the Modern Movement. In Pancho's architecture, low- and high-tech solutions are combined to produce a unique vision of the twentieth century architectural culture.

Fig. 6.34 House of the three giraffes

Fig. 6.35 The red house

The red house of 1966 (Fig. 6.35) uses a precise mesh in the design of the plant, in which the walls are thickened in an expressive way to allow the windows to be receded in relation to the façade. On the exterior surface are the wooden shutters that give character to the image of this house, widely diffused by the strategy of protection to solar irradiation. From the same period, a group of houses that Pancho

Fig. 6.36 The pyramidal nursery

named "family of Euclidean palaces" is located in the neighbourhood of Sommerschield, in the north area of Maputo. Like the previous example, they are drawn on a precise geometric mesh, but make use of great spatial complexity. They have a clear volumetric definition, though the structure loosens from the volume of the house fragmenting the façades, usually from the side view, offering outdoor areas that are sometimes shadowed by architectural elements. The windows include gaps for natural ventilation, revealing the great technical advancement of carpentry for that time, which were carefully designed (Guedes 2009, p. 225).

The pyramidal nursery (Fig. 6.36) belongs to the group of works called the "American-Egyptian style", influenced by the American architect Louis Khan. The Khovolar Residence at the Swiss Mission designed in 1966 (Fig. 6.37) bears similarities to the Police orphans and widows private building, both of which implemented Beta opening systems to increase natural ventilation.

In his final thesis of architectural school, Pancho presented a project inspired by the geometric variations of Frank Lloyd Wright. During his years at architectural school, he developed projects inspired by Le Corbusier and became interested in architects as diverse as Mies, Aalto and Goff, all of whom helped him to develop the exploration of his own architecture of 25 styles. Stiloguedes is one of those styles that he referred to with greater intensity and that he pursued over the years. From his participation in the meetings of Team X in 1962, a visit to Maputo was organised, among which were Alison and Peter Smithson, who went to Mozambique to visit his recent works, namely the Stiloguedes.

Stiloguedes

The first book of Pancho Guedes' autobiography is the Stiloguedes, which contains the works from 1951 to 1958 that the architect considered more emblematic and

Fig. 6.37 The Khovolar Residence at the Swiss Mission

representative. These projects show their way of interpreting the Modern Movement, to which the author adds unique figurative elements that make their buildings expressive and unique. For the most part, it has fairly rational plants and integrates principles of the Modern Movement. This family has several types of buildings, including single-family dwellings, collective housing, schools and industrial buildings, so it does not follow a typology or specific programme. The first project of this group is the Leite Martins house (Figs. 6.38 and 6.39), "the plane house", modern "with something of a case study house" (Magri and Tavares 2011, p. 26). What characterises this house are the soft curvature covers coated with a waterproofing mortar of lime and white stone (Magri and Tavares 2011, p. 28). The raised bedrooms volume creates a living area covered by the same area of the room but without walls, a space that, along with the inner courtyard, denotes the tropicalisation of the architecture of the Modern Movement.

The Prometheus building (Figs. 6.40 and 6.41) is one of the works of this family. Contemporary construction of the Unité d'habitation in Marseille by Le Corbusier shares with this the clarity in the structure and the use of the brise-soleil. However, it has distinct characteristics: the seven structural elements function as "trees" constituted by pillars and beams with large consoles that cross the façade of the building. In addition to the structure, the building is made up of "a specific number of different and precise concrete parts" that were assembled "by carefully fulfilling the instruction book" (Magri and Tavares 2011, p. 31). The final effect is a volume that illustrates how it was constructed by coupling, allowing a lightness effect reinforced by the spacing between parts, filled with empty and full volumes, with balconies and windows connected, which, by the chromatic differences between the structure and the other elements, make their constructive method known. According

Fig. 6.38 The plane house

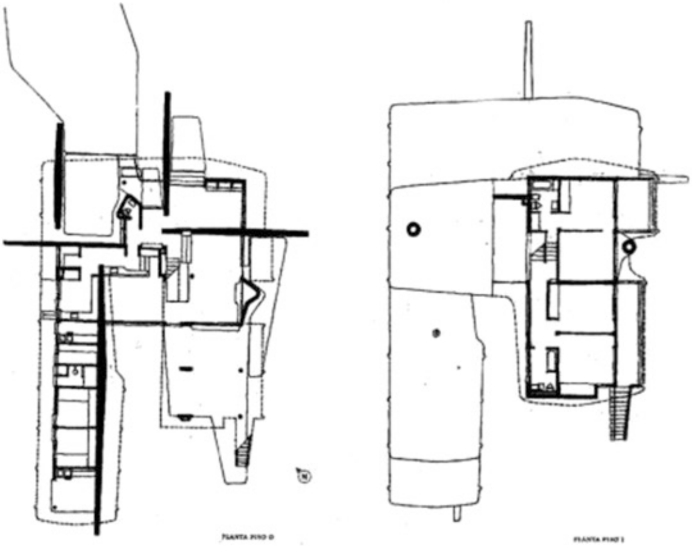

Fig. 6.39 The plane house: plans

to Pancho on the Stiloguedes: "it is a bizarre and fantastic family of buildings with beaks and teeth, with beams ripping the spaces around, invented as if some of the walls were about to separate" (Guedes 2009, p. 79). The loose elements promote greater cross ventilation of the interior of the volume, the large console balconies

Fig. 6.40 The Prometheus building

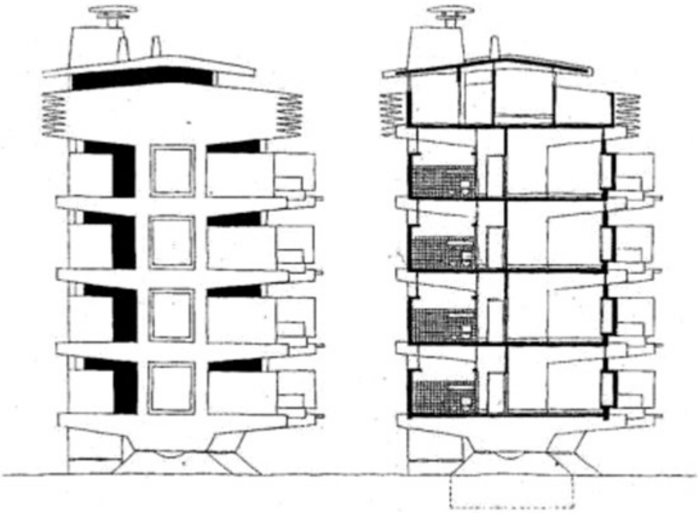

Fig. 6.41 The Prometheus building: elevation and section

give shade and the small openings allow interior ventilation, mainly in the lower phases of the slabs, and enable the exploration of constructive elements in the architecture of this building, to jointly adapt to local weather conditions.

The house Matos Ribeiro built in 1952/1953 (Fig. 6.42) applied some of the elements used in the Prometheus building, like the balconies supported by cantilever

Fig. 6.42 House Matos Ribeiro

beams and the double windows with ventilation next to the ceilings. The main spaces of the houses are oriented to the southeast, to guarantee a reduced exposure to solar radiation. The use of a patio allows the main bedroom to be oriented to the interior, protecting it from the low radiation of spring. This interior patio, the ground floor and the verticality of the volumes that make up the houses contribute to thermal cooling of the whole building.

The Otto Barbosa Garage constructed in 1952 (Fig. 6.43) stands out mainly for the biomorphism of its design, with its enormous teeth of vertical shading that protect the windows from the blunt light from the west, the only one that reaches the façade due to its orientation. The building is described by Pancho as having teeth: "It is a deep, square mouth with angular brise-soleils that crunch space immediately ahead" (Guedes 2009, p. 90). The oversized teeth and claws used in several buildings ensured improvement in the control of temperature variations inside the buildings and, consequently, the feeling of thermal comfort.

The building named the "Smiling Lion" of 1956/1958 (Figs. 6.44 and 6.45), probably his most emblematic work, presents a summary of the aspects previously described and that were tried in other works, used here with greater freedom and expressiveness, due to the fact that the client is also the architect. The structure follows the same principle of the structure of the Prometheus building, an element composed of pillars and beams that repeats according to a module supported in two points and that resolves all the sustentation of the building, raising it out of the ground. On the top façades to the north and south, the structural element is replaced by a concrete wall with a suggestive configuration, inspired by the children's drawings of his son Peter. It is the concrete walls that suggest the name of the building and protect the building from sun exposure to the north and south. The building

Fig. 6.43 Otto Barbosa Garage

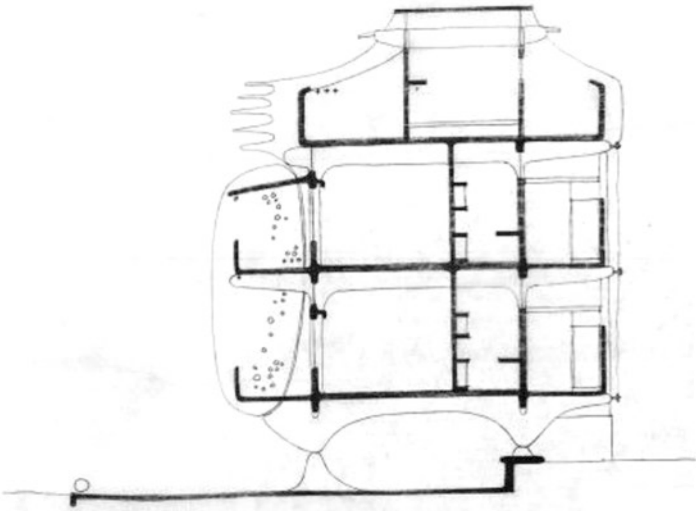

Fig. 6.44 Smiling Lion: section

opens to the east and west, protecting the interior with vertical blades of shade that delimit the balconies in the façade. They are attached to the structure but are presented as independent elements that seem suspended, an effect reinforced by the chromatic difference and the joint that separates them from the structure. The balconies supported by the balanced beams are surrounded by blades and horizontal

Fig. 6.45 Smiling Lion

shading on the second floor, creating cool outdoor seating areas. The vertical blades also serve to reduce direct radiation in the windows and balconies. The galleries open to the west, already tested in the Tonelli building, solving, with the boxes of stairs in the two tops, the whole circulation system. These galleries also prevent the penetration of direct radiation in the few windows, from the kitchens and bathrooms, existing in this façade. All the windows in the east have a separate flag, which allows the entrance of light even with the rest hidden, as was already happening in the Prometheus building and in the house Matos Ribeiro. The coverage of corrugated domes is similar to the projects of the Tabosa Vaz building and Barclays Bank, but, in both cases, it was never built. The vaults appear at the top of the service floor, in conjunction with the two huge parapets/murals that mark the building's east and west façades.

It is in the sections, rather than in the plans, that we understand the whole functioning of the building. "The plans in the Stiloguedes buildings are simple, very direct and functional. It is the sections that are decorated, contorted and full of exaggerations. These are their reflections on the façades that make them architecture" (Guedes 2009, p. 79). The volume of the building raised in relation to the ground allows its natural ventilation predominantly from the east. The garden at the rear of the building guarantees the constancy of this ventilation. The galleries open to the west, cool in the morning, force cross ventilation in the building and refresh it during the part of the day when the radiation reaches the east openings. During the rest of the day, this façade is shadowed. The façade to the west, due to being the hottest, is retracted, being completely overshadowed by the galleries and stairwells. The large panels obscure the terraces on the roof floor, making this space cool. The roof vaults, built from of thin slabs of concrete and aerodynamic in shape, are ventilated on both sides. The living spaces of this floor have openings only near the roof, which causes them to be ventilated, forcing hot air to rise and be expelled outwards. The constructive elements of expressive character and that cause great visual impact are, in its genesis, the efficient application of architectural components that guarantee thermal optimisation without unnecessary energy expenses. The use of accumulated knowledge through the observation and implementation of solutions already tested in previous buildings allowed for a practical combination of the elements used in this internationally celebrated project.

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Chapter 7
Software Tools

Gonçalo Araújo

Nowadays, there are several simulation software for building performance analysis. Whether for energetic or structural analysis, these programs work as a powerful development and support tool for the design, concept, and execution of a project.

With these tools one can determine indoor comfort levels and building energy consumptions, supporting test, and development solutions for better shading, building orientation, glazing areas, and ventilation.

This provides a more conscious and passive design, which is crucial for sustainable projects that look toward comfort and energy such as areas with extreme climate conditions, third world countries with low GDP that are not able to facilitate construction technologies, or even large-scale temporary housing for catastrophe victims.

Furthermore, besides helping with design solutions that should nonetheless include the bioclimatic strategies described in this book, it might be helpful determining construction and planning laws for the country, regarding energy consumption, height of the buildings, construction materials, and any other factor that might influence the urban framework of the country.

Among the several programs available like EnergyPlus, DOE, Ladybug and Honeybee plug-in or the discontinued Ecotect (currently a built-in feature in Revit), the program chosen for this user's manual was Ladybug, Honeybee, and Butterfly add-on for Grasshopper. This choice was made because of the wide amplitude and versatility that this plug-in offers to 3D modelling files, due to its compatibility with both Autodesk Dynamo and Grasshopper for Rhino, as well as the ability of offering a continuous analysis alongside the development of the project. Consequently, this will grant the designer a safe project development that meets requirements from concept to execution phase.

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All these values, combined with the graphic and appealing interface, allow low-experienced users to find robust project solutions. Finally, Ladybug and Honeybee plug-in performs the connection between these programs directly to the Rhino and Grasshopper display, turning the usage of complex engineering software such as these, easier to use and visualize.

First, the weather data file from EnergyPlus website will be introduced, and then a small case study of a three-bedroom house model in Dakar, Senegal, will be analyzed. Subsequently, a sequence of environmental analysis will be shown and explained, which translate an end to end process of energy and comfort optimization. These simulations should be indicative of the potential of the program and the importance of a conscious passive design process. However, it will not be shown as a step-by-step process of the software usage. It will be described instead the knowledge required to use such programs, broadening the sense of the user to the process and good practices on passive design and not only within the scope of the software shown.

7.1 Climatic Context

As observed (Figs. 7.1 and 7.2), the Universal Thermal Climate Index reveals a higher real feel temperature than the dry bulb temperature recorded. From May to October, temperatures generally range 27–33 °C, with maximum temperatures hitting 36 and 38°. This data suggests some preoccupancy the designer must have to provide a sustainable and comfortable solution for its users.

Furthermore, the humidity values (Fig. 7.3) translate a stable value of relative humidity over the year and show not only values going up during the night but also a higher average of humidity percentage during the summer, around 60%, with large periods reaching even higher up to 100% air saturation, which becomes a problem

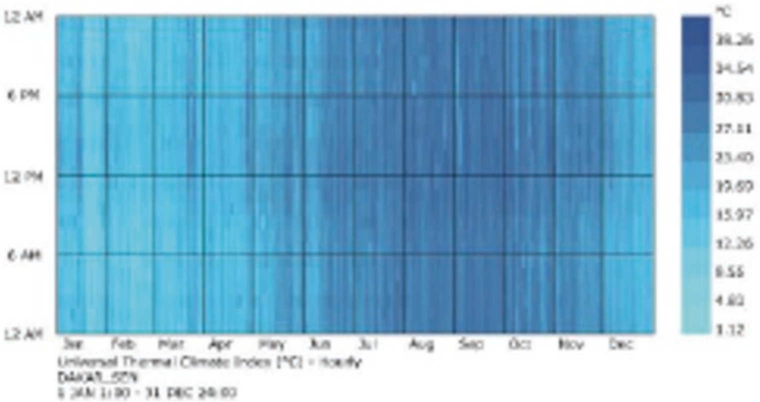

Fig. 7.1 Annual Universal Thermal Climate Index

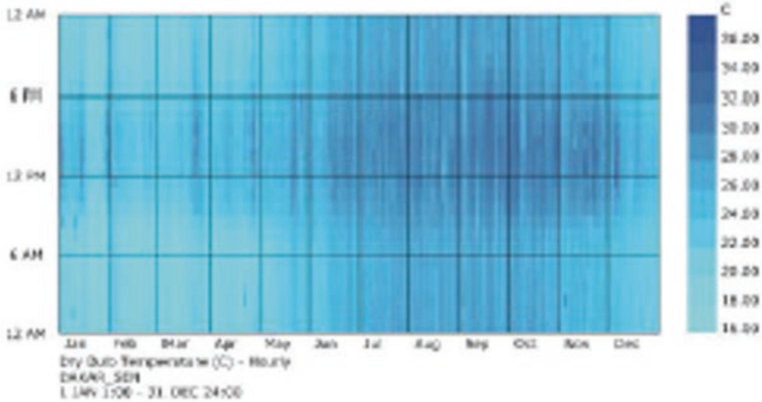

Fig. 7.2 Annual dry bulb temperature

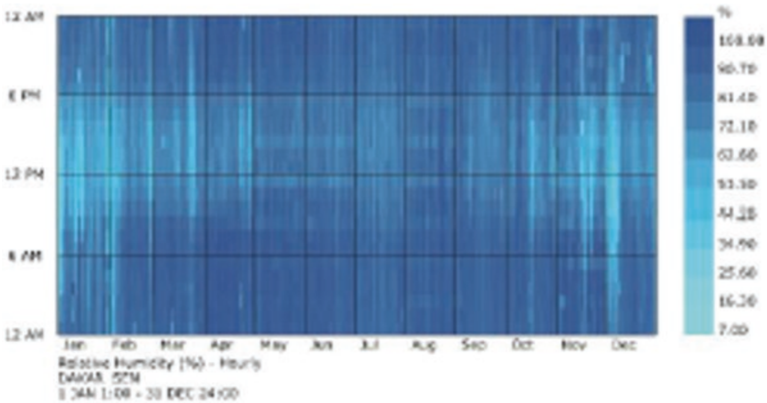

Fig. 7.3 Annual humidity percentage

when comfort areas of humidity for humans tend to be from 30% to 50%. When compared to the winter records, a distinct lower percentage value can be seen, from 7% to 34% during some hours of the day but maintaining high levels of air saturation during most parts of the morning and night. Consequently, it is already possible to limit the analysis period and study the impact of passive design strategies during the period from May to October.

Another climate disadvantage observed is the relative wind speed during the year offering difficulties for passive and direct ventilation solutions (Fig. 7.4). Nonetheless, it is observed a constant presence of winds coming from the north to northwest with temperatures inferior to 25° for 50% of the time of the analysis period, as well as calm moments with no wind only for 10% of the time (Figs. 7.5 and 7.6). This is relevant especially for summer time when direct ventilation must be a passive solution to improve and deal with indoor comfort.

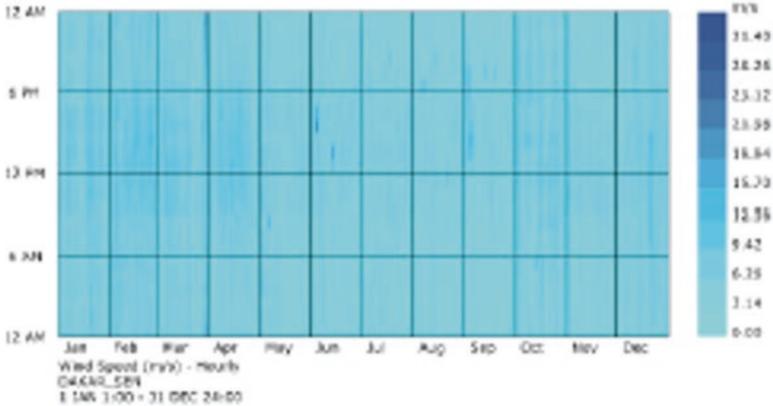

Fig. 7.4 Annual wind speed

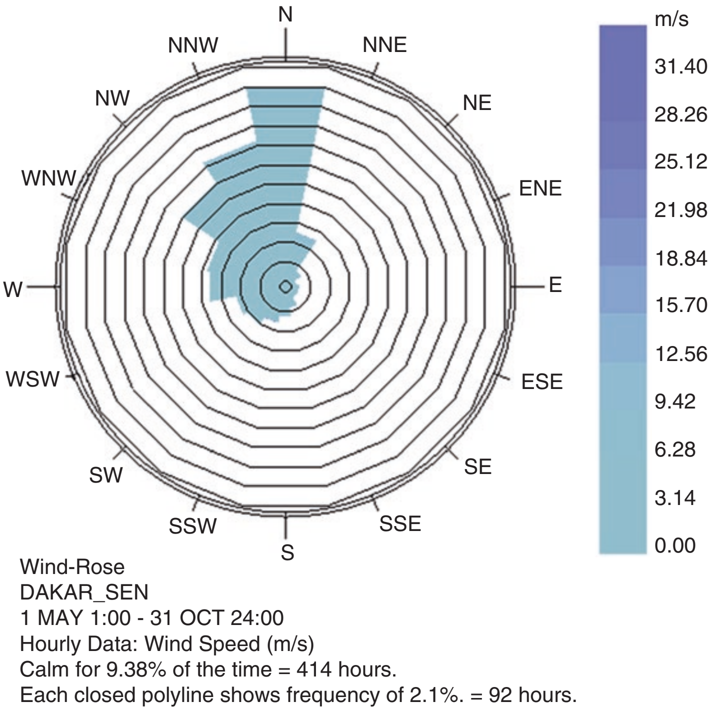

Fig. 7.5 Hourly wind (From May to October)

Finally, some conclusions can also be drawn from the stereographic diagram observed (Fig. 7.7). The direct normal radiation has higher incidence from the southeast to the southwest, suggesting south facades to be controlled regarding exposure and glazing areas, as well as dimensions and roofing angles. While on the west and east sides, very low values for radiation are recorded. Higher levels of radiation are observed near the solstice periods.

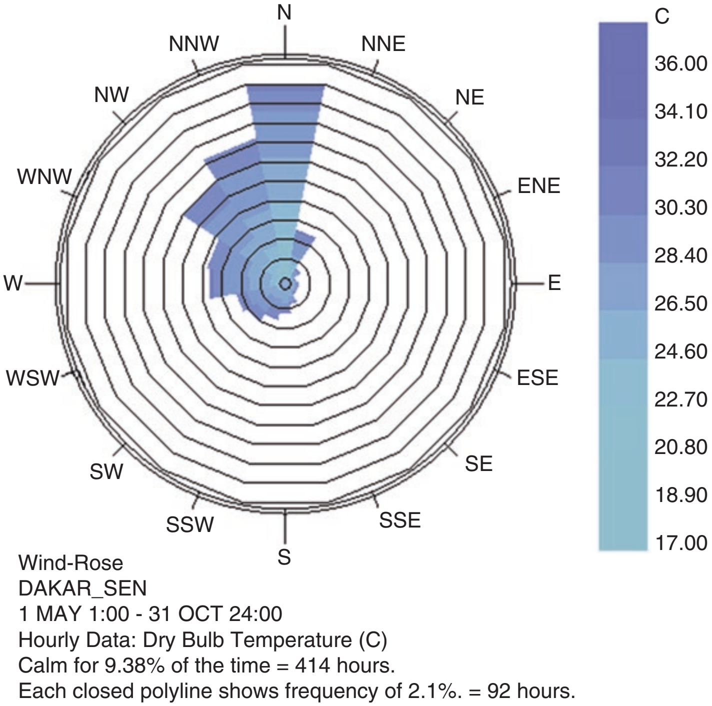

Fig. 7.6 Hourly wind temperature (From May to October)

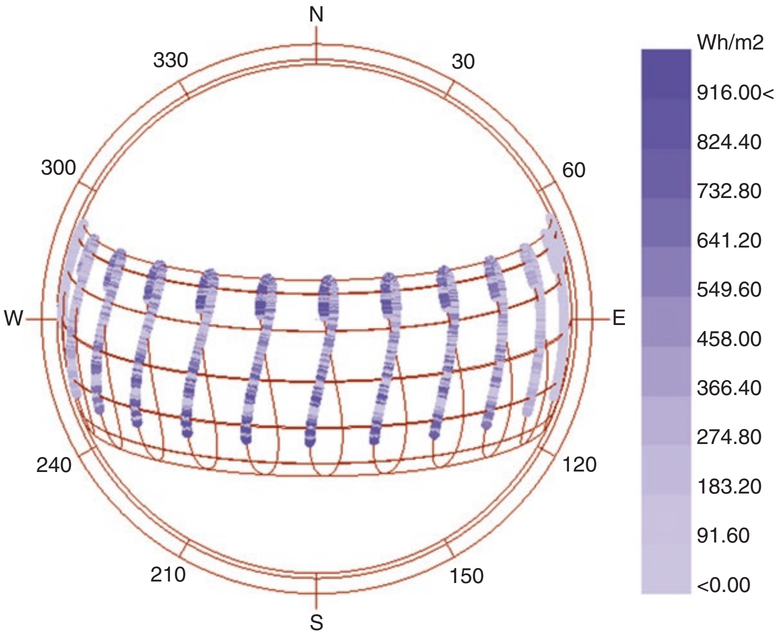

Fig. 7.7 Stereographic diagram for Dakar, Senegal, with direct normal radiation mapped hourly (From May to October)

7.2 Bioclimatic Performance of a Three-Bedroom House Model

In this section are presented the first results of the current case study and the impact of passive strategies for the conception of pilot bioclimatic and sustainable housing for rural and remote environments.

The aim of the strategy and project is to build with local materials, low environmental impact, reduced cost, and complexity of construction to be possible for the population to replicate, spread, divulge, and adapt to other areas and functions.

Some of the main criteria considered for the concept and design of the proposal were the relation with the surroundings, population, and climate. The goal was to develop a functional, pedagogic, and enhancer tool, able to change construction paradigms sustained by locally accessible materials. Therefore, it is of utmost importance to be able to convey a list of recommendations toward the region-specific conditions.

Additionally, local workers and local materials play a major role in the constructive process that adapts rural and ancient construction methods with the necessary contemporary changes for the local community to live comfortably, with the expectation of dissemination and perpetuation of these knowledges not only in construction but also preserving and maintaining with total autonomy.

Aware of the recent construction technologies, it is normal to get an image associated with poverty and precarity by the local populations when it comes to adobe and wood construction. This reveals a preference for concrete and ceramic bricks. Even though it might get better results, the cost of these new methodologies when faced with results obtained is revealed to be less ergonomic and efficient, thus, reinforcing the challenge of de-mystifying these construction materials.

The proposed challenge is to evaluate and test the thermal and luminous performance of the building in Dakar.

To obtain solar radiation, illumination and natural ventilation results for the proposed model were used the Ladybug, Honeybee, and Butterfly plug-ins for Grasshopper, which are available also for Dynamo in Autodesk. These perform a simplification and a direct connection to more engineering-focused simulation programs such as Radiance, EnergyPlus, Daysim, OpenStudio, OpenFOAM, and much more. These tools allow a quantification and qualification of the studied conceptual models, directing us to a mediation and adjustment of preliminary results obtained with these programs. Moreover, the ability of processing these tools with programs such as Grasshopper is that it also allows to parametrize the 3D model and enhance it using existent optimization models such as the genetic algorithm, unifying the whole design process through the parameters used to model the building.

In this case the main building is not parametrized except the different versions of the project like glazing and shading where it is easily switched between designs and allows a faster workflow of analysis and enhancement.

For pragmatical reasons such as divergence of contents and heavy hardware processing, grasshopper coding and optimization algorithms will not be part of the descriptions and demonstrations. However, a specific description of the workflow and decision-making processes will be shown and explained.

Finally, it's important to mention that there are much more functions and components available in the plug-in that can perform much more analysis and simulation combinations which invite the user to explore and experiment with his models and imagination.

Form, Orientation, Function and Program|Illuminance, and Radiation and Ventilation Analysis and Strategies

The solution adopted for the design of the house was a simple three-module house with a living room, kitchen, and bathroom on the west volume, connected to the bedrooms and another bathroom on the east block (Fig. 7.8). The second floor may be accessible for storage areas, and its function is to increase the air cubing available as well as allowing a better ventilation.

For the interior and exterior walls, it was considered a material with a strong thermal inertia such as adobe bricks, to reduce heat conductivity from outdoors. Finally, for the roof, it was chosen galvanized steel.

The building develops from south to north with the south facades being the least exposed. The glazing was added based on a percentage of the façade area correspondent for each zone. Since the winds come mostly from the north, it was decided to have a large percentage of area of glazing following that quadrant for natural ventilation purposes: a medium on the east and west, a small percentage in the south façade, and an air wall on the gable roof facing these winds (Figs. 7.9 and 7.10).

A first version was developed with *one window* (Fig. 7.11) for each division exterior façade, following the percentages of area of glazing assigned (35% total area north, 25% east and west, and 10% to the south). Thus, the simulations were run, and looking at the illuminance study results for V1 (Fig. 7.12), it's observable

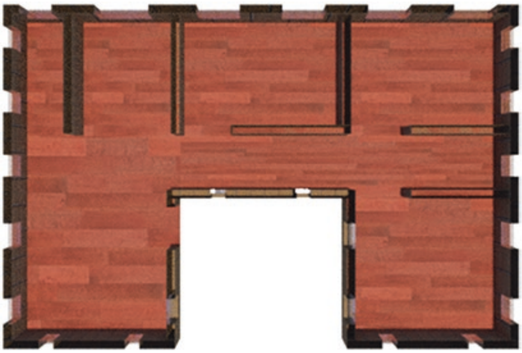

Fig. 7.8 Program plan

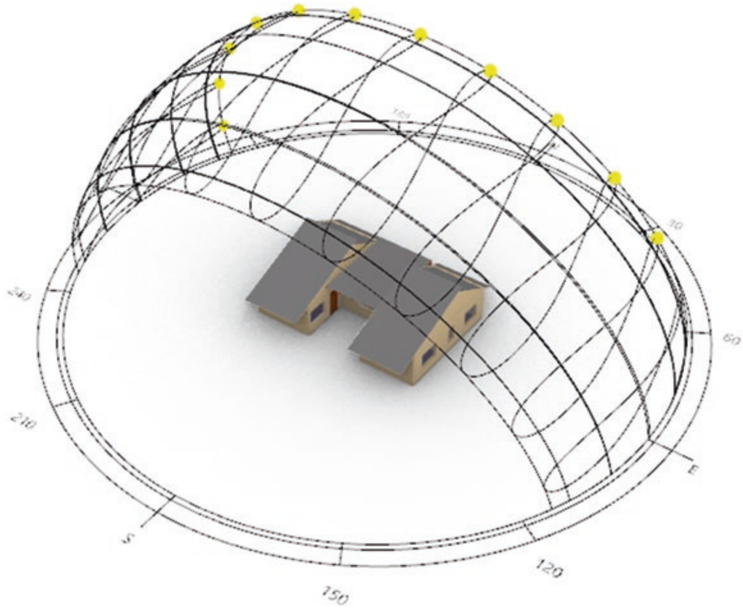

Fig. 7.9 Sun path for the month of June V1

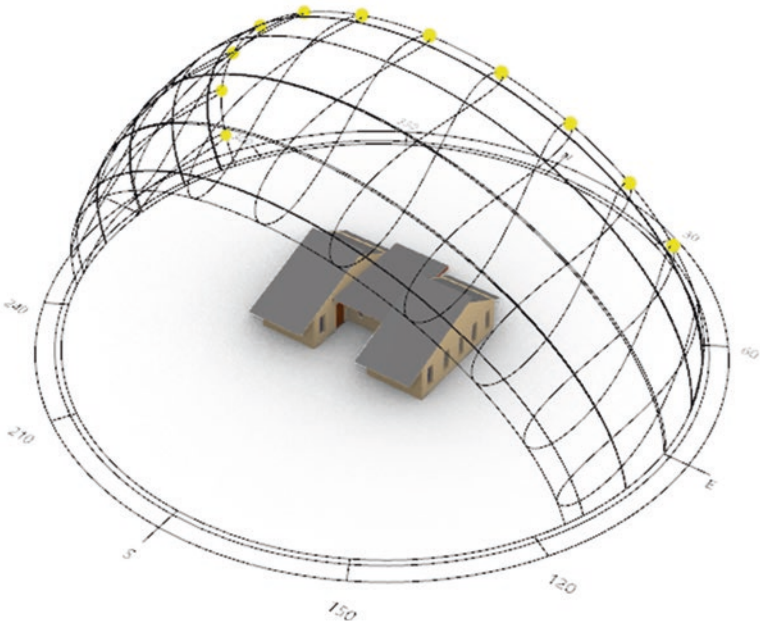

Fig. 7.10 Sun path for the month of June V2

Fig. 7.11 South façade perspective V1. 12:00 h Summer solstice

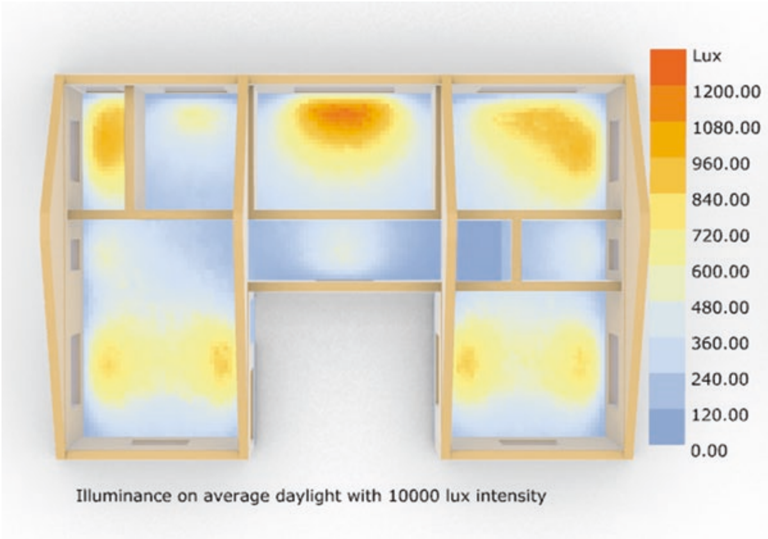

Fig. 7.12 Cumulative illuminance study on average daylight V1

Fig. 7.13 South façade perspective V2. 12:00 h Summer solstice

a large focus coming from the single glazing areas which might cause visual discomfort and excessive radiation accumulation in certain areas of the house.

Moreover, it shows a high level of sunlight exposure on the north façade during the winter period. Consequently, from these preliminary results, a second version V2 was designed with a higher number of windows, equidistant but with the same glazing area as V1 and a porch covering the north façade to prevent excessive sunlight and radiation to penetrate the rooms from the north (Fig. 7.13).

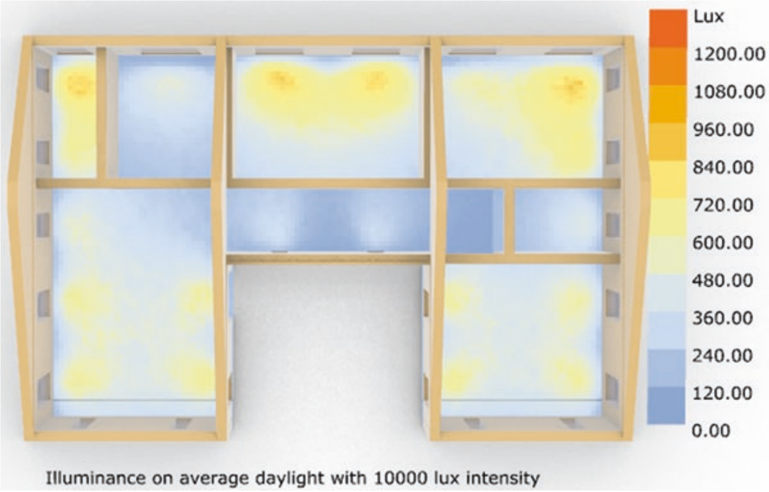

Fig. 7.14 Cumulative Illuminance study on average daylight V2

Fig. 7.15 Sunlight hours analysis. North facade during summer solstice. V1 (right) and V2 (left). Performance analysis: Dynamic simulation with EnergyPlus, Radiance, Daysim, and OpenFOAM in Grasshopper and Rhino

Naturally it is visible in the V2 model less illuminance intensity on previous orange areas and a better distribution of the light, with less average intensity and better distribution (Fig. 7.14). This ensures better results for the daylight performance of V2 with less incident radiation on surfaces ultimately enhancing the visual and, eventually, the thermal comfort of the users.

Following the workflow, from the annual sunlight hours analysis and comparison, it can be confirmed the impact of the changes made in the design. Specifically, it is visible an improvement on the middle northern room (Fig. 7.15) that gets much less exposure with the extension of the roof. Additionally, by looking at the radiation analysis in V2 south façade during the winter and summer solstice, it's observable a good distribution of incident radiation during the whole year, from end to end (Figs. 7.16 and 7.17).

By looking at the comfort simulations, it is possible to observe already some interesting facts related to the performance of the house when compared to the exterior environment. Additionally, the graph that compares the annual interior operative temperature in the southern room, with the exterior, shows a more continuous and stable development of the indoor temperatures that reach their peak

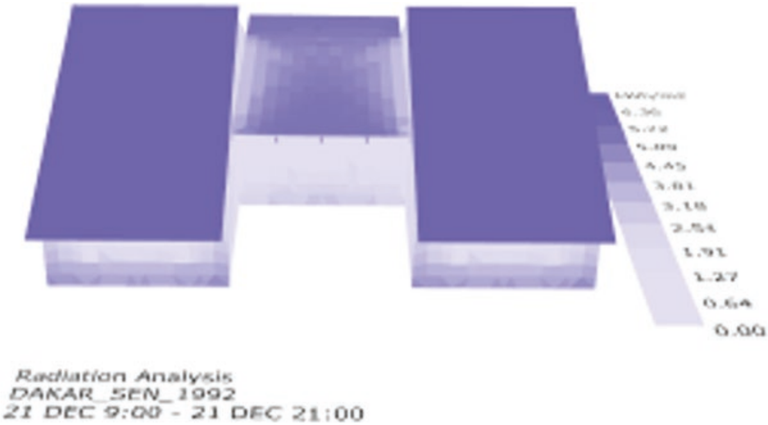

Fig. 7.16 Cumulative radiation V2 – 21 December. Performance analysis: Dynamic simulation with EnergyPlus, Radiance, Daysim, and OpenFOAM in Grasshopper and Rhino

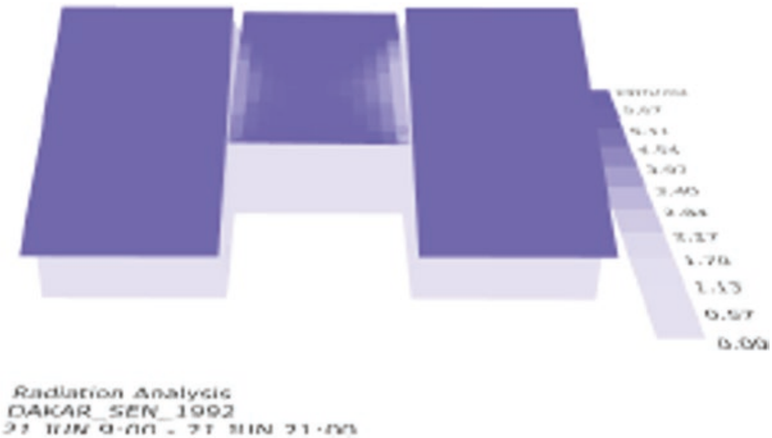

Fig. 7.17 Cumulative radiation V2 – 21 June. Performance analysis: Dynamic simulation with EnergyPlus, Radiance, Daysim, and OpenFOAM in Grasshopper and Rhino

around noon, decreasing relatively during mornings and night (Fig. 7.18). Again, by looking at the indoor operative temperature, it was registered a maximum of 34, translating a decrease of 4° from the maximum temperature outside previously observed (Fig. 7.19).

While it was already verified a significant improvement in indoor temperatures, it is by analyzing the natural ventilation graphs that one can really understand the impact of the passive design strategies, mostly from natural ventilation and shading, that represent easy strategies to adapt a project to its environment and reduce overall consumption.

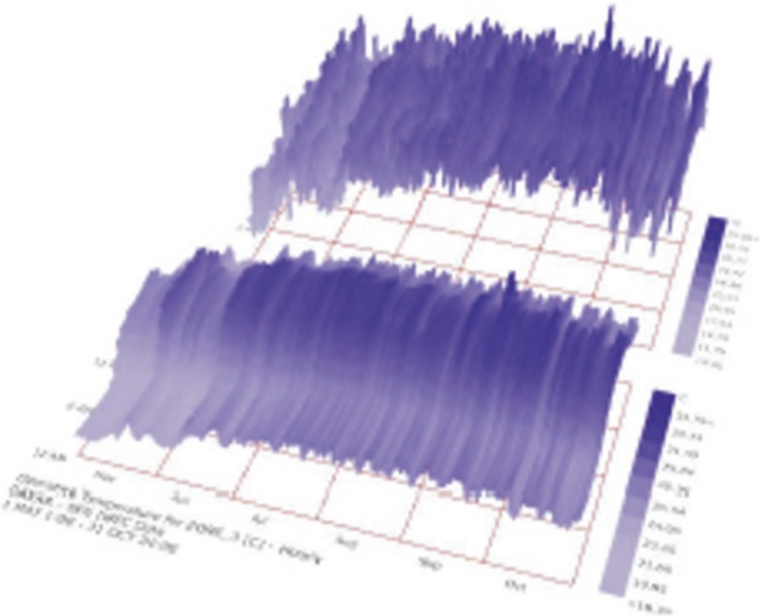

Fig. 7.18 Southeast room operative indoor temperature (bottom) and exterior UTCI or "real feel." Annual hourly date

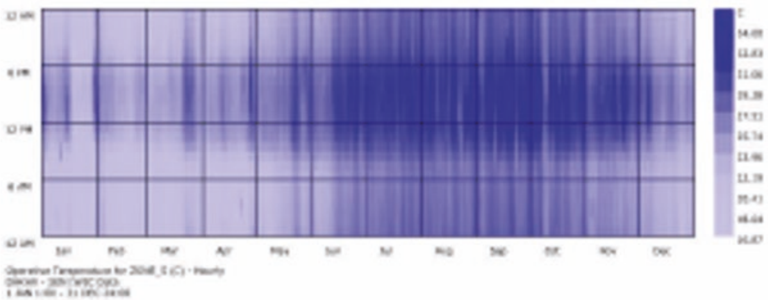

Fig. 7.19 Operative temperature for the northeast room. Annual hourly data

By looking at the monthly heat gains and losses, from natural ventilation (Fig. 7.20), it is visible in May the highest heat loss (around negative 234 kWh) and in October the smallest (around negative 134 kWh). When comparing this graph with the total monthly solar gain (Fig. 7.21), it is visible an inverse proportionality between the months where most solar gains are harnessed and the months where the biggest heat losses occur due to natural ventilation. This implies a resulting balance of heat losses during most months, instead of gains, which indicates good ventilation performances. The same is visible for the annual hourly data regarding total gains and natural ventilation balance (Figs. 7.22 and 7.23).

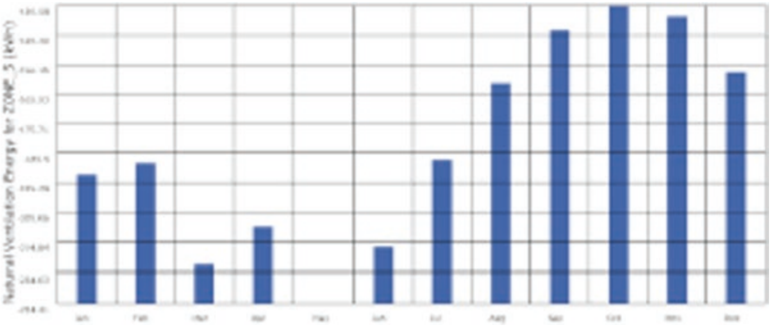

Fig. 7.20 Monthly natural ventilation heat balance for the northeast room

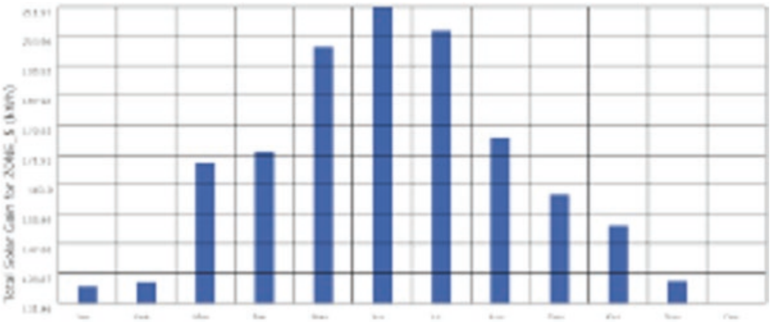

Fig. 7.21 Monthly total solar gains for the northeast room

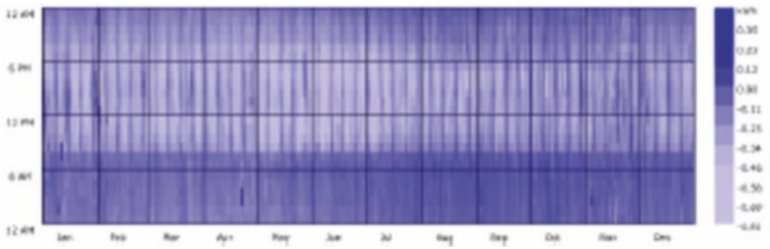

Fig. 7.22 Natural ventilation heat balance for the northeast room. Annual hourly data

It is also important to notice the darker shades of blue in the annual hourly solar gain graph from March to July in the northeast room (Fig. 7.23) that relate to the northern façade controlled exposure during certain periods of this time as seen above. Furthermore, if we analyze and compare the monthly solar gains and natural ventilation in the living room (Fig. 7.24), with the graphs above, it is discernible different peaks of total solar gains mainly during the period from October to March, with the lowest values recorded during the summer from June to September. The reason this happens is mainly due to the sun path during the winter solstice that

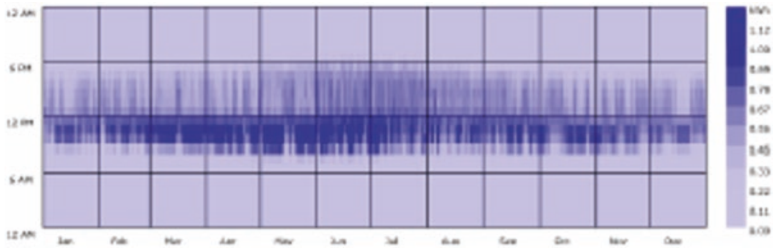

Fig. 7.23 Total solar gains for the northeast room. Annual hourly data

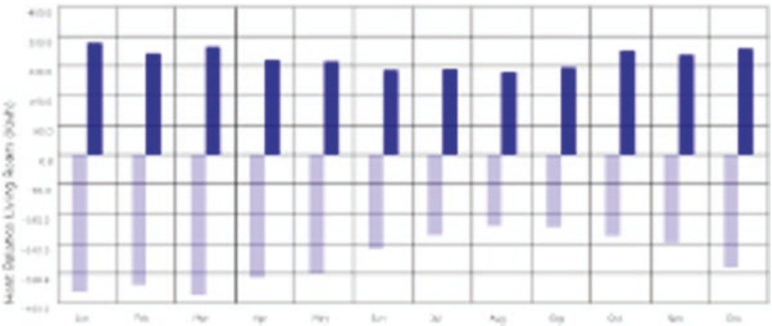

Fig. 7.24 Monthly heat balance in living room – solar heat gains and natural ventilation

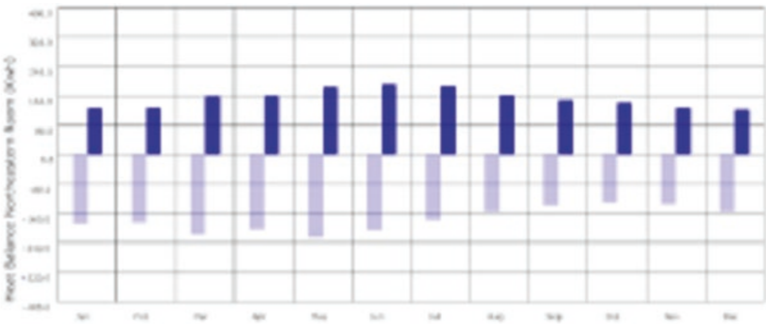

Fig. 7.25 Monthly heat balance in northeastern room – solar heat gains and natural ventilation

creates a wider angle facing the south façade, increasing the amount of heat gains during this period in the southernmost areas.

The disposition and design of the house, as well as the shading strategies applied in the south and north facades after V2, are visible when correlating the heat balance graphs for both southwestern living room and the northeastern bedroom.

The solstice sun paths observed previously are coherent with the results observed, showing the living room with more heat gains and losses during winter and the room during summer (Figs. 7.24 and 7.25). Nonetheless, it is also observ-

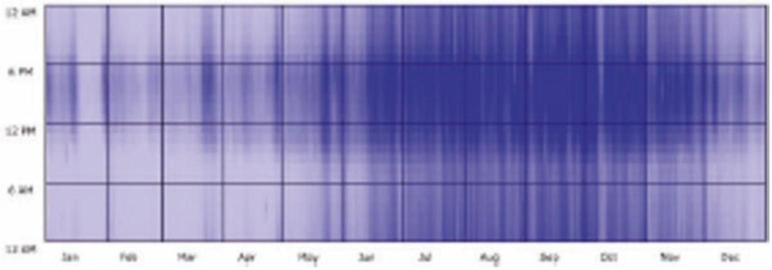

Fig. 7.26 Annual hourly data – PMV living room

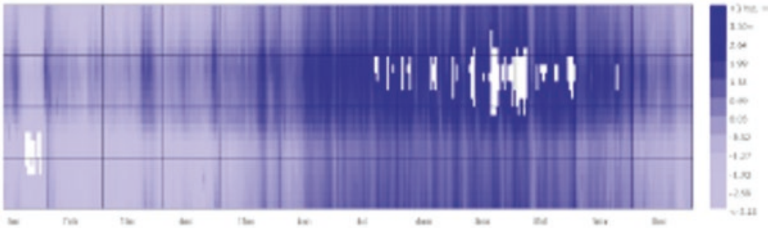

Fig. 7.27 Annual hourly data with conditional parameters – 2 < PMV < 2

able an *overall* lesser amount of gains and losses in the northeastern room, confirming statements and decisions made through observation of the stereographic diagram (Fig. 7.3).

For the comfort diagrams and the Fanger predicted mean vote calculation and simulation, it was adopted a clothing level of 0.5 (t-shirt and shorts).

By observing the graph for the annual hourly data of the PMV in the living room (Fig. 7.26), it is observable that, yearlong, the periods where people are discomfortable (cold or hot) are minimum. Furthermore, in Fig. 7.27, it was applied a filter excluding all the hours in the mesh that would not fit the parameters of comfort, which were the hours where the values were bigger than 2 and smaller then −2.

According to the scale, these conditions try to quantify the comfort point where one starts being cold or hot, assuming a certain clothing level.

Mostly, the periods where people might feel hot from noon to 7:00 p.m. are arguably from mid-September to beginning of October.

All these comfort results emphasize the impact of passive design strategies, using local materials with high thermal inertia in non-conditioned environments.

To close the building performance simulations, it is necessary to verify if the air flow within is correct and functioning normally. The goal would be to verify if there are any over ventilated areas and others with low air circulation.

By looking at the images that illustrate the air flow and pressure in V2 (Figs. 7.28 and 7.29), it is verifiable the correct functioning of the ventilation system regarding northern winds and air distribution in the house.

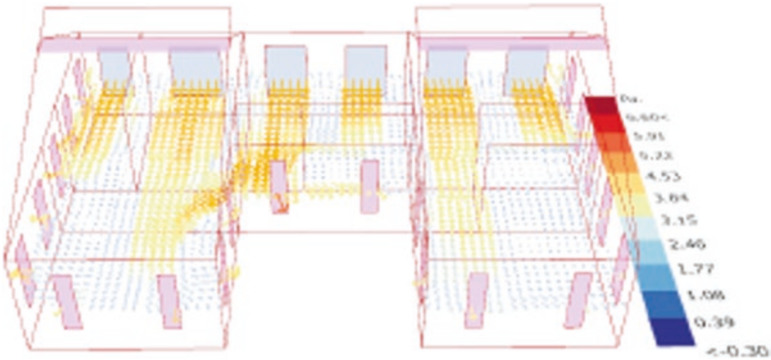

Fig. 7.28 South perspective view air flow and pressure – V2

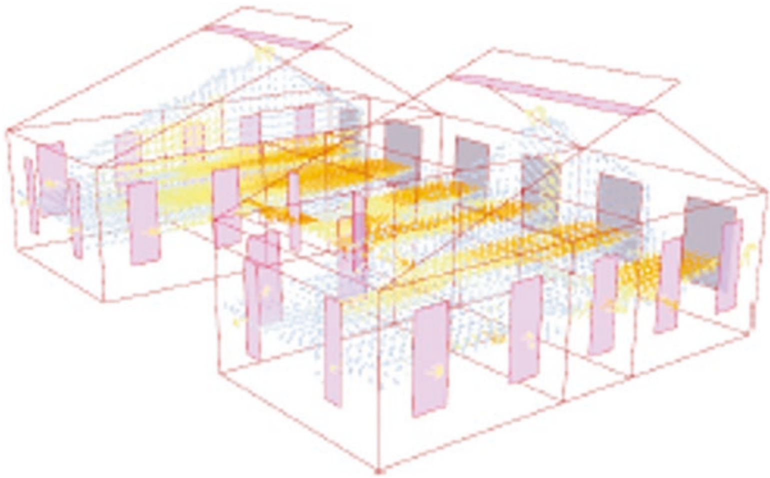

Fig. 7.29 Southeast perspective view air flow and pressure – V2

However, it is also noticed a higher pressure and flow of air in the southwestern room vertically and horizontally. This is mainly due to the absence of walls between the kitchen and living room, opposite to the western volume where the rooms are divided. Additionally, the position of the door in the middle northern bedroom, which is designed in the left side, induces an uneven airflow for both sides. Consequently, a minor change was applied as visible (Figs. 7.30 and 7.31), where the door of the room was centered.

To finalize, it is important to observe, pending parameters and conditions, the adaptive chart model.

This model was designed in response to the shortcomings of the PMV model that became apparent after the application to naturally ventilated buildings. Consequently, the adaptive comfort model was created over hundreds of field studies where people in naturally ventilated buildings were asked how comfortable they were. Users showed a capability of adapting themselves to the monthly mean

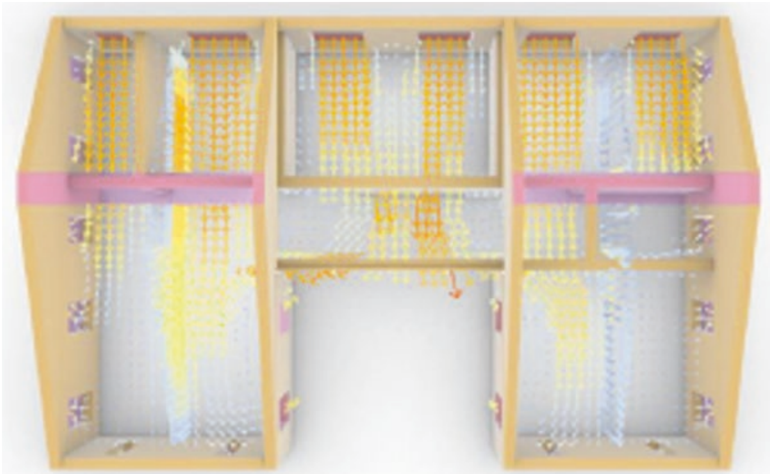

Fig. 7.30 Perspective plan – air flow and pressure – V3

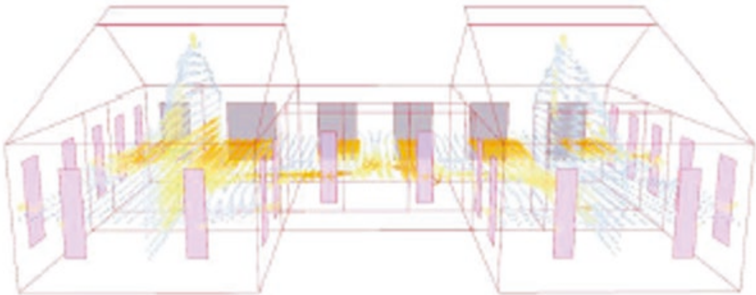

Fig. 7.31 South perspective view –air flow and pressure – V3

temperature and would be comfortable in buildings if the indoor temperature remained averagely similar.

By looking at the charts for the ASHRAE standard 55-2013 (Fig. 7.32), it is visible that both the southeastern living room and the northeastern bedroom have most of their annual hours compliant with the admissible comfort levels with better results for prevailing outdoor high temperatures between the 26 and 28°. These results translate the clothing level chosen for the adaptive model of 0.5, since for cold temperatures, clothing level can be adapted and, therefore, correct the number of hours slightly below the comfort model visible in the graphs.

Furthermore, it is also recorded more hours of compliance within the standards in the northeastern room, where there are less hours above the adaptive model predicted.

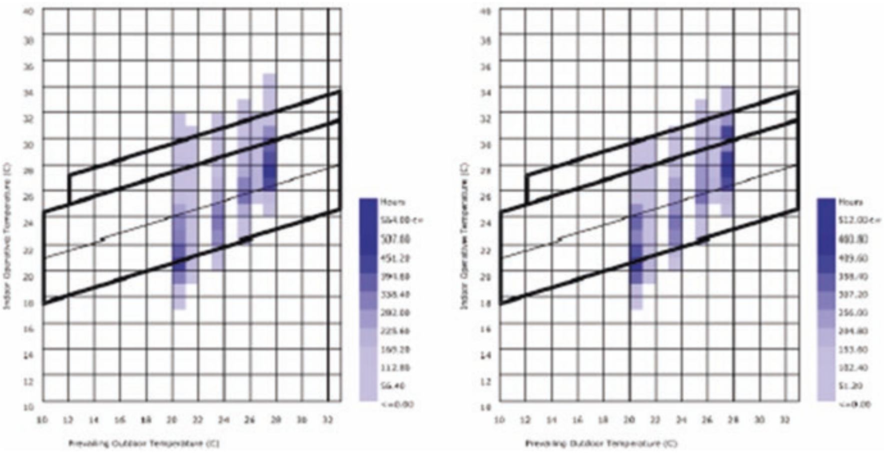

Fig. 7.32 Number of hours that living room (left) and northeastern bedroom (right) are complaint with the ASHRAE 55-2013 model

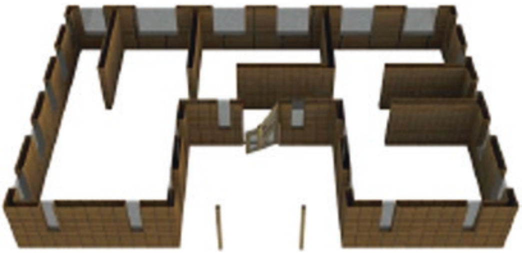

Fig. 7.33 Section plan – V3

Fig. 7.34 Eastern section – V3

Finally, based on all these preliminary results and following the workflow predicted, it is now possible to understand the impact of the design strategies developed and maybe correct some fewer desirable results, mainly on the southern façade zones such as the southernmost rooms register a bigger heat gain and bigger operative temperatures. One way to do this would be to extend the southern porch and entrance to the limit of the south façade, creating an open covered area, limiting the mean incident radiation on the eastern and western facades of the southeast living room and the opposite room (Figs. 7.33 and 7.34).

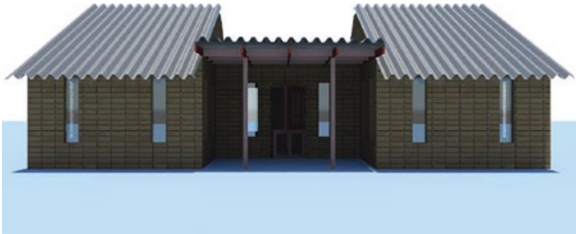

Fig. 7.35 South ground perspective – V3

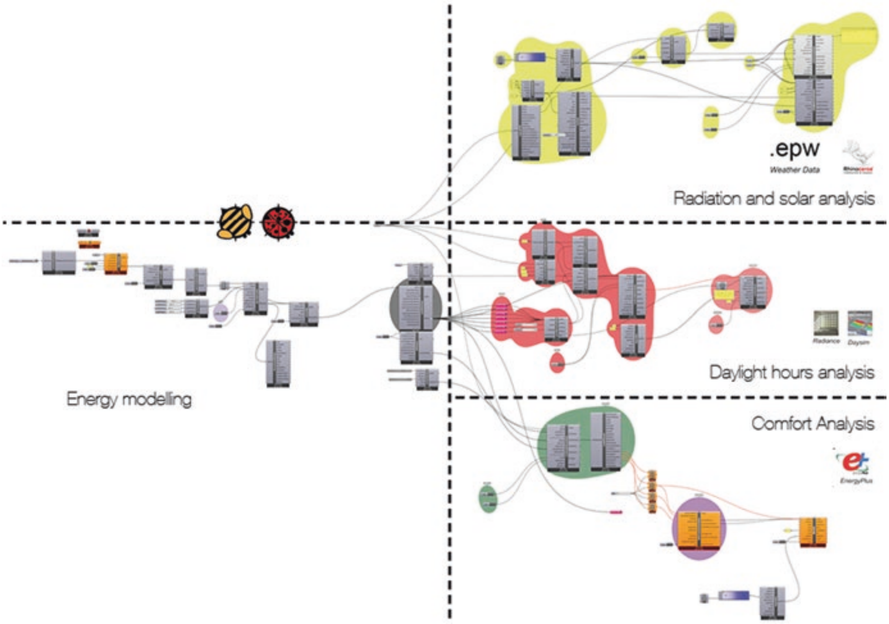

Fig. 7.36 Grasshopper workflow diagram

Concluding, it is possible to highlight the following strategies:

- High focus on natural ventilation and materials with high thermal inertia
- Protect facades that show high level of incident radiations and try to develop the project considering these analyses
- Impermeabilization and insolation with local materials due to high relative humidity
- High volume of interiors, with bigger height to promote hot air circulation
- Air walls at roofing level coincident with wind direction

The correct combination and wide spreading of these easy to follow strategies will allow to assure the correct performance of a three-bedroom house facility built only with local materials and easy construction techniques in an efficient way (Figs. 7.35 and 7.36).

Part III
Urban Sustainability

Chapter 8
Slums in African Cities

José Forjaz and Jéssica Lage

Over the last century, there has been an impressive growth of the world urban population. If there were 7 billion people in 2011, it is currently estimated to have reached 8.5 billion. This growth has not been gradual; from 1950 to the present, the number of people has almost tripled to the point where the number of inhabitants in urban areas exceeds the number of inhabitants in rural areas. This growth was not uniform either, and in urban areas of developing countries, population growth occurred in parallel with accelerated urbanization, contributing to a high and particularly rapid growth rate, with an estimated average of 2% a year, compared to the average rate of 0.5% in urban areas of more developed countries (United Nations 2015). This acceleration, coupled with the low economic conditions, has hampered the process of sustainable consolidation of urban structures where the difficulties in guaranteeing the minimum and decent conditions in the urban and housing context are accentuated.

About one billion people live in slums, meaning that about one in eight people live with some kind of urban deprivation with complex social and urban problems, which requires particular attention of the same dimension. Despite efforts to combat the spread of this problem, resulting in a decrease in the global percentage of the population living in slums – from 39% to 30% – between 2000 and 2014, absolute numbers continue to increase (UN Habitat 2003). However, Africa continues to be one of the fastest-growing continents with the highest percentage of people living in slums, about 60%, more than half of the urban population. With an annual growth rate of 1.4% and an urban population growth rate of 3.4%, it is estimated that the value of population living in urban areas will increase from 400 million in 2010 to 1.2 billion in 2050 (ibid.).

The rapid urbanization, which occurs especially near urban centers, is driven by several factors such as "high birth rate, rural-urban migration, expansion of urban settlements through annexation, reclassification of rural areas, and, in some

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countries, negative events such as conflicts and disasters (…). Given that African cities are among the poorest in the world, their growth rates signal a major challenge to their resource base, to build and to sustain adequate infrastructure and public services for their growing populations" (Veras 2018). These problems require the adoption of new policies and intervention measures in the context of urban management leading to sustainable urban, social, and economic development.

8.1 A Brief History

The word slum was first used in England, around the 1820s, to describe the degraded urban areas consisting of substandard dwellings and prevalence of crime. In the late nineteenth century, the definition of slum was first published in the Oxford English Dictionary as "a street, alley, court, situated in a crowded district of a town or city and inhabited by people of a low class or by the very poor; a number of these streets or courts forming a thickly populated neighborhood or district where the houses and the conditions of life are of a squalid and wretched character" (Moreno 2003). Subsequently, the word began to be used more freely and used to describe generally areas and dwellings unfit for living. With the expansion of the slum phenomenon around the world and the need to define the concepts in legal documents and land use planning instruments, other types of terminologies, such as informal settlements and informal housing, emerge.

Regardless of the terminology used, the applied concepts were usually formulated as opposed to the emergence of urbanism understood and practiced as project and science-based planning policy, that is, everything that did not fit into what is technically defined was considered informal. This concept is usually related to all types of urban construction, poverty, urban or peripheral, and mostly has a pejorative meaning.

Still in the late nineteenth and early twentieth centuries, such settlements began to be noticed in France, India, and in some places in North America, and between 1950 and 1970 in Latin America. Thus publications and studies appear to deepen the knowledge and to discuss their futures. There was a division of perception among the academics who explored this theme, with different positions. Some, such as Riis (1912) and Lewis (1965), focused on the negative aspects of settlements, such as social disorganization, illegality, poverty, and crime; and others such as Mangin (1967) who, in addition to recognizing existing problems, also identified positive aspects such as the existence of supportive communities with the spirit of self-help and personal growth opportunities. Two classes are born, the "slums of despair" and "slums of hope," respectively.

Through studies for the UN, Charles Abrams (1966) exposed to the world problems and the real conditions faced by the population in slums, and contrary to what was already being discussed, Abrams defended policies of intervention based on improvements in situ and the participation of the residents, identifying the community organization as a key point for its urbanization and infrastructuring.

In comparison, John Turner published, according to your point of view, social ideals in defense of the construction of housing, infrastructure, and the development of strategies, policies, and interventions in favor of the underprivileged population. Turner lived in Peru between 1957 and 1965 and developed projects related to self-construction in the informal settlements and worked, like Abrams, for the UN. In Peru, he found that families were improving their housing according to their financial conditions and believed that helping to develop this type of solution, combined with the integration of community participation, was more realistic and more beneficial than the housing production policies in subsidized social neighborhoods. Against this principle, the implications of the architect's role went beyond design, thus developing social and political accountability in this field.

8.2 Global Awareness of the Urban Problem

In 1976, the first United Nations Conference on Human Settlements was held in Vancouver, Canada – Habitat I. For the first time, the situation of rapid urbanization and its possible consequences was openly discussed, leading to action plans and recommendations for sustainable urban development. The conference paved the way for recognition of the direct participation of organized society in policy-making and preparation programs for the planning, production, and improvement of their settlements. It also considered the action of the inhabitants in the production and management of their habitat to be important, thus marking the beginning of declarations of principles, recommendations, and experiences within the policies of management, financing, production, and transformation of urban space (Seaforth 2002).

Twenty years later, the second conference of the UN Habitat program was held. Entitled Habitat II, it was held in Istanbul and included this time the participation of nongovernment sectors, addressing housing and urbanization issues. Reaffirming the right to adequate housing, it also encouraged decentralization and the participation of the population in the urban process. This conference culminated with the "Habitat Agenda," a document approved by the participating countries, describing the principles to be implemented for sustainable urban development within a context in which urban population percentages tend to grow exponentially.

Habitat III, held less than 2 years ago in Quito, Ecuador, was attended by more than 30,000 people and 167 countries. As in Habitat II, the New Urban Agenda was launched with the recent guiding principles for sustainable urban development for the next 20 years. The urban context has changed considerably since the first conference. In 1976 the world population was around 4.1 billion people, with about 38% of them living in urban centers; in 1996 there were about 5.8 billion people, among them 45% urban. At the time of Habitat III (2016), the world's population had already reached 8.3 billion with more than half (55%) living in urban centers.[1]

[1] UN statistical data available at esa.un.org/unpd/wup.

This scenario led to the development of more appropriate measures for urban growth and expansion, encompassing urban, peri-urban, and rural areas, guiding governments to address challenges through national and local development policy frameworks. With regard to informal settlements, some key action points are "the recognition of the informal settlement and slum challenge and the mainstreaming of human rights; systemic and citi-wide/ 'at scale' approaches; appropriate long term financial investment and inclusive financing options; and developing participatory, robust, standardized data collection processes" (UN Habitat 2015a).

Also organized by UN Habitat and to discuss the urban issues inherent in rapid urbanization and their impacts on cities, communities, economies, and policies, the World Urban Forums are held every 2 years since 2001.

At the ninth session of the World Urban Forum, which was held in Kuala Lumpur, Malaysia, in February 2018, a number of studies and experiences on slums were presented. On the one hand, it was shown the challenges faced by many urban dwellers in developing countries who suffer from forced expropriations in the name of the city's growth and the precarious housing conditions they face; and on the other hand, it was also presented practical works elaborated with slum communities on participatory planning, improvement of infrastructures, and use of local building materials.

These forums aim to raise awareness of sustainable urbanization, improve the collective knowledge on sustainable urban development through open and inclusive debates with the exchange of best practices and policies, and increase coordination and cooperation among the different stakeholders for the advancement and implementation of sustainable urbanization (UN Habitat n.d.-b).[2]

In addition to the conferences and meetings that have taken place, in face of the challenges, not only urban, but in general, "world leaders met at the special Millennium Summit of the United Nations in September 2000 to establish a series of goals for humanity in the 21st century, based on the key policy documents from the series of major United Nations conferences held during the previous decade, including Agenda 21 and The Habitat Agenda" (UN Habitat 2003). As a result, 8 specific global goals (the Millennium Development Goals or MDGs) and 18 targets were defined to combat the various existing problems, such as poverty (Goal 1: Eradicate extreme poverty and hunger) and environmental degradation (Goal 7: Ensure environmental sustainability). So far, efforts toward achieving the Millennium Development Goals in the area of slum improvement have resulted in approximately 200 million additional city dwellers to gaining access to clean water, adequate sanitation, and durable housing. As a consequence, from 2000 to 2010, the proportion of urban residents in developing countries living in slums decreased from 46% to 36%. However, as has already been said, currently the number of people moving into slums is increasing. Especially in sub-Saharan Africa, the proportion of slum dwellers decreased because the growth of the urban population more than compensated the growth of slum dwellers (J-PAL 2012).

[2] https://unhabitat.org/wuf/

8.3 Definitions and Categorization

According to UN Habitat (2015a), there is a difference between the concepts “informal settlements,” and “slums.” informal settlements are residential areas where (1) inhabitants have no security of tenure vis-à-vis the land or dwellings they inhabit, with modalities ranging from squatting to informal rental housing; (2) the neighborhoods usually lack, or are cut off from, basic services and city infrastructure; and (3) the housing may not comply with current planning and building regulations and is often situated in geographically and environmentally hazardous areas. On the other hand, in this case, slums are considered “the most deprived and excluded form of informal settlements characterized by poverty and large agglomerations of dilapidated housing often located in the most hazardous urban land. In addition to tenure insecurity, slum dwellers lack formal supply of basic infrastructure and services, public space and green areas, and are constantly exposed to eviction, disease and violence.” In this chapter we will treat both terms as the same, because of lack of consensus and because most of the time informal settlements are called slums (Cities Alliance 2000).

In order to define the slums, the needs of their inhabitants are quantified in certain aspects. UN Habitat (2003), in order to unify the different definitions that vary from place to place, according to the perception and concept of what a slum is, considers as slum if its inhabitants suffer from one or more deficiencies such as: insufficient access to potable water (less than 20 liters per person per day), limited access to sanitary facilities or other infrastructure, poor durability and structural quality of housing, the excess of inhabitants by habitable compartment (more than three people) and lastly, the lack of security of tenure and use of housing and land. Another feature that determines to some extent the inclusion of areas in this definition is the low economic status of its inhabitants.

Each country and region uses these deficiencies and needs to designate their own slums or informal settlements. The designations usually vary, from adaptation to the different languages to the differences in their formation, locations, and characteristics. As an example, we have in France and Francophone countries the *Bidonvilles*, in Brazil the *Favelas*, in Latin America the *Barriadas*, in Angola the *Musseques*, and in Maputo the *Neighborhoods of Caniço*.

Although a common term, slum, is used for all types of inadequate housing and basic services, it is necessary to know the typology of this slum through a categorization based on its place of origin, its formation, and evolution and by its initial intention of use and by its form of expansion. Categorizing the identity of the space and its problems facilitates the development of urban intervention plans that are better adapted to each situation.

The expressions used in the 1960s and 1970s on the views of academics about slums were rescued and are currently used for the division of the slums into two categories: *Slums of hope* – “progressing” settlements, which are characterized by new, normally self-built structures, usually illegal (e.g., squatters) that are in, or have recently been through, a process of development, consolidation, and improvement – and *Slums of despair*, "declining" neighborhoods, in which environmental conditions and domestic services are undergoing a process of degeneration (UN Habitat 2003, p. 9).

Within the first category, more oriented to its formation, there are, for example, the iconic constructions on hills, found in Brazil and Mexico, commonly identified with the term *favelas*. This term is generally used to describe a set of agglomerated and vertically distributed constructions (Fig. 8.1), usually composed of two or three floors, which arose from the concentration and occupation of the poorer population in the hills – which were the vacant spaces closest to the urban centers. We also have *irregular settlements* (Fig. 8.2) which are usually characterized by their horizontal expansion and disorderly layout, also near the major urban centers. We are usually facing individual plots subdivided by own initiative according to the demand for housing in the area. The houses are mostly of a single floor, self-built without approval of the government, and with the absence or insufficiency of infrastructure.

"Declining areas" include urban centers in cities that have suffered processes of degradation of buildings and infrastructures. It can also be considered in this category the *cortiços*, Portuguese term for "tenements" used to define a set of residences in height, subdivided into rented blocks, overcrowded, and usually with common sanitary facilities. This term includes buildings that did not finish their construction process, as well as finished buildings that were subsequently closed and abandoned for various reasons, such as the "Grande Hotel" in Beira in Mozambique which,

Fig. 8.1 Inside Rocinha favela, Rio de Janeiro, Brazil, 2010. (By: Chensiyuan/CC-BY-SA-4.0)

Fig. 8.2 Aerial view of Mafalala neighborhood, 2018. (By: Johan Mottelson and Remígio Chilaule)

because it was not profitable, was closed after 20 years and currently is home to at least a thousand people (Fig. 8.3), and buildings built for industrial workers in certain areas but which were then leased and subleased leading to the deficiencies found in common slums. Another type of construction that falls into the same category are the *degraded housing complexes* that are normally built by the public sector to accommodate a population with low economic conditions and have undergone structural and infrastructural degradation processes and are in urgent need of rehabilitation.

Regardless of the existing designations or categories, it is understood that the concept evolves and changes over time, so as the urban areas. The only common aspect is that these areas are considered unwanted places and where the poor live. However, all the awareness process of examining this non-legalized urban phenomenon contributes to the recognition of these settlements, commonly referred as informal, to an appreciation of space as social production and to help overcome the negative meaning of this concept.

Fig. 8.3 Grande Hotel, Beira, Mozambique 2009. By Michiel Van Balen/ CC-BY-2.0

8.4 Characteristics of Slums and Living Conditions

The definitions of slums are formulated according to their characteristics, so some of these have already been listed. Knowing that slums and informal settlements have numerous dimensions and are represented in various formats and typologies, their characteristics also vary accordingly. In the worst cases, slums may include all of the deficiencies and attributes presented here, and in other cases, only a few of these may be found.

The UN Habitat (2003) provides an overview of features found in definitions used in national and local governments, statistical offices, institutions involved in slum issues, and public perceptions:

1. *Lack of basic services* – this includes the lack of access to infrastructure such as sanitation, water supply, rainwater drainage systems, electricity, street lighting, and waste collection system.
2. *Substandard housing or illegal and inadequate building structures* – existence of substandard or inadequate structures without the minimum requirements for residential buildings in accordance with legal construction standards. Most buildings are built without plans and projects approved by public authorities and inspection entities, resulting in dwellings with compromised environmental quality, e.g., ventilation and lighting problems. In some slums of developing countries, the building is still built of nonpermanent materials and unsuitable for construction.

3. *Overcrowding and high density* – due to the low economic conditions of the population that live here and because slums are usually close to large urban centers, there is a high housing density and, consequently, a high population density in these areas. Most of the time this also results from the cohabitation by different families in the same dwelling and by the excess of inhabitants by habitable compartments.
4. *Unhealthy living conditions and hazardous locations* – the lack of basic services such as sanitation and water supply results in unhealthy environments and dangerous to public health; on the other hand, the improvised condition of the slums makes the location of some of these to be in places unsuitable for settlement and reserved for nonresidential purposes, such as ecological protected areas, places near landfills, and areas subject to flooding and landslides. This feature shows the spatial marginalization to which these settlements are subject.
5. *Insecure tenure* – one of the most striking features of the slum and from which the term "informal" derives is the insecure tenure and the lack of legal documents authorizing the construction and occupation of the dwellings. As such, slums are considered illegal and outside the formal mechanisms for noncompliance with current land use plans in the area.
6. *Poverty and social exclusion* – unsurprisingly, the majority of the population living in these areas has low economic conditions. As pointed out by UN Habitat (2003, p. 11), this "is not seen as an inherent characteristic of slums, but as a cause (and, to a large extent, a consequence) of slum conditions. Slum conditions are physical and statutory manifestations that create barriers to human and social development. Furthermore, slums are areas of social exclusion that are often perceived to have high levels of crime and other measures of social dislocation. In some definitions, such areas are associated with certain vulnerable groups of population, such as recent immigrants, internally displaced persons or ethnic minorities."
7. *Minimum settlement size* – although slums differ greatly in size, in some parts of the world for a settlement to be considered slum, it needs to have a minimal dimension. Thus, for example, in some countries a small group of five isolated houses cannot be considered slum because it does not have an urban extension with the characteristics and problems that define slums.

Other specific characteristics can be found in certain categories of slums. Irregular settlements, for example, have a clear and recognizable spatial disorder with an organic layout structure that is representative of the poorest African countries. In these areas, the organic layout usually consists of uneven plots with no access roads and a predominance of tortuous dirt roads with no defined width and with several pedestrian streets without continuity. The spacing between the houses is usually small with several buildings per plot. This urban structure makes it difficult to regularize the settlement and the distribution and rehabilitation of basic infrastructure and services – facing problems of urban precariousness exacerbated by high levels of population and housing density. In certain slums, there is also an aspect of neglect and deterioration of the dwellings, of the residential complexes if this is the case, of their yards, and of the roads.

Another important feature to mention is that certain slums are mostly residential. Since a large part of the population is officially unemployed, the commercial services that may exist are also considered to be informal and used as a means of subsistence. In Africa, nine out of ten urban and rural workers have informal jobs (Kolli 2016). Slums, being mostly residential, also lack public spaces and public services such as schools, hospitals, and libraries and government services, among others.

There are several problems and difficulties that the economically disadvantaged population faces, but there are also virtues that should not be ignored – the process of self-help, the sense of community, self-construction according to their way of life, and their culture and identity. This must be present not only in the description of these areas but also in the elaboration of any type of plan and strategy of problem-solving and urban intervention.

8.5 Emergence and Growth

As there are differences between the types of slums, there are also different causes and factors that influence their emergence and growth. These vary from place to place; however, in Africa there are some more relevant:

1. *Colonialism and marginalization* – In some African countries, colonialism is seen as one of the starting points of emergence of slums. The growth of colonial cities as development poles attracted the population of rural areas, and the colonialists used this population as cheap labor force. At the same time, a spatial, economic, social, and racial marginalization was maintained that excluded the population of these centers, creating small human settlements around the larger cities without any regulation or infrastructure.
2. *Rural-urban migration, urbanization, and population growth* – In African countries, rural-urban migration manifested itself strongly in the periods of war and instability that occurred throughout the fights for independence. This migration was aggravated by independence. Rural populations have moved to urban areas in search of better living conditions, such as employment and access to public services such as schools and hospitals. However, not everyone was able to find work because of the increasing competition in the labor market and lack of academic and professional qualifications. By not being able to afford appropriate places to live, they settled in cheaper areas and further away from the urban centers, forming and expanding the slums.

   Africa as a continent has one of the highest rates of change of the urban population in the world. According to the World Cities Report 2016 (UN Habitat 2016a), the African urban population rose from about 236,904 in 1995 to 471,602 in 2015. This means a growth rate of 3.4% and an increase in the percentage of urban population from 37% to 40.4% between 1995 and 2015. Of this urban population, more than half live in slums. It is estimated that by 2025 about 45% of the African population will be urban. Sub-Saharan Africa is the region of

Africa and the world with the highest percentage of urban population living in slums, accounting for about 56% in 2014. Although the percentages of population living in slums tend to decrease in this region and worldwide, the absolute numbers of people living in slums tends to increase.

Rapid urbanization coupled with the exponential growth of the population leads to the overburdening of urban centers and to the degradation of existing urban infrastructures. The population without places to live in the center, however, is occupying the empty spaces unfit to live subjecting themselves to precarious conditions.

3. *Poor urban planning and discriminatory real estate market* – As already mentioned, the rapid growth of the urban population leads to a progressive densification. Small human settlements near urban centers are expanding and consolidating without government regulation and not according to current planning legislation. Local governments themselves are unable to respond to this phenomenon with appropriate urban tools and plans. The lack of coordination between government departments and insufficient financial resources hampers this task.

In some cases, urban planning and management criteria are also de-linked to the real needs of the majority of the population and without these being included in the urban planning processes. Governments end up establishing technically ideal urban and environmental laws, but, due to ignorance of the socioeconomic conditions and the consolidation of an elitist and discriminatory land market, the population with low incomes is excluded to areas that the market has no interest. These areas are usually areas far from the centers, with poor access and transportation and without installed infrastructure. The population in turn also occupies areas subject to environmental preservation and inappropriate areas of all kinds, becoming, gradually, spatially marginalized.

Insufficient financial resources on the part of governments also play a central role in the deficiency of adequate housing policies and the lack of housing options offered, or at low, cost through social housing programs. "Central and local governments that tried to afford investments in housing constructions schemes, e.g. in sub-Saharan Africa between 1970 and 1990, found that matching housing supply with population growth was the road to bankruptcy. Also, Informal housing finance is limited in size and cannot accommodate the vast potential demand" (UN Habitat 2010).

The real estate market, in turn, does not offer affordable housing to the low-income population, leading the population to move to the informal land market where housing costs less. This factor causes, on the one hand, the subdivision of land for the construction of new dwellings and consequent densification of housing, and on the other, causes an increase in insecurity of land tenure and in the lack of legal documents authorizing the construction and occupation of the houses.

Other factors influence the formation and expansion of slums, such as natural disasters and social conflicts (as in the case of civil wars in many African countries), which lead to the migration of families from affected areas, both on their own initiative and by action and government intervention, to safer areas.

Although the term slum encompasses several types of urban poverty within various categories, in Africa the most common spatial expressions are progressing settlements. These include squatter settlements and semilegal subdivisions, differentiated by the first being occupied without the explicit permission of the owner and the second to have been subdivided, resold, rented, or leased by its legal owner or customary landowner to people who build their houses upon it, usually through self-help processes. This kind of settlements are sometimes described as self-help or self-built settlements, spontaneous settlements, marginal settlements, or just slums (UN Habitat 2003).

Their formation usually has nothing spontaneous and is the result of a gradual process of occupation and incremental growth. While the parallel reality of the formal urban usually follows the following process – (1) obtaining title to land ownership, (2) the installation of urban infrastructure, (3) the construction of housing, and (4) land occupation – these types of settlements tend to develop inversely.

The population, for various causes already spoken, occupies vacant spaces near urban centers with small housing groups (usually provisional and self-built) for fear of expropriation due to lack of security of land tenure. These agglomerations, over time and by the government's inactivity in demolishing or expropriating, consolidate. This step is reflected in the investment in their homes with the use of more permanent and resistant materials. With consolidation, these settlements become denser, making removal of dwellings and inhabitants more difficult. Slums emerge, consolidate, and become denser, as their problems. In cases where there was no urban infrastructure in these areas, it becomes increasingly difficult to install in a sustainable manner; and where there was some sort of infrastructure, it becomes compromised, deteriorates, and does not support the new number of houses and inhabitants.

Some authors have formulated steps for the development of slums; Abebe (2011), for example, divides this evolution into three stages, infancy, consolidation, and saturation, based on the concentration of dwellings within the limits of a given area in which the settlement is emerging. The infancy stage would be from the first house to the point where 50% of the settlement area in question would be built-up; consolidation stage would be the stage of expansion and occupation of empty spaces in which up to 80% of the area would be occupied for housing construction; and saturation stage where by the lack of space to expand, densification occurs vertically through new floors in existing dwellings. According to this theory, most settlements in African countries are still in the consolidation stage, but many are already progressively moving into phase three.

Although most of this type of settlements start out as being of illegal occupation, over time they are becoming somewhat accepted by the government. They reach the limit of illegality and legality and the limit of tolerance and recognition, providing in some cases to the population, security of possession of land through customary rights.

In sub-Saharan Africa, much of the land is owned by customary landowners. In Mozambique, for example, land is owned by the state and cannot be sold. The territorial occupation is carried out according to two land tenure systems, the written law of the state and customary law. It is estimated that 14% of the land is owned by the state, 3% is by written law[3] (with the right of usage and benefit of land), and 80% of the total land is under customary law (UNECA 2003). Customary occupation can be done in a variety of ways – by occupation time, by attribution from local and traditional authorities, and by inheritance – and is accepted by the state provided they do not contradict the Constitution. Due to discrepancies and omissions between the Land Law and customary law and due to the difficulty in the management of these lands by the state, this type of occupation hinders urban and housing control. Another existing problem is that land used for the settlement may not be recognized as suitable for urban development or may not be in accordance with the provision of infrastructure or existing urban planning laws and regulations.

8.6 Intervention Approaches

As slums began to emerge, and when the scale of this phenomenon and its future consequences really began to dawn, attempts were made to develop strategies to address the problems and to prevent them from escalating.

Since the mid-nineteenth century, many theories, policies, and intervention strategies have been developed. These range from more radical measures such as forced removal with the aim of eradicating the problem to more humane actions such as the development of programs to provide rights to the population and to help them improve their housing and urban spaces.

Frequently, policy approaches derive from the lessons learned and critical analysis of the previous endeavors and attempts. However, clear changes in the accepted wisdom of how best to deal with slums, and resulting changes in the approaches used, would be difficult to see as a straightforward process of policy evolution over time. While new policy approaches have been developed in response to the new requirements and to overcome the deficiencies of the past, many "old" approaches, or at least some of their components, continue to be used today (UN Habitat 2003, p. 129).

As already mentioned, the issue of slums is very complex and covers a number of social, economic, political, and cultural aspects. It also involves various players and comes in various forms and formats and has several causes, production processes, characteristics, and needs. It is difficult to establish a single ideal action policy that works in all situations. It is also difficult to effectively control how these policies are implemented in all countries, particularly in developing countries such as African countries. In any case, governments and international agencies seek approaches to alleviate deficiencies in growing settlements and in the housing acquisition process by expanding the legal provision of housing to cover lower-income households – which is one of the focal points in the expansion process of this phenomenon.

[3] Called "DUAT – Direito e Uso de Aproveitamento de Terra".

Here are some of the approaches that have been implemented in the last decades and their repercussions:

Negligence and the Laissez-Faire Attitude

In most developing countries, between 1950 and 1970, urban authorities saw the formation of slums as an illegal and temporary phenomenon that would be overcome with territorial planning policies and programs focused on containing rural-urban migration and improvement of economic conditions in rural areas (Turner 1970).

Throughout this period, there was a deliberate neglect of the housing and urban problems that the inhabitants faced, hoping that by ignoring, people would not settle and would return to rural areas. This type of approach was also expressed in planning documents, where most of the areas occupied by this settlements were represented as unoccupied and even vacant areas for future expansion of urban centers (UN Habitat 2003, pp. 129–130).

Needless to say, the growth of slums has not slowed down with this type of action, instead it has resulted in their growth and expansion, aggravating the problems it already had.

Forced Evictions

The eviction of slums was an approach implemented mainly during the 1970s and 1980s; however, this does not mean that it is no longer used, being seen today in some developing countries.

Some municipal authorities, given the expansion of slums, have simply chosen to partially or completely remove the slums and their inhabitants. This reasoning is derived from the realization that slums were illegal and were not recognized by law and also because they were mostly illegal occupants of land, which belonged to other people or even to the state. Other arguments were used to justify this type of decision: slums with irregular layout that do not follow any urban norms and without infrastructures, slums in areas unsuitable for housing and with environmental and health risks, and slums in areas reserved for the expansion of the city and in prime locations for the real estate market. These actions were usually accompanied by various forms of harassment and repression and consequent demolition, often without any negotiations with the community, financial compensation, or resettlement alternatives.

In some cases, setbacks have been encountered by local authorities during the expropriation process, such as settlements with underestimated dimensions and high housing and population densities, making removal of slums financially impracticable, and slums with a large community organization that often stood up to the removals and claimed for decent housing, causing political and social pressure on governments.

When the expropriations were carried on anyway, the population sought to settle in the vacant areas closest to the center, on the outskirts of cities where planning control was deficient, creating the same situation again. The population that were resettled in more distant areas and that already had employment in the center suffered from the rupture of preexisting social relations and from the high cost of transportation. Most of these preferred to leave the reallocation areas and seek or even create new settlements closer to the previous ones.

One of the most recently reported cases was the forced eviction of more than 10,000 families from a slum in Badia East, Lagos, in 2013. A local tribal king claimed ownership of the land on which the settlement was located and where most people had lived for more than 20 years. With the government's inactivity, part of the settlement was destroyed without giving people the opportunity to take their belongings. Many homes, services, sources of income, and even a school and a hospital were demolished. This eviction, which was highly condemned by Amnesty International for the clear violation of human rights, did not even come with some sort of compensation or area for relocation. People who had already lost all their possessions were forced to go to the street, other settlements, slums, and family houses that were located nearby (Figs. 8.4). A similar case to this also happened in Kibera, Kenya, where the majority of the population got their houses destroyed with no prospect of ressetelement (Fig. 8.5).

Luckily, although this practice is occasionally used, it is mostly used in cases that require specific and emergency solutions, initially considering other less drastic alternatives. The removal of slums does not solve the slum issue; it simply ignores and consequently exacerbates its social causes.

Resettlement

Displacement often comes with resettlement in other more appropriate areas to inhabit. This relocation is usually done in peripheral and semirural areas, accompanied or not by infrastructural conditions and low-cost social housing.

Often this approach is made without consulting the affected population and can be accompanied by protests and opposition to relocation for many reasons such as lack of conditions, infrastructure, services, transportation, and housing in the new

Fig. 8.4 Slum in Lagos, Nigeria. (By: Stefan Magdalinski/CC-BY-2.0)

Fig. 8.5 Destruction of a slum in Kibera, Kenya, 2009. (By: SuSanA Secretariat/CC-BY-2.0)

area or even because it ignores the social and economic factors such as interpersonal relationships, livelihoods, and previous workplaces. In other cases, it is possible to have social mediation with mutual agreement and cooperation of the families involved, especially if the location of the current settlement brings environmental and health risks to the people and if the new resettlement area has better quality, not only in urban conditions but also with economic opportunities.

Public Housing

Some governments in developing countries, in an attempt to improve the urbanization and building standards, to solve the housing problem and to persuade slum dwellers to leave their homes, began to mass-build subsidized low-income housing.

In contrast to stable economic growth contexts, in developing countries governments do not have the capacity to subsidize housing along with the housing necessities and demands. Even with efforts aimed at this type of approach, the percentage of beneficiaries is very low compared to the dimension of those in need.

The implemented housing policies seek to stimulate the demand with housing financing systems for the low-income population and stimulate the supply in partnership with the private sector by offering tax and urban incentives if they agree to assist in increasing the low-cost housing supply. This provision strategy by funding entities suggests that there will be some return on the investment, even if partial – meaning the new residents would pay a rent or a certain amount for the property. This strategy usually comes with restrictions as there is a need for stable income to pay for the financing, which often does not exist.

Unfortunately, most of the time when housing is built, the scenarios are not very favorable. The houses end up being allocated to government employees through unreliable schemes or even end up being bought from the residents themselves, by upper classes, for the business opportunity. This gentrification process may initially seem beneficial to the neighborhood; however, the lower-income people who have been assigned housing and who initially choose not to sell their homes to new stakeholders will eventually be unable to keep up with the cost of living and will gradually be forced to give in and leave the area.

Another issue that accompanies the housing mass construction is the imposition of design and construction standards and preestablished typologies that are poorly adjusted to the population's lifestyle and without their participation, opinion, or saying. In these cases, the dwellings do not satisfy, reflect, or comply with the real needs of the residents. Often this factor results in dissatisfaction and in some cases in the abandonment of these new homes and search for other settlements to live (Fig. 8.6).

Fig. 8.6 Two storey housing project in EastBank Alexandra, Johannesburg 2007. By: Media Club. Via: Flickr / CC-BY- SA-2.0

Slum Upgrading

Slum upgrading is based on implementing strategies of gradual integration of the settlement with the neighborhood or with the city itself improving existing environmental and habitability conditions, enabling the consolidation of the settlement, raising it to acceptable urban standards, and keeping the population on site.

The upgrade can consist of implementing and improving existing infrastructure, such as water supply, sanitation, drainage of rainwater, and electricity networks, in improving road systems such as paving and widening roads, and also in the parceling of the plots, in land regularization, in the assurance of land tenure, and in the development of housing improvements.

However, "Slum upgrading is not simply about water or drainage or housing. It is about putting into motion the economic, social, institutional and community activities that are needed to turn around downward trends in an area. These activities should be undertaken cooperatively among all parties involved—residents, community groups, businesses as well as local and national authorities if applicable. (…) Ultimately, upgrading efforts aim to create a dynamic in the community where there is a sense of ownership, entitlement and inward investment in the area" (Cities Alliance 2016).

These actions can be accompanied by environmental risk removals, social facility constructions such as hospitals and schools, and in some cases even assistance in economic services in order to increase employment in the area and by providing appropriate urban and community management tools. This approach is increasingly being used because it does not entail the costs of involuntary removals and forced resettlement and allows the population to remain on site, preserving the community's social and economic ties.

> The work of UN Habitat and the international system of aid organizations has for over three decades followed the paradigm that was first set in motion by the World Bank in the 1970s to upgrade slums rather than just clear and rehouse their populations. Coming on the back of Turner's work on ideas of vernacular or traditional knowledge in building, of poor people's creativity or of user sovereignty in self-housing solutions (Turner 1976), slum upgrade then evolved into a process usually tied to Structural Adjustment Programs, especially in African and South American cities. (Ascenção n.d.)

Interventions can be made at various levels: *simple upgrade*, in low- and medium-density cases and without the need for complex infrastructure interventions; *complex upgrade*, in cases of high densities, accompanied sometimes with the removal of some of the dwellings and inhabitants in order to regularize the urban network and increase the access roads; *gradual upgrade*, which consists of determining short-term, medium-term, and long-term intervention steps that can include both simple upgrade and complex upgrade; and the *localized upgrade*, also called *urban acupuncture* in which small-scale-specific construction operations are carried out to revitalize an area or space with the intention of improving the surrounding urban context. On this last type of intervention, the VPUU (Violence Prevention through

Fig. 8.7 Safe-Hub Gugulethu/Manenberg, 2016. © VPUU NPC

Urban Upgrading),[4] based in Cape Town, South Africa, among other activities, designs, builds, and activates small multifunctional community buildings or “Active Boxes” across deprived communities. These buildings allow the communities to co-create safe and sustainable neighborhoods. One of these examples is the “Safe Hub” (Fig. 8.7) and is located in one of the most violent areas in Cape Town. It has about 500 m^2 and serves about 1000 youth weekly with different activities such as weekly night leagues, after-school programs, tutoring, a Youth Café, and Parent Dialogues.

This type of community facilities not only explores the social potential that the communities already possess, relating residents to sports and cultural activities, but also improves urban development in the area. Also in Brazil, specifically in the “Complexo do Alemão” slum, the same kind of urban acupuncture intervention was implemented through a cable car connecting the slum to the rest of the city, creating an innovative solution for the lack of infrastructure and mobility.

Slum upgrade requires large involvement and commitment from the government, long-term follow-up, and some type of maintenance by municipal entities and by residents themselves. It is still considered one of the best solutions for the communities involved since these interventions have direct effects on the neighborhood, the dwelling, and the resident. By improving the urban situation, services, and security, residents will be motivated to invest more in the quality of their housing and infrastructure, and this will also generate personal improvements, e.g., in their economic and health situation and in investments in their education (Fig. 8.8).

[4] VPUU is an area-based community development program that aims at safe and integrated communities, citizenship, pride, and the improvement of quality of life for the residents in local neighborhoods through a comprehensive range of urban improvements and social interventions (http://vpuu.org.za/who-we-are/).

Fig. 8.8 Ongoing expansion and improvement of a gray water collector in Mafalala, Maputo, 2018. (By: Remígio Chilaúle)

Sites and Services

The scheme of sites and services began in the 1970s in some countries in South America, Africa, and Asia, supported by some international development agencies such as the World Bank that not only encouraged this approach but also funded many of these projects.

As has been seen, the housing provision to those in need is not a financially sustainable option for most countries. The concept of sites and services arises in an attempt to minimize the public costs and subsidies necessary for this conventional housing production. In most slums, the population already builds their homes incrementally and according to their possessions. These programs provide only the basic conditions that the residents normally do not have access to by themselves, such as appropriate and legalized land, essential basic infrastructure and services, accessible public services, and sometimes a part of financing for the housing construction.

There are several types of programs used according to the players involved, their resources, and ultimate objectives and to the degree of the community organization. The role of the public entities is basically the provision of a proper area to inhabit with good access and mobility, where incrementally will be held demarcation of plots and roads and installation of water supply, electricity, lighting, and sanitation, and areas will be reserved for public spaces and for construction of public facilities. This type of program will often go to the point to determine in the plots which walls of the future house will collect infrastructure such as water points, sanitation, and electricity; to determine the location for latrines and future bathrooms; and in some cases to even build the roof's structure or the roof itself. The role of the inhabitant in turn is the construction of the house, in phases and according to their possessions and their investment in resources, work, and time.

One of the best examples of the implementation of this type of scheme and considered one of the most successful in Africa, especially with regard to reaching the target group, is the Dandora Community Development Project in Nairobi, Kenya, that started its implementation in 1975. This project, which was funded by the World Bank, consisted of about 6000 plots provided with access to roads, electricity, sanitation, water supply, and public and social services within the neighborhood. The plots had a core consisting of either a kitchen or toilet and shower and were also given technical support and help with loans to build additional rooms. This project was a success for several reasons: (1) the local government authority played an enabling and supportive role; (2) the project ensured that economically disadvantaged families were encouraged and supported to move in; (3) the project implementation provided a wide variety of options to accommodate various target groups and different construction processes; (4) there was transparency in the selection of beneficiaries; and (5) one of the most curious trait was that the design of the project made it unattractive to people of higher-income groups, making them not take over the project (Oladokun et al. 2013).

Although sites and services have several advantages, it also have some long-term implementation challenges especially visible in developing countries: requires strong political commitment from national and local government; requires negotiation of several public or private lands for the implementation of the programs; the incremental process takes time, often years, making it appear unfinished, and over time leading to abandonment and deterioration; and needs appropriate urban planning standards and regulations to enable the incremental development process (Gattoni 2009).

They can also find other restrictions, namely:

- the location of available land may not be accessible to either the residents or to the necessary infrastructures;
- the bureaucratic procedures for selecting eligible candidates tend to be time-consuming and laborious, opening up space for corruption and may also exclude many low-income families who are genuinely deprived simply because they do not have a stable income or are working in the sector informal;
- delays in the provision of services may occur due to a lack of coordination between the various service delivery agencies;
- the requirements by the implementing agencies can act as a barrier, for instance: (1) construction standards and quality of construction that often makes it inaccessible to beneficiaries, and (2) the type of activity that in allowed to take place in the new area, such as restricting the construction of small informal economic services or even the restriction to rent to third parties the built rooms - these restrictions may limit the opportunities for residents to earn additional income to pay for the plot and for the house;
- and financiers' cost recovery is usually unsatisfactory, due to residents' lack of capacity (who have already had to pay for the plot, services and, over time, the construction of their houses), due to the inadequacy of collection methods and due to the lack of sanctions for non-payment (Srinivas n.d.).

> The positive aspect of sites-and-services schemes that deserves support is its recognition of the ability of people to house themselves, with a little backing from the government agencies. Thus the role of the government changes from that of a "provider" to an "enabler". It also enables them to save scarce resources by "sharing" the responsibility of housing with the intended beneficiaries. On the part of the beneficiaries, it makes best use of existing/potential resources, both at the household level as well as the community level. On a large scale, it enables the low-income families to obtain decent housing and services, at levels that can be afforded by them. (…) While sites-and-services schemes are not a blanket solution for all ills of low-income housing, it does provide potential for future housing, making best use of existing resources, both governmental and household. (ibid.)

Participatory Slum Improvement/Upgrading

In recent years and due to the experience gained by the various types of slums intervention, theories of a more participatory and inclusive approach have emerged. "It is now good practice to involve the communities from the outset, often through a formalized process, and to require a contribution from the occupants, which gives them both commitment and rewards" (UN Habitat 2003, p. 132). Some of the examples of success implemented with the participative methodology that we can mention are the self-help partnership projects in Alexandria, Egypt, which are to be integrated, upscaled, and replicated throughout the country and the partnerships for upgrading in Dakar, Senegal, which have impacted more than one million inhabitants (ibid.).

This participatory approach places residents at the center of all decisions, initiatives, and interventions undertaken, encouraging them to improve their living conditions consciously and proactively. As Turner (1972) pointed out, the decision, empowerment, and accountability of the population are fundamental components for the success of any intervention in slums.

Many institutions, agencies, and local governments have been involved in this type of approach over the last years.

In 2008, the Participatory Slum Upgrading Programme (PSUP) was launched, following the same principles. It is a joint effort program between African, Caribbean and Pacific Group of States (ACP), the European Commission (EC), and UN Habitat and has reached out to around 39 ACP countries and 190 cities and has provided the necessary enabling framework for improving the lives of at least two million slum dwellers. This approach is grounded on its emphasis on integrating slum dwellers into the broader urban fabric and adopting a positive stance toward slum dwellers and in situ slum upgrading, using city-wide participatory planning methods. The PSUP includes slums in urban maps and facilitates communication between local and even regional stakeholders, which is a key part of positive change in the policy of sustainable and inclusive urbanization. This results in the beginning of a strategic urban planning, an increased budgetary allocations and the formation of partnerships between the various stakeholders for the sustainable improvement of the living conditions of slum dwellers (PSUP, UN Habitat, n.d.-a; UN Habitat, 2015b).

According to UN Habitat (2016b), the PSUP Programme is implemented through five strategic and integrated interventions aimed at (1) generating evidence-based knowledge on slums and enhancing the capacity of stakeholders to strengthen policies and develop inclusive city-wide plans; (2) improving governance and slum upgrading institutions by strengthening collaborative linkages across sectors and stakeholder groups including slum dwellers and horizontally incorporating all levels of government; (3) promoting participatory urban planning and design strategies that guide safe, resilient, and sustainable urban growth and renewal within a city-wide framework; (4) facilitating strategic partnerships between national authorities, local authorities, and slum dwellers on the one hand and institutions that are able to tailor appropriate pro-poor financial mechanisms for sustainable slum upgrading; and (5) guiding implementation of community-driven and incremental slum upgrading interventions.

> Reflecting the call of the 2030 Agenda for Sustainable Development to end poverty and the specific Goal 11 to make cities and human settlements inclusive, safe, resilient and sustainable by upgrading slums, PSUP is an approach that delivers many Sustainable Development Goals (SDG) objectives as well as fulfills the "housing at the center" idea contained in the New Urban Agenda. (ibid.)

8.7 Strategies for Rehabilitation[5]

A strategy for the improvement and rehabilitation of slums is a difficult issue to establish and to solve.

The slum condition is the consequence of regional, national, and global dimensions of the underdevelopment of certain regions, nations, and cities rooted in a complex social, economic, cultural, and political causes and circumstances that cannot be understood and resolved unless joining and integrating efforts on all these fronts.

Some basic dimensions of the slum problem must be understood before any strategies are established and implemented. We consider as indispensable the following principles that should guide the actions of any of rehabilitation or improvement program:

- Slum is in most cases the consequence of a long and complex process of families and individuals adjusting to adverse conditions, where their often opposing interests find a form of coexistence in a precarious balance but, despite everything, recognized by all.
- The long life learning in an urban environment is, in most cases, better understood by those who settle in so-called slums, with a deeper understanding of habits of civility and codes of behavior, than by those who transfer directly from a rural situation to an urbanized neighborhood, better organized spatially, with better infrastructures and more central.
- The willingness, ability, and motivation to improve the quality of life and housing in slums are high and easy to mobilize if there is a sound action program and residents feel this action is realistic and plausible.

[5] Adapted from the text written by José Forjaz (2005) as part of a project for the improvement and rehabilitation of slums in Mozambique, funded by Habitat – United Nations.

- The priorities order of any contribution or support to the slum should always be established with the residents of the area under consideration and never a priori, even if some interventions seem more basic and indispensable to planners. The very process of involving residents in this definition is a strategic step that will give residents the notion of project "ownership."
- The development of a program, with its sectorial projects, should always count with the residents as the largest reserve of manpower and human resources for its implementation; in this way one of the main conditions for the success of any intervention is guaranteed, employment, even on a temporary basis.
- A clear definition of land use and occupation rights is an essential condition to obtain active and unconditional participation of residents in any slums intervention and rehabilitation.
- The use and occupation rights must be established, registered in cadaster, and certified and assured to each and every resident family.
- All areas or parcels of land should be given a clear status of usage and benefit rights at the end of a slum rehabilitation exercise.
- As for the city planned area, slum projects should always consider all resident households or individuals and their spatial domains and rights, whatever the process extent or difficulty. Experience shows that where residents are involved in the rehabilitation process from the outset, setting priorities and implementing strategies, tasks that might seem almost impossible without their cooperation, are not only possible but easily accomplished.

The stated principles have been established through a practice that considers the beneficiaries of any rehabilitation action as the primary responsible for their own future and the consequences of their own attitudes and choices. This is a sine qua non condition for the success of any program or project.

Current and Recognized Limits of Slums Rehabilitation Actions

Within the economic, technical, administrative, and cultural context of urban planning and renewal interventions in any African city, we must establish a general order of priorities that can serve as a guideline for building a successful scenario for such interventions.

Financial Returns and Limits

The financial limits of any project must be established according to the objectives to be achieved. In other words – the financial limits relate to the scope and the size of the operations to be carried out. In this sense, we have only two practices:

- Pre-define a financial resources limit to be employed for a specific objective and then establish the physical or social boundaries of the project.

- Establish the objectives and limits of the intervention and then quantify commensurable financial resources with the desired results.

In the first case, the financial agents should wait for the development of the project to know what was actually achieved with the financial resources allocated. In the latter case, such agents should accept the definition of the objectives and the extent to which the financial resources to be allocated should be quantified.

Slum rehabilitation and improvement is an expensive but highly profitable exercise because it produces powerful economic and social results from the start of its development. These results can and should be measured by their social and economic impact on the communities affected by the investment, as well as by increasing the capacity of the city to gain a deeper understanding of its own problems and to improve its technical and administrative capacity solving them. No less important are the environmental benefits obtained by improving living conditions in the improved areas, as well as in the city in general.

The experience gained in operations of this nature is not directly reusable since there are not two slums with the same physical, infrastructural, or social conditions.

Administrative and Technical Limits

Most municipalities in African countries have severe limitations in their administrative and technical capacity to intervene in the improvement of living conditions in slums that are in almost all cases part of their periphery.

In the administrative context, there is usually a very passive, highly bureaucratic, and rigid attitude, with little capacity to create or accept new attitudes and ways of solving problems. The forms of data and documentation archiving are manifestly inefficient, there is no transport capability to detect and solve problems in loco, and the motivation is generally low.

In addition, most departments do not have sufficient and trained staff, with good working conditions, acceptable salaries, and technical direction. Workers in the municipality are paid as civil servants and do not have any other facilities or prerogatives. The temptation to sell favors and prioritize access to decision-making mechanisms is commonplace and current practice and very difficult to eradicate. The decentralization of decisions and control to neighborhood structures encounters the same problems and represents an extra burden on municipal finances.

In the technical field the situation is not better. In fact, the availability of technical capacity is reduced, without long experience, poorly paid, and forced to extra work. In most cases, in any of the services, there is not a single technician trained in any of the engineering or urban planning fields. Working conditions, where technical services exist, are often inadequate and insufficient. Filing materials, cadastral registers, cartography, topographic surveys, aerial photos and their restitution, documentation on infrastructures and maps, etc. are, as a rule, nonexistent, outdated, or of very low quality. Demographic records and surveys are also very general so that they can serve as a reliable basis, and there is usually no socioeconomic information.

Social Order

Within the conditions described, it is admirable the sense of order and peaceful coexistence that the majority of citizens enjoy and practice in the absence of formal instruments of social control and information.

This must be understood in the light of the very strong traditional social structures where family ties and hierarchical relationships maintain their social relevance. “Informal” authority, which these traditions embody, is accepted as an indispensable form of social integration of the individual. This is a fundamental aspect to be considered in the design and design of any intervention that may alter the physical form of urban settlement of a group of people, since social, economic, and cultural relations can be adversely affected even if, at first glance, it may appear that such interventions can only bring them advantages.

Persons subjected to transfer operations from their place of residence have a very strong sense of the possible consequences of these changes in their daily lives and will resist them until they are positively convinced of their immediate and long-term benefits.

The Planning Environment

Planning for positive changes in the conditions of a human group, spontaneously organized in so-called slums, cannot be an experimental exercise or a pilot project where residents are taken as guinea pigs to be used to prove a theory or to fulfill a goal projected by a consultancy of a more or less technocratic nature.

Rehabilitation or upgrading of a favela requires the permanent presence of a planning team and a carefully built relationship with residents, which is the basis for mutual trust.

The eradication of slums requires a structure with in-depth knowledge of field operations which includes not only physical characteristics of the area but its social composition, the internal dynamics of the group, and the real authority structure. The disturbing elements of stability which could affect the residents and the history of the urban form and the system of values with special meaning for the social group are other dimensions essential to study and equate.

For what has been said, there is also the need for the perfect comprehension of the importance of relations with others neighborhoods, their correct insertion of urban infrastructures and their needs in terms of services and social equipment.

Therefore, it can be said that the improvement of slums cannot be reduced to a project exercise where several parameters combine in an equation, in a more or less rational way, to be applied as a “solution” or remedy, since the diseased tissue of the city is made of people. There are no formulas of general application to the problem of eradication of slums.

The essential key to success in these works is participation, and this is not achieved by the interpretation of technical documents. It has to be achieved and materialized in the field, with residents and on the basis of permanent contact and permanent.

Any attempt to reduce exercises on slum improvement to a programmable series of operations, quantifiable in terms of cost and time, is designed to failure or result in a form of violence on the rights and aspirations of those who should be the beneficiaries of such operations.

The above interpretation distances from the position that considers that the improvement and rehabilitation of an urban area, especially slums, necessarily implicates in the removal of the majority of the families from their place of residence, which would be, in the first place, against most laws of African countries and against the political ideologies of their governments.

The basic premise is that residents, probably the vast majority of them, acquire customary rights, of "occupation in good faith" of the plot in which they reside, if they are settled for long enough. However, even that a family does not fit into this parameter, there will certainly be no interest in making their life even more difficult, forcing them to move and achieve any geometric order of efficiency and very debatable justification.

The imposition of a straight orthogonal grid system with the ground subdivided into blocks as the only solution for a structured urban fabric is, in most cases, consolidated slums, a violence which should not even be considered as it entails excessive costs and the alienation of residents in terms of their peaceful relations with the authorities.

The environment for the proposed planning above should be a central theme for discussion in a forum dedicated to problems of upgrading and rehabilitation of slums. It is not possible to build a national attitude and policy for the purpose of "cities without slums" without the definition of a general and commonly accepted position to this problem.

The implications of an operations philosophy as set out above are that cities must acquire the technical capacity to organize and administrate and be provided with the necessary tools and resources for the planning of rehabilitation operations to improve their slums, since such programs cannot be fulfilled just by projects on paper. Most African countries have a limited number of trained planners, mostly located in major cities and with more expectations of what can be secured by an employee's salary.

There is, however, a sufficient number of young people, mainly graduates, willing and available, and to ensure sufficient capacity for all possible rehabilitation programs and improvement of slums in the main cities of those countries, if conditions are minimally guaranteed for acceptable working conditions. In Mozambique, this experience is very positive and reliable, in which with a smaller fraction of the cost. Rather to import these projects and specialists, the technical needs that allow building a solid and consistent program of improvement and rehabilitation of slums can be resolved internally.

Another condition is essential for the success of the program, which depends on technicians with limited experience in the face of major difficulties. These technicians need constant technical support to give them confidence and permanent control, since in most cases they will be working in large isolation and with many difficulties of access to technical information. On the other hand, the exchange of experiences and the learning from the successes and mistakes of others also indicates the need for a support that works as a place of concentration and dissemination of experiences and of building a collective memory on this matter.

The creation of a central support unit made up of experienced, highly mobile technicians with access to specialized technical capacity whenever necessary, is an indispensable complement to the distribution of technical capacity by the municipalities.

How to Use the Resources Available for the Improvement and Rehabilitation of Slums

Slums are urban areas that do not provide residents with minimally acceptable living conditions.

These conditions are of a different nature and should be studied and resolved with various strategies. The most obvious aspects that require attention and corrective measures are:

- The occupation of inadequate places where the risk of floods or other forms of erosion can even lead to loss of life
- An inadequate location in relation to the urban structure of the city, the system of streets and roads, or topography of the terrain
- Lack of basic services – water, sanitation, garbage collection, energy, and communications
- Exaggerated human density
- Very low build quality in homes and other buildings
- Lack of an adequate road network
- Lack of public lighting
- Lack of a personal identification system such as street names and house numbers
- Lack of organized public spaces
- Insufficient provision in terms of social facilities such as schools, medical services, markets, organized commerce, public administration, police, leisure equipment, religious buildings and dignified sports and cultural facilities, banks, etc.

Some other characteristics of slums in Mozambique are less tangible but nevertheless still significant to the lives of the residents:

- Lack of safety in relation to the occupied area
- Non-awareness of the legal rights and mechanisms to be used and those to appeal to the defense of their own rights
- Inaccessibility to credit

- Distance (psychological and physical) from municipal authorities
- Failure of a communal spirit and motivation for associative initiatives
- Lack of control of criminal and illegal activities

Of course, not all of these conditions exist in all slums and with the same degree of importance or incidence, but these are problems that must be considered when designing an intervention strategy for the rehabilitation or improvement of slums.

Therefore, the possibility that through one of the bi- or multi-cooperation agencies there may be funds available to intervene decisively in the improvement or rehabilitation of slums in African cities can be considered.

What to Do

What is the order of priorities of the problems to be addressed first? Where to start? In what city? In which slum? This is a series of very difficult questions to answer and requires policy decisions that should be translated into guidance documents.

However, before and to inform the policy decision, there is a need to define a basic strategy for the quantification of the financial, technical, and logistical resources necessary for the intervention. What are the parameters essential to consider for the construction of this strategy? Taking the indications that come to us from the previous situation described, the following aspects should be considered as a solid basis on which to construct a strategy:

- The need for an intimate knowledge of the state of affairs in all aspects above and any other specifics in each case.
- The need to consider the rights of all residents as the first reality on which to base intervention: this means that, even in cases where there may be an imperious need to transfer the families, each family is entitled to compensation proportionate to the value of their occupation and situation.
- The need to establish a data and registration system for each case and each family occupation, duly recognized and witnessed by neighbors.
- The need to know the number of residents, their demographic composition, professional qualification, wages or sources of income, etc.
- The insertion of the slum in the urban structure and its connection with the road system, infrastructure networks, services, etc.
- Topography, hydrology, geology, ecology, microclimate, and all parameters and dimensions of the site.
- The potential of the municipality to provide the necessary data and information and to assist or carry out the intervention program.
- Possible alternatives for the transfer of all or part of the residents, if necessary.
- The existence of community or social organizations to be involved in the whole process and in families.
- The structure of the municipal authority in the neighborhood.

It is easy to recognize that much of the information and, in certain cases, almost all the necessary information do not exist or are impossible to obtain with the technical and logistical means available in the municipalities. Not only the lack of information but the municipalities do not have the necessary capacity to direct and control the investigation operations, registration, and creation of databases and systematize your files, query, and update and finally make use of information.

This situation is true, to varying degrees of severity, for almost every municipality in African cities.

The above operations are a sine qua non for the viability of any slum or, for the same reasons, for any intervention in the cities. One cannot wait for administrations fully operating and equipped with experienced and competent technical staff for the upgrading or rehabilitation programs as urgently as possible needed for African cities. But one must use the opportunity that arises for the launch and development of a slum improvement program, to build capacity, acquire necessary experience and to create the municipal administrative and technical structures for the correct functioning of these cities.

This means that, assuming that you have the resources for a "slum-free city", the first step should be to create the necessary mechanisms to make municipalities able to identify and quantify the problem and equip them with the cartographic means and the technical data indispensable to any rehabilitation or resettlement exercise and with the necessary and sufficient means for archiving and consulting the collected data.

The first and most common obstacle to the design of a viable and realistic intervention in any African cities is in fact the lack of the most basic and essential information in usable form. In most cities, a series of planning exercises and planning territory, commissioned and paid to consultants from all parts of the world, from inside or outside, take up a lot of space in public administration shelves and drawers and serve little purpose because neither in its elaboration nor for its impossible implementation were they created or involved in any degree of local capacity. These considerations bring us back to the first element indispensable to any planning strategy – participation.

Participation is a necessary form of work not only in finding solutions to urban problems but also as an indispensable element in the training of the technical municipal sector. To prepare a plan away from its human context and its administrative reality, or without involvement of the local community and municipal agencies, is to miss the best opportunity to form the people and build the institution.

One may risk setting a first priority, where it does not yet exist: the creation and institutionalization of internal competence for planning and to conduct, monitor, and implement the planning of instruments in each municipality. To materialize this first step, or priority, three resources are required:

- Technical and administrative capacity within the municipality
- Logistic and material conditions for the work of the technicians and for the services in charge of the planning
- Technical and legal support

This mechanism, which until now has been virtually absent in all municipal administrations, should make possible the organization and operation of the participation process.

We have already seen that in African countries, we can find trained professionals, in sufficient numbers, capable and available to assume the responsibilities defined in the terms of reference, outlined here, for the your job. Existing examples demonstrate their ability to adapt to very difficult conditions of producing very relevant results with a minimum of technical support.

Where the greatest difficulties are manifested and where external contributions can make a difference is in the creation of working conditions, both logistic and financial, to pay these technicians, acquire the equipment and ensure working conditions for their planning exercises. The presence of these technicians in the municipal administration does not, by itself, guarantee the solution of planning problems since they will face a large number of situations requiring external technical support, up to now impossible to provide on a permanent basis to all municipal administrations.

This needs to be set as a new priority - the creation of a national support mechanism for each of the countries to meet the needs of the technical services of the different municipalities, to solve specific cases of a technical nature and to act as a crossing mechanism of experiences and information, and also to hire the specialized capacity to solve *sui generis* problems.

The nature of this mechanism, as well as its insertion into the national municipal system, is not simple to define and to quantify. However, it is clear that it must be composed and appeal to the most experienced technicians in the country to consultants in the definition of programs, technical strategies, and solutions for each problem that cannot be resolved locally. Ideally, it should be an independent body capable of building a philosophical basis for the broad guidelines of planning to be proposed to each and every municipality of the countries. It should most likely be dependent on an Association of Municipalities provide an in-depth and extended view of the difficulties of urban planning in the country, and a discussion of the policies produced as the result of the common experience, that this body would integrate.

It is our conviction that without this mechanism of support the acquisition of experience, in all the diverse situations, cannot be sufficiently matured or become a usable set of guidelines for urban planning activity, and in particular for rehabilitation and rehabilitation programs and improvement of slums in African countries.

The creation of a consultancy body of this nature requires sufficient resources for the fees, for the establishment of minimum working conditions and for its own administration and an administrative and permanent technician. The logistics of this component within the overall strategy assume some importance given, whereas a high incidence of transport should be foreseen and a substantial specialized. They should be provided with sophisticated computerized means and an advanced system of archiving and distribution of information.

This body should also assume as its task the preparation for publication and dissemination of the information as a vehicle for contacts between municipalities and with international organizations. Finally, it should also take responsibility for the regular organization of technical nature where the experiences and advances in planning are discussed and object of critical analysis.

The description of the nature of this support mechanism makes clear that it is not proposed to duplicate any existing governmental structure or assume any of its functions. This description is intended to also clarify the notion that it should be a very "light" administrative body whose usefulness will depend exclusively on its efficiency and responsiveness.

8.8 Concluding Notes

Framing the notions, the diversity of typologies and problems encountered in slums, and the interventions implemented throughout history to solve them, the importance of finding operational planning mechanisms designed specifically for each of the intervention cases is emphasized. This is the main factor that we consider to be decisive for the successful application of resources, which are always scarce in African countries, to solve the problem.

In addition to the adaptation approaches presented throughout the chapter, it is also important to find proactive approaches that can be a decisive factor for sustainable urban development in the context of the high rate of urban growth in the next decades.

The problem of defining and quantifying a decisive contribution to the improvement of slums cannot, within the limits of such a contribution, be resolved or even definitively established. It is our conviction, however, that without understanding what has been shown and without the mechanisms proposed here, not even this definition and quantification will be possible or valid since the application of resources, without the capacity for its administration, can only lead to waste and frustration and to delay structured solutions for this, very urgent, order of urban problems.

If participation is the key to successful slums improvement and planning is an indispensable condition for proper use of resources, then the establishment of planning capacity is the indispensable condition for the success of the participation oriented to the most effective use of available resources.

In line with the Cities Without Slums initiative in the United Nations Millennium Development Goals, we recognize that poverty is one of the root causes and at the same time one of the consequences of slums. In order to counter this, actions and policies are also needed to reduce or eradicate poverty. We would also like to isolate a particular aspect of the impact of slum upgrading operations, which are often overlooked but which have a fundamental value for the sustainability of interventions, especially in African countries where poverty and unemployment rates are predominant high. The application of funds and external resources in the slum environment can and should be a privileged moment to provide employment to residents who can learn new skills and abilities and develop economic initiatives, contributing to a positive sense of change, without which the causes to the degradation situation will subsist.

The rehabilitation of a slum should lead to the creation of permanent jobs, once the notion of common services and benefits is inserted into the community values, which should be one of the main consequences of any urban improvement intervention.

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Chapter 9
Sustainability Challenges for Sub-Saharan Africa: Vulnerability, Justice and Human Capabilities

Carla Gomes

9.1 Introduction

The global discourse on a desirable path to development has long moved from an emphasis on economic growth towards a conception of development as the fulfilment of human capabilities and freedoms. The concept of human development – considering levels of education and nutrition, among other factors – has been widely adopted by the United Nations and international institutions, beyond a conventional notion that mostly associated development with the gross domestic product of countries.

Still, the underlying goal behind global policy agendas such as the United Nations Millennium Development Goals (2000–2015) was to meet human necessities, such as food, housing and education. The problem of natural limits to growth (Meadows and Club of Rome 1972), or planetary boundaries (Rockström et al. 2009), was not yet fully integrated into the development agenda. This disarticulation has persisted as climate and environment global negotiations moved forward, under the umbrella of different agencies of the United Nations (Conferences of the Parties of the United Nations Framework Convention on Climate Change – UNFCCC, Rio +10, Rio +20).

It was only recently, in 2015, more than two decades after the breakthrough UN Conference Rio'92 – which instituted landmark policies such as the Agenda 21 and principles such as the 3 R's for waste management (reduce, reuse, recycle) – that the development and environment agendas have come together more firmly, and formally, as the Sustainable Development Goals (SDG). The new sustainable development agenda for 2030 was approved in 2015, in parallel to the Paris Agreement on Climate Change, inaugurating a new stage in development global policy.

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The SDGs, comprised of 17 sustainable development goals with 169 targets and 230 indicators, cover a wide range of fields such as health, education and access to water and energy, and embody the official recognition that poverty alleviation cannot be fulfilled at the expense of the planetary resources and future generations.

Yet, the SDGs rely strongly on technological optimism: on one hand, the expectation that technological solutions will provide the answer to most difficulties and on the other, without a full acknowledgment of the trade-offs between the 17 goals themselves. Hillerbrand (2018), for instance, questions the association swiftly established between renewable energy and sustainable technology, when the utilisation of renewable energy requires a consideration of its social and environmental implications in each local context.

For some socio-environmental problems, such as emissions of sulphur dioxide (SO_2), ‘end of pipe’ technologies may have served well – apparently giving reason to the environmental Kuznets curve hypothesis – Haberl et al. (2011) argue. However, the authors are sceptic about the reach of technological ‘fixes’ and consider that a post-sustainable development approach will be required over the coming decades – a more profound social and economic change that goes beyond the modus operandi of the industrial era, a real socio-metabolic transition.

The SGDs are a largely consensual agenda and therefore encompass a myriad of specific goals and indicators that do not necessarily reinforce each other – such as employment growth and the conservation of ecological resources. Furthermore, there is a need to address the social impacts of adopting given technologies, i.e. integrating the human dimension when operationalising a notion of sustainability in development initiatives. Each local context – in its political, cultural and social dimensions – will significantly influence how energy, or water, is utilised, distributed and negotiated, for instance.

The current challenge is to operationalise a concept of sustainability that is compatible with human freedoms and capabilities (Sen 2013), as well as democratic principles of political participation (Holden et al. 2014). We need to interrogate whether sustainability policies contribute to the fulfilment of human needs and well-being but also whether they are just for individuals, social groups and communities. In this chapter, I will argue that the perspectives of human capabilities and environmental justice (EJ) – which have been gaining ground in the study of international development – are especially fruitful for a critical examination of the SDGs.

There are also very important synergies between the SDGs. Energy access and use (SGD 7), for instance, are inextricably associated with gender equality (SDG 5), if we consider the burdens that fall mostly on women and children (e.g. collecting wood and cooking). The same can be said of water collection and transportation in most rural areas in Africa (SDG 6).

The gradual convergence of the justice movements across the developing world – for climate, food, land and environmental and land justice – is a good expression of how these fields are inextricably connected. The often adverse reaction of local communities to climate mitigation programmes, reforestation and conservation initiatives (such as REDD) demonstrates the complexity of human-environment relationships and also the dissonance between global agendas and local realities (Martin 2017).

Sub-Saharan Africa (SSA) has recurrently been the region considered as lagging behind in relation to most development goals – such as access to clean water and energy. More than half of the world's extreme poor live in sub-Saharan Africa (ECOSOC-UN 2018). In addition to the SDGs, other agendas were established with the goal of tackling poverty and boosting human development in the continent – the Agenda 2063, by the African Union, and the High Fives (Hi5s) of the African Development Bank (AfDB).[1] These have different time frames, but many of the goals converge.

Energy and water access are as always among the key priorities for African development, across the different policy agendas. And there is a growing argument that these two resources should be evaluated as a nexus, often in addition to land and food (WELF). The implementation of the SDGs will undoubtedly constitute a testing ground for nexus thinking, as a way to represent and analyse the trade-offs and synergies between different policy goals (Bazilian et al. 2011; Ringler et al. 2013).

The poverty-environment nexus is also crucial, as the poorest people often are those who rely most directly on natural resources and those who take the heavier burden of their depletion or environmental changes, such as climate change (United Nations Development Programme 2016). It is therefore determinant to take into account how the distribution of resources is shaped in a specific local context. Far from being a straightforward issue, access to resources involves complex social and political dynamics. As Ribot and Peluso (2003) have argued, people can obtain access through various ways, resorting to a 'bundle' of power and resources, which include social relations and identities, technology and knowledge.

Environmental justice researchers have increasingly integrated the capabilities approach within their conceptions of social justice (Edwards et al. 2016). Considering Martha Nussbaum's list of central human capabilities (2011), there are many points in common between conceptualisations of procedural justice, in the EJ approach, and such capabilities as 'Control over one's Political Environment' – *Being able to participate effectively in political choices that govern one's life; having the right of political participation, protections of free speech and association*.

Distributional and access concerns – over land and natural resources, among others – have been central to justice theories since Rawls's Theory of Justice and Sen's Idea of Justice. Recognition of one's values and ideas – about the good life and the proper way to relate with the environment – also pervade the capability approach, including recognition from government institutions and relations of mutual recognition (within work, family and friendship realms).

The capability approach poses difficult challenges, though. It is focused on the individual and adopts a subjective and comparative conception of well-being, rather than universal principles of fairness. In this light, for a specific policy or agenda to

[1] Five priority areas were included in the AfDB 10-year strategy (2013–2022): Light Up and Power Africa, Feed Africa, Industrialize Africa, Integrate Africa and Improve the Quality of Life for the People of Africa.

be considered just, it has to take into account what the involved people value most and which type of life they consider worth living and pursuing, across multiple dimensions: material, emotional, spiritual and affective. In other words, what is their conception of the 'good life' (Dworkin 2011).

There is much scope for further integration between the capability and EJ approaches, which are particularly appropriate for a critical examination of sustainable development agendas on the horizon of 2030 and beyond. There are also multiple challenges ahead – methodological, ethical and political – if we envision an international development that is simultaneously sustainable and just, in the absence of universal definitions for both sustainability and justice.

I will now address the key challenges in four areas critical for sustainable development in rural Africa over the coming decades. These are related to SGD number 7 (energy), 6 (water), 2 (food security) and 13 (climate change).

9.2 Energy

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all

From 2000 to 2016, the proportion of the global population with access to electricity increased from 78% to 87%, with the absolute number of people living without access to electricity dipping to just below 1 billion (ECOSOC-UN 2018).

The number of people without access to electricity in sub-Saharan Africa stopped increasing in 2013 and has since declined, led by strong efforts in Cote d'Ivoire, Ethiopia, Ghana, Kenya, Sudan and Tanzania. Since 2012, the pace of electrification has nearly tripled relative to the rate between 2000 and 2012 (International Energy Agency 2017).

The total installed generation capacity in sub-Saharan Africa is 122 gigawatts (GW). Almost three-quarters are fossil fuel-based, with coal accounting for 35%. Renewables make up about a quarter of total capacity, mostly secured by large-scale hydropower. The International Energy Agency estimates that, in an optimist scenario in which new policies are implemented, hydropower capacity in SSA increases from around 20 GW in 2012 to nearly 95 GW in 2040, representing one-quarter of the growth in total power generation capacity (IEA 2014).

Around 18 million people gained access from renewable-based power in sub-Saharan Africa each year between 2012 and 2015, particularly large-scale hydropower and geothermal (mainly in Kenya), a considerable increase from the 3.5 million people who gained access from renewables each year on average from 2000 to 2012 (IEA 2017).

Still, whereas India is expected to achieve universal access in the early 2020s, due to its electrification efforts, in sub-Saharan Africa these efforts are not enough to compensate for population growth (both urban and rural). By 2030, 600 million out of the 674 million people without access to electricity will live in sub-Saharan Africa, a majority of them in rural areas, where the electrification rate is less than 25% (71% in urban areas) (Fig. 9.1).

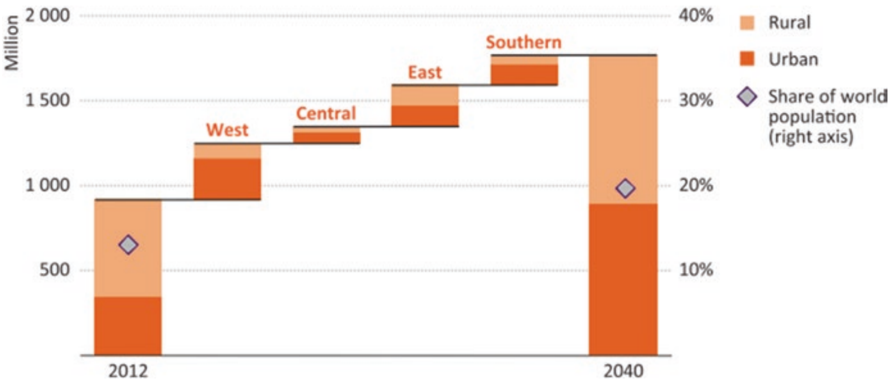

Fig. 9.1 Population growth in Africa (IEA 2014)

Another persistent problem is the lack of clean cooking. Reliance on coal for cooking, without adequate conditions, causes air pollution, which is deemed responsible for some 2.5 million premature deaths each year, apart from various health problems, such as cardiovascular disease, stroke, chronic obstructive pulmonary disease, lung cancer and acute lower respiratory infections (IEA 2017). Sub-Saharan Africa, most of Asia and Oceania (excluding Australia/New Zealand), have the highest mortality rate from air pollution (ECOSOC-UN 2018).

As Holden et al. (2014) point out, although there is a positive outlook for the development of RES, various factors will influence their integration in the energy system in Africa, such as costs, environmental issues, public acceptance and infrastructure constraints. The high reliance on external funding, lack of continuity and low levels of ownership among local communities have been issues constraining the implementation of renewable energy projects in African countries (Gomes 2010).

If we envisage an integrated concept of sustainable development, with attention to its social dimensions, we need to carefully assess the impacts on local livelihoods and well-being of the implantation of RES infrastructures. On the other hand, RES has required energy-storing technologies, such as lithium batteries, which mining – concentrated in just a few countries in the world, such as Bolivia – has also raised concerns over its impacts on local communities (Sanchez-Lopez 2017).

9.3 Water

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Although there have been undeniable advances over the MDGs period – an increase of 20% in access to improved sources of drinking water – this remains a huge challenge for sub-Saharan Africa. In 2015, approximately half of the global population living without access to an improved source of drinking water were in this region

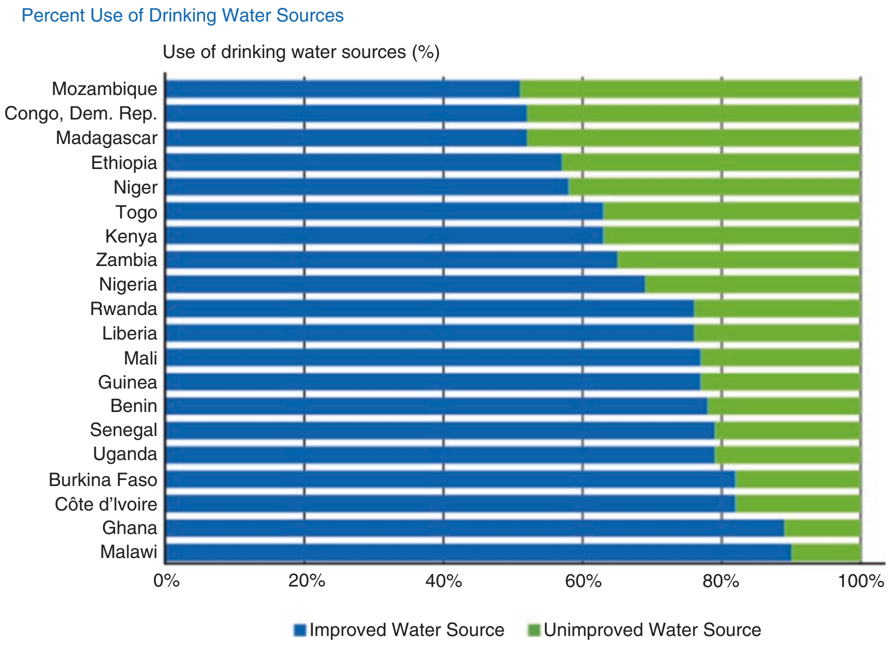

Fig. 9.2 Access to drinking water sources (WHO/UNICEF 2018)

(ECOSOC-UN 2018). The MDG goal of achieving 74% access globally is yet to be accomplished, and in SSA more than one-third of the population still lacks access.

Among the rural population in SSA (excluding high income), 43% of people had access to at least basic water services in 2015, up from 30% in 2000 (WHO/UNICEF 2018). This includes access to any improved source that is no more than 30 minutes away from the household (round trip), such as piped water or protected springs (Fig. 9.2).

Lack of access to clean water and sanitation has obvious and historically recognised consequences. Water-borne diseases (such as dysentery, cholera, typhoid, diarrhoea) are still among the main causes of death, especially for children under 5 years old (ECOSOC-UN 2018). The burden falls especially in vulnerable social groups as women and children, requiring long walks to collect water, for instance – contributing to frequent school dropout and reducing time available for a myriad of household and economic activities.

Another critical issue is irrigation, as most smallholder farmers rely on rainfed agriculture, which is becoming more challenging in face of population growth and climate change. Sub-Saharan Africa, once again, is the region with the lowest irrigation rates in the world, around 4% of the cultivated area, against approximately 21% at global level. Historically, there were a number of factors that led to low levels of irrigation in SSA, including low population density and diets based on crops that did not require much water. However, with population growth and new attention from

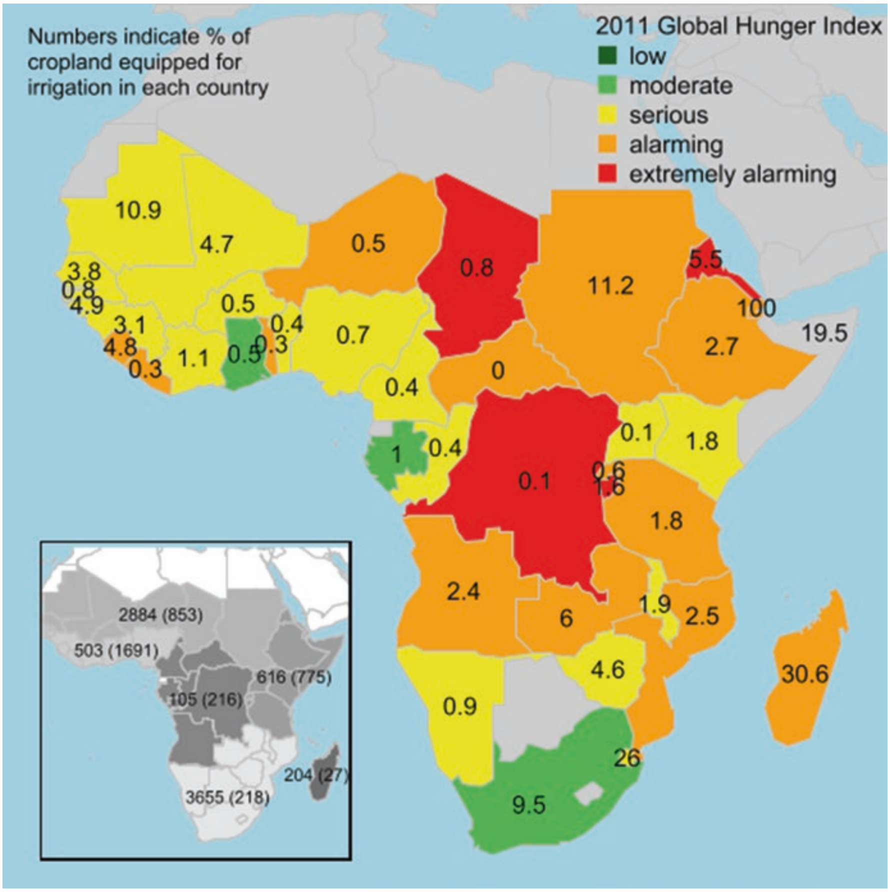

Fig. 9.3 Irrigation coverage in SSA (International Food Policy Research Institute 2012)

agriculture investors, this trend is expected to change significantly over the next decades (You et al. 2011).

If there is still a wide potential to invest in irrigation systems in Africa, it is also true that not all countries have significant water resources available. Seven countries concentrate about 60% of the irrigation potential (Angola, Sudan, Egypt, Zaïre, Ethiopia, Mozambique and Nigeria), while at the other end of the list, 18 countries share only 5% of this potential (Fig. 9.3).

The infrastructure costs and the availability of water resources have to be carefully assessed, if large-scale irrigation systems are to be sustainable in economic, social and environmental terms and over the longer term. On the other hand, population growth and the surge of land acquisitions (or concessions) by corporate investors, often transnational, increases competition for lands located near rivers and other natural resources, which will also require careful attention over the next decades.

In face of the challenges ahead, there are different strategies on the table. Large-scale irrigation systems might not be the best option for every region. Distributed smallholder irrigation systems, adaptable to social and environmental circumstances, will also require more investment in the future, especially on simpler and low-cost technologies such as low-cost motorised pumps. Agricultural productivity, including the ability to produce crops all year round, will be key to improve food security.

9.4 Land and Food

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Faced with multiple pressures, including climate change and population growth, the prospects for reducing hunger are not at their best today. The Progress Report released by the United Nations in May 2018 acknowledges that 'after a prolonged decline, world hunger appears to be on the rise again' and the prospect of ending hunger and malnutrition by 2030 has become more difficult (ECOSOC-UN 2018).

SSA is the only region globally where per capita production of staple foods has declined over the last 50 years and where major famines persist, mostly due to recurrent droughts and difficult climatic conditions in general (Burney et al. 2013). The majority of smallholders in Africa hold only 1 or 2 hectares of land, and as population grows, it has been increasingly difficult to secure enough area to grow their household crops, especially with good productive conditions.

Malnutrition manifests itself in various forms and has serious long-term consequences for the world's children. While declining in almost every region, stunting (being too short for one's age) globally affected 22% of children under 5–151 million children in 2017. Three quarters of these children lived in Southern Asia and sub-Saharan Africa. In 2017, 51 million children under 5 suffered from wasting – low weight for one's height – and 38 million were affected by obesity.

Volatile food prices and low government support for agriculture are among the critical factors for current trends of malnourishment in sub-Saharan Africa. Food insecurity is a persistent problem across the region, aggravated by military conflicts and subsequent migrations.

There have been calls for an African Green Revolution, through a dramatic increase in agricultural productivity (Diao et al. 2008; Kerr 2012). An Alliance for a Green Revolution in Africa (AGRA) was created in 2006, chaired by the former Secretary General of the United Nations, Kofi Annan, and is funded by the Bill and Melinda Gates and the Rockefeller Foundations. The main goal is to increase the incomes of smallholders and improve food security for 30 million farming households in 11 African countries by 2021. The selected countries are located in three geographical areas considered to be 'high-potential' and 'under-exploited agroecologies': the Guinea Savannah zone (Ghana, Nigeria, Mali and Burkina Faso), the East African Highlands (Ethiopia, Kenya, Uganda, Rwanda and Tanzania), and the Miombo woodland (Malawi and Mozambique) (AGRA 2018).

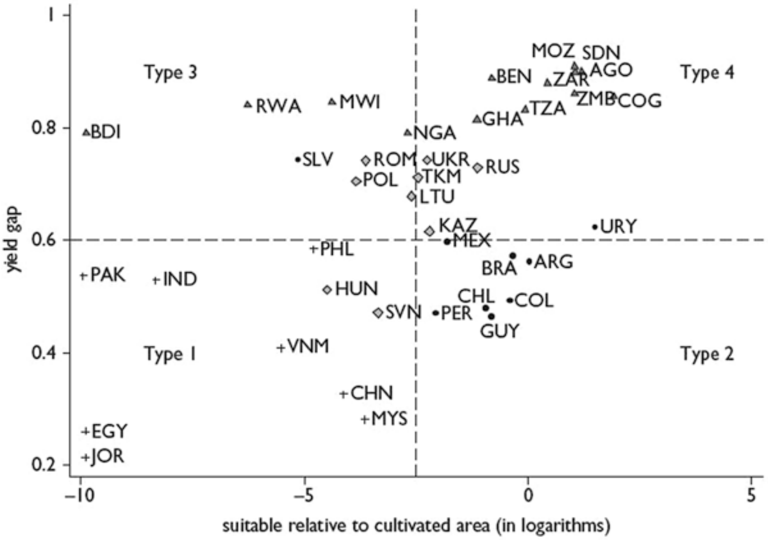

Fig. 9.4 Potential land availability vs. for increasing yields. (© World Bank. https://openknowledge.worldbank.org/handle/10986/2263. License: CC BY 3.0) (Countries classified in four types: little land for expansion, low yield gap (type 1); suitable land available, low yield gap (type 2); little land available, high yield gap (type 3), suitable land available, high yield gap (type 4). Most countries identified as type 4, i.e. with larger yield gaps, are in sub-Saharan Africa, including Mozambique (MOZ), Tanzania (TZA), Sudan (SDN) or Zambia (ZMB). Some of these countries have been top targets for land investors, such as Mozambique, South Sudan and the Democratic Republic of Congo)

In addition, the low productivity of smallholder farmers and the perception that arable land has been underused (Fig. 9.4) have been key arguments in support of the liberalisation of land markets across African countries. There was a surge of large-scale land acquisitions over the last decade – often in the form of long-term government concessions (usually 50 years renewable). On one hand, these farmland investments bring new capital and machinery and are expected to generate employment in rural areas. On the other, they have been raising concerns among non-governmental organisations (NGO) and civic movements, which fear negative impacts on local food security and land access.

The rise in land deals, besides population growth, is one of the factors contributing for competition over the most accessible and productive lands (not necessarily those that have considered to be under-explored). Areas near rivers and infrastructures, such as roads, have been attracting the most investors, according to recent research (Hall et al. 2015). Increased pressure over land availability might also constrain local practices, including shifting cultivation, and traditional strategies for climate resilience. In recent empirical research in Mozambique, smallholder farmers recurrently report they no longer practice shifting cultivation due to a 'lack of space' (Gomes 2017).

While international organisations, land investors and national governments back a 'Green Revolution' for Africa – supported on 'modern' inputs such as machinery, chemicals and possibly genetically modified organisms (GMO) – NGOs, civic movements and peasant organisations advocate for an agriculture which values local knowledge more and for approaches that allow to conciliate traditional practices with innovative ones such as Conservation Agriculture or Evergreen Agriculture. There is a growing concern that 'modern' agriculture requires that smallholder farmers abandon their lands, in countries where around 70% of the population depends on their farm plots for survival. The potential for local employment – one of the major perceived benefits of these projects – has also proved more modest than expected (Li 2009).

Although most African countries have not adopted genetically modified crops yet, many have started field tests and intend to begin production of GMO varieties in the near future, including, for instance, varieties of drought-resistant maize. Countries such as Mozambique, Tanzania or Kenya have recently conducted field tests, but adoption of GMOs in Africa remains controversial (Falck-Zepeda 2013).

The critical challenge, in sum, is to increase food production and agricultural productivity in a sustainable way, in the environmental and social dimensions. This requires controlling chemical pollution (pesticides, fertilizers) and the emission of greenhouse gases (e.g. methane), avoiding overexploitation of water sources, while also preventing social disparities and conflicts. 'We will have to produce more with less', recognises FAO's 2017 report on the State of Food and Agriculture. It is estimated that food production will need to double over the next 30 years, to keep pace with population growth while improving food security. Climate change will make the fulfilment of that goal even more challenging.

9.5 Climate Change

Goal 13. Take urgent action to combat climate change and its impacts

Climate change is expected to affect the African continent severely over the next decades. Around 70% of the population lives in rural areas and depends on smallholder agriculture, which is becoming increasingly difficult with unstable weather, recurrent droughts, floods and heavy rains. A significant reduction in annual precipitation is expected in Western and Southern Africa. FAO's report 'State of Food and Agriculture' acknowledges that climate change is a significant threat, with the potential to undermine decades of achievements in poverty and hunger alleviation (FAO 2017).

According to the most recent report of the Intergovernmental Panel on Climate Change, maize-based production systems in sub-Saharan Africa are among the most vulnerable to loss of agricultural productivity. Besides more frequent and intense climatic events, the rise in mean temperatures will favour the propagation of crop diseases (Niang et al. 2014). Climate change is also expected to have a significant impact on the potential for irrigation expansion, as well as affect the suitability of given crops for specific geographical areas (You et al. 2011)

The Agricultural Model Intercomparison and Improvement Project estimates that until 2050 the mean global productivity will decline between 5% and 7%, relative to a world without climate changes (AGMIP 2018).

In parallel with mitigation efforts, adaptation is already the priority in global climate policy, in line with the Paris Agreement (approved in 2015, in force since 2016) and the Sendai Framework for Disaster Risk Reduction 2015–2030. Most countries in SSA have already initiated the process to elaborate their National Adaptation Plans. Seychelles, Nigeria, Cote d'Ivoire, Zimbabwe, Kenya, Gabon, Cameroon and Ghana, for example, have been integrating adaptation into national development planning. Giving the impacts expect on agriculture and water availability, land use planning is a critical area in this context (NAP-GSP 2017).

9.6 Conclusions: Capabilities and Justice for Sustainability

There is a strong risk that climate change reduces the impact of aid and development initiatives in the poorest regions of sub-Saharan Africa, over the coming decades. The least developed regions (according the human development indexes) are often the most vulnerable to climate change. It is the case, for instance, of Northern Mozambique, where official surveys reveal that rural poverty has not been improving and agricultural productivity remains insufficient. Worse still, climate change is expected to aggravate the situation, especially due to the higher frequency and intensity of droughts, floods and heavy rains.

Having said this, any changes in practices – whether adoption of new technologies or management techniques – will be faced with cultural, economic and political constraints that should be careful observed. Venot and Clement (2013) note that interventions for water management, for instance, have a political nature, and therefore attention has to be paid to procedural (participation and empowerment) and distributive (equity) justice issues when analysing different options. Public participation in decisions regarding these initiatives, as well as acceptance of change, are some of the key implementation issues that we will have to consider when striving to materialise a notion of sustainable development (Holden et al. 2014).

Furthermore, recent economic shifts, such as the surge in large-scale land acquisitions, can reinforce existent social inequities (Gomes 2017). A closer attention has to be paid to the differentiated – and sometimes even unintended – effects on the most vulnerable groups of society, taking into account the specific circumstances of each local context – environmental, cultural, social and political.

While pursuing the SDGs, it is crucial to investigate the socio-economic realities influencing climate resilience and food security, for instance. Innovations such as climate-smart agriculture will require, beyond technical solutions, genuine recognition of the local practices and ecological knowledge. In general, indicators and targets of sustainability need to be more context sensitive (Hillerbrand 2018).

From the perspective of the capability framework, climate change impacts appear as disrupting these specific human capabilities and thus impairing human development. On one hand, the capabilities approach can be applied to the mapping of climate vulnerabilities, with the direct involvement of the affected communities. On the other hand, the preservation or restoration of capabilities can work as a benchmark for adaptation policies and strategies (Schlosberg 2012).

In pursuing a sustainable development that protects and enhances human well-being – a socially sustainable development – there are tensions needing further analysis, such as whether, and when, we should give prominence to individual or societal goals (Edwards et al. 2016). The combined perspective of human capabilities and environmental justice can offer a fruitful contribution for analysing the trade-offs involved in achieving the SDGs, in Africa and elsewhere.

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Chapter 10
Toward Sustainable and Smart Cities in Africa: A Review and Challenges

Maria Lampreia Dos Santos and Manuel Mota

10.1 Introduction

This chapter presents the main challenges to be overcoming in order to have sustainable and smart cities in Africa in the future. The analysis highlines confirm the existence of huge challenges, problems, and restrictions about social, economic, and environmental and political issues in Africa. This chapter analyzes the main constraints of urban development on the African continent and confirms that smart cities will be possible in Africa when the current problems of sustainable development (economic, social, environmental, and political) are overcome. However, the chapter allows us to understand why this is the first chapter in the literature to address the topic of smart cities in Africa. It should be noted that in this continent there are at least two of the world's largest cities in terms of inhabitants, and the population growth rate of the African continent is about 2.5%. So, this is a world problem to minimize. The concern about the problems of sustainable development in this region and how to promote it toward sustainable cities competes to all and the follow way will affect all of the world sustainable development.

In the last decade there have been unprecedented and often unforeseen economic, political, social, and environmental changes with direct impacts on the urban environment in general in the world and in Africa in particular.

At political level the instability arising in some regions of Africa and the Middle East (Fisher and Rucki 2017) allied to the unfavorable economic conditions (due to the fact that they are mostly African countries in development), as well as economic

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volatility in the energy sector (Brewer et al. 2014), combined with change in environmental conditions, because nowadays climate change has severe implications for the security of individuals, communities, cities, regions in Africa and in the planet (Yigitcanlar and Kamruzzaman 2018; Fann et al. 2015). All these factors combined have led to migratory movements out of African countries and tending toward urban centers in Africa and abroad.

Nowadays 40.6% of the population in Africa lives in urban areas (World Bank 2018), but the rate of urbanization varies across regions on the African continent. Increasing urbanization in sub-Saharan Africa was recognized by Schlesinger et al. (2015), as well the impacts and spatial configuration transformations in and around towns and cities.

Some of the biggest cities in the world are on the African continent, namely, Lagos (Nigeria) on the Mediterranean/African continent. The growth rate of urban population is increasing following the world trend with about 55% living in urban areas in 2017 (World Bank 2017). The year 2007 marked an important development in the history of urban cities in the world, because, for the first time, the share of total population living in cities exceeded 50%. Urbanization has become a major global trend, with ever-increasing degrees of urbanization reaching 70% (Kourtit et al. 2017; Dos Santos 2016): By 2050, 75% of the world's population will be living in urban areas (United Nations 2015), and this figure will reach over 80% at the end of the century (Yigitcanlar and Dizdaroglu 2014; Yigitcanlar and Kamruzzaman 2018).

This implies that cities in African continent also need to be sustainable and smart. Over the last decades, these interlinked issues of developments have started to converge under the new heading of smart sustainable cities (Höjer and Wangel 2015). In recent years, the concept of smart sustainable cities has come to the fore, and it is rapidly gaining momentum and worldwide attention as a promising response to the challenge of urban sustainability (Bibri and Krogstie 2017). Despite numerous research opportunities available that are worth exploring, the field of smart sustainable cities is still in its early stages of development (Bibri and Krogstie 2017). According to these authors, this pertains particularly to ecologically and technologically advanced nations, but are in absence in African cities. So far, there are yet few links between sustainability and smart cities in the developed countries. However, there is not yet any reference in the literature to smart sustainable cities in Africa. Similarly, in Africa, cities now face much greater challenges than those affecting developed countries. These challenges are related to economic, social, environmental, and political factors. Therefore, in order for cities in Africa to move toward smartness in the future, it is necessary to previously solve problems of sustainability which nowadays affect them.

In order to address the critical issue of whether smart city policy leads to sustainability of cities, the chapter focuses on the following two research questions:

1. Do smart cities bring sustainability to African cities in terms of economic, social, political, and environmental impacts or the analysis must be done on the opposite way?
2. What are the main factors that lead to sustainability and smartness of African cities?

More specifically, this chapter aims:

(a) To analyze the main economic, social, and environmental problems in the main urban region of Africa
(b) To analyze the current state-of-the-art about urban development, smart cities, and smart sustainable cities;
(c) To analyze if the actual developments concerned about smart cities and sustainability are adjusted to African cities;
(d) To understand the main social, economic, and environmental problems in African cities that can compromise the long-term sustainable development and smartness.

This chapter making a fourfold contribution in the literature:

1. Although there are many studies in the scientific field of smart cities, few of them had analyzed the topic smart cities and sustainability and none of them so far analyzed the complex situation in African cities nor brought to the scientific debate and forecast new insights about these topics.
2. This holistic approach used to analyze sustainable and smart cities in Africa is believed to be the first of its kind and hence has not been, to the best of our knowledge, produced elsewhere.
3. This chapter gives insights to stakeholders and public decision-makers about the way forward in the promotion and development of cities in Africa in a sustainable way, in order to foster research in these innovative areas.
4. This chapter broadens new research opportunities to explore and bring more knowledge in smart sustainable cities in general and in Africa in particular.

10.2 The African Cities: Main Challenges to Sustainable Development

Laros and Jones (2014) analyze the actual situation of major urban areas and cities on African continent. Due to the fact of the big differences among all the major cities in Africa the authors and the literature separate the continent by different areas and challenges of development. According to these authors, the overarching challenge for Africa in the decades to come is massive population growth in a context of widespread poverty that, in combination, generate complex and interrelated threats to the human habitat (Laros and Jones 2014). Table 10.1 presents the main challenges of social, economic, environmental, and political problems in African regions to sustainable development.

The analysis of all the problems on the African continent presented in Table 10.1 shows that it is still difficult in most of these cases and urban regions to promote and develop smart cities. However, if we do not move toward good urban management and sustainability in all its dimensions, Africa's current problems will tend to increase and development will be a more distant target.

Table 10.1 Main challenges of social, economic, environmental, and political problems in African regions/cities

Region and cities	Main challenges				
Region in Africa	Major city	Economics	Social	Environmental	Political
Northern Africa	Cairo (11 million inhabitants)	Low income/habitant; Low attractiveness for FDI.	Young unemployment; Exclusion; Low professional skills and education; Social struggle Migration and refugees' problems on the borders.	Climate change, projected to exacerbate existing desertification and water stress; Urban pressure and exclusion; Highly urbanized.	Political instability from "The Arab Spring"; Political struggle.
Western Africa	Is the most rapidly urbanizing sub-region Significant gaps in urban data availability and reliability in the sub-region.	Economic activities conducted by small, informal sector actors, as well as larger formal sector actors, are mediated through urban agglomerations along corridors, which extend across borders and sub-regions Emerging urban middle classes in the sub-region are key to sustaining growth and foreign direct investment.	Lack of regional and local urban infrastructure hampers sub-regional economic growth and development. Key regional infrastructure deficits in logistics and transport, port infrastructure, information and communications technologies (ICT), and energy persist to the detriment of efficient storage, transportation of goods and people, etc.	Current and projected climate change impacts in Western Africa takes on two broad spatial dimensions.	Conflict and instability also characterize the sub-region, with climate and environmental pressures often increasing religious and ethnic conflicts in the Sahel, placing additional pressures on cities to absorb conflict refugees and internally displaced persons.

		Economic growth is largely driven by extractive activities in the minerals and energy sectors and agriculture, whereas tertiary sector activities dominate;		Northern parts of the sub-region, which border the Sahel, are experiencing southward migration of the semi-arid Sahel. To the south and south-west of the region, along the coastal belt, the vulnerability of dense urban corridors and agglomerations to climate change-related pressures such as flooding, storm surges, sea-level rise, saline intrusion, and coastal erosion is projected to increase; Climate changes in temperature and precipitation.	
Eastern Africa	Eastern Africa is the world's least urbanized but fastest urbanizing sub-region. By the end of the current decade its urban population will have increased by 50% and the total number of urban dwellers in 2040 is expected to be five times that of 2010.	Regional economic vulnerabilities The sub-region's mining potential remains unrealized, and the agricultural sector is far more important.	The region's cities exhibit high levels of poverty and inequality and fast growth of slums and informal settlements.	Climate change increases various threats in a sub-region where economies are vulnerable due to their dependence on smallholder agriculture and pastoralism.	Further consequences of food insecurity and inter-communal violence contribute to internal displacement and refugee flows, many of these toward "emergency" informal settlements, which soon become established as informal urban communities.

(continued)

Table 10.1 (continued)

Region and cities	Main challenges				
Region in Africa	Major city	Economics	Social	Environmental	Political
Central Africa Is rapidly urbanizing, the sub-region is not expected to reach a region-wide urban majority.	Kinshasa (population of over 9 million) continues to dominate Central Africa as the sub-region's largest and fastest growing urban system.	Highest levels of FDI Characterized by deep poverty and inequality; Lower rate of unemployment in some of the sub-region's cities. Urban economies in the sub-region have started to struggle as they depend heavily on the export of mining, especially the exploitation and export of copper, diamond, oil, and timbers.	Most capital cities in the region function as hubs for complex international financial transactions as well as command posts for the management of multinational organizations. Mass investments in infrastructure building, in the service sector, and in the tourism industry have helped too.	Climate change is projected to induce agricultural losses, increasing the threat of food insecurity; Deforestation, too, is a major concern for all countries in the sub-region since they are losing large tracts of forest and tons of soil every year and experience declining biodiversity.	The political system presents corruption at some levels; High number of slums and informal settlements. Urban governance in Central Africa is beset by deep institutional failures, which are partly catalyzed by, and result in, informal land and housing acquisition. Recent decentralization efforts have led to additional urban governance problems with municipal institutions not reaching the poor urban majorities due to inefficiency, over-bureaucratization, corruption, and nepotistic practices that directly or indirectly give preference to the wealthy and politically connected. Municipalities are largely unable to collect revenues to finance their services.

Southern Africa	Southern Africa, the most urbanized region in sub-Saharan Africa, is projected to reach an overall region-wide urban majority around the end of the current decade.	Despite the region's economic success in terms of gross domestic product (GDP) growth, relative to other countries south of the Sahara, widespread inequality characterizes the primary condition of Southern African cities.	People living in slums and informal settlements in Southern Africa is generally lower than the rest of the continent – (except for Angola, Mozambique and Zambia) – urban planning efforts in Southern African cities face key challenges in common with other sub-regions: urban sprawl, substantial housing backlogs, poverty and inequality, segregation, slum and informal settlement proliferation within city centers and on the urban peripheries, as well as inadequate infrastructure and service provision.	With increased prevailing temperatures and changing rainfall patterns, food security is likely to become an increased concern across much of Southern Africa. Encouragement of non-polluting forms of urban and peri-urban agriculture and forestry may contribute to local food security, especially for some of the urban poor, enhance livelihoods.	Agents of change in Southern Africa are diverse, including the private sector and public private partnerships as well as civil society. The large youth bulge and high levels of youth unemployment constitute both a challenge and opportunity for the sub-region; that is a labor pool for growth and a potential base for political transition toward stronger democratic practices.

Source: Laros and Jones (2014) adapted
FDI Foreign direct investment

10.3 Smart Cities

The topic of smart cities brings together a large number of previous studies, including research directed at conceptual, analytical, and overarching levels, as well as research on specific technologies and their potentials and opportunities (Bibri and Krogstie 2017). Indeed, recent years have witnessed a great interest and a proliferation of academic publications on the topic of smart cities. This reflects the magnitude and diversity of research within the field according to these last authors (Bibri and Krogstie 2017).

Smart cities are known not only from a technological point of view but also for its economic, social, and environmental sustainability. Smart cities aim to mobilize all knowledge centers and information and communication technologies (ICT) into innovation hubs in order to strengthen the socio-economic progress around the world (Dos Santos 2016).

The focus of smart cities has been and still is seen only from the point of view of ICT, which is a reductive vision for both the cities of the world in general and those of the African continent in particular that present major challenges in the field of sustainable development.

The notion of sustainability appears from long decades on scientific, political, and managerial debate and involves all the societal actors. This concept applied to the rural or urban, at the micro or macro level, always involves the traditional dimensions of the sustainability, namely, economic, social, and environmental components. Lately, this concept has become even more comprehensive and still includes the political component, as it has become a global goal and is currently a concern of international organizations, namely, the United Nations (UN) through the "Millennium Development Goals" (Dos Santos and Diz 2019; Kumar et al. 2016) the FAO, as well as, the governments at the country level.

The notion of urban sustainability was born from the realization that the predominant paradigm of social, economic, environmental, political, and urban development was oblivious to the risks of and triggering environmental crises as well as to the implications of and worsening social decays, causing ecological and social deprivation and imperiling future life (Bibri and Krogstie 2017). Sustainability epitomizes a holistic, long-term perspective based on the premise of consciously and incessantly going with the grain of nature and providing the conditions for deploying the frameworks necessary for its operationalization and its translation into practices in a more intelligent way in order to reach a sustainable society (Bibri and Krogstie 2017). In light of global commitments to achieving sustainable development goals, we have to see how the corporate interest to enhance economic prosperity is in conflict with the other two pillars such as environmental and social equity (Kummitha and Crutzen 2017).

As a societal thinking paradigm, sustainability is espoused to guide and configure societal development in its prominent spheres, including science and innovation, technology, economy, urban planning, policy, politics, and institutionalization (Bibri and Krogstie 2017).

With more than half of the world's population living in urban areas and about 41% in Africa, this is also where the use of energy, land, food, and other resources and logistics is increasingly originating (Höjer and Wangel 2015; Dos Santos 2016). The ongoing concentration of the global population in urban areas thus implies that these are increasingly important when it comes to addressing issues of sustainable development, which implies that sustainable urban development has become a prerequisite for sustainable development according to Höjer and Wangel (2015).

Combining sustainable development and urbanization issues, the area of sustainable cities has become of interest for research, education, policy making, and businesses – an interest that has been manifested in all parts of society. In academia it can be seen in scientific journals, university education, research programs, and university departments specifically devoted to addressing sustainable urban development (Höjer and Wangel 2015).

Despite this interest by the themes smart cities and sustainable development, the research developed is still in the beginning, being addressed in a partial way and even with some contradictions. These contradictions begin with the concepts of smart cities and sustainability.

According to Vanolo (2014), smart city is an efficient, technologically advanced, green and socially inclusive city. Following this line of thought, the focus of smart city is the technology at the forefront of generating solutions for ecological, societal, economic, and political challenges (Yigitcanlar and Kamruzzaman 2018). In spite of this, this point of view has been criticized by various authors for being based almost exclusively on information and communication technologies (ICT) as a way of solving the majority of problems of cities. In fact, ICT is nowadays present in our life in all the domains. Therefore, the immediate association between smart cities and ICT is reductionist. Following Höjer and Wangel (2015), most of the ICT included in the smart city concepts already exist. According to these authors, the novelty is thus not so much the individual technologies, products, or services but the interconnection and the synchronization of these and the systems they include, so that they work in concerted and coordinated action in all the domains in a city (urbanization, health, transport, communication, education, commerce and e-commerce, etc.). In urban or rural environments, the use of ICT must be managed, mostly based on *big data* and *artificial intelligence*, being part of our daily lives and presenting the best solutions in various domains and are not exclusive from smart cities (Dos Santos 2018). The major complexity occurs because nowadays the majority or near-majority of the population lives in urban areas.

The results presented for the different urban/rural regions of Africa show that despite the diversity of social, economic, environmental, and political problems, there is a matrix practically common in all regions of the African continent. This common problem involves serious social, economic, and environmental risks stemming from the phenomenon of climate change, and safety and food subsistence may be even more important, which will further widen the development gap and long distance of smart cities and sustainable development. Programs of technology transfer and development aid by developed countries will therefore play a key role in this region.

10.4 Conclusion and Discussion

The main results highlighted confirm the importance of minimizing the problems of sustainable development on the African continent; otherwise, the developed world will suffer the impacts in the future. It is also clear that the development of smart cities, not being a mirage in Africa, needs a long way in the direction of sustainable development. In other words, prior to the development of smart cities, it will be necessary in Africa to create an environment that provides development in a sustainable way. Only in this way, reducing and minimizing social, economic, and environmental gaps will it be possible in the future to build smart and sustainable cities.

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Chapter 11
Urban Management: The Building Permit in an Urban Land Development Context

Klas Ernald Borges

A building permit is a tool for the public authorities to control urban development. Such a tool is found worldwide, including in African countries. It is such a fundamental part of public management and found everywhere – at least in urban areas. Suburban areas might have mostly informal settlements in many developing countries, which means that many of the buildings have been constructed without any building permit. These areas can also be described as illegal settlements.

However, the general model is that a building permit is the basis in the relationship between the public authority and the private actor. This is also our focus.

This chapter will focus on the role of the building permit and how this permit is integrated – or not – in an urban development framework. We will use the building permit as one tool – a jigsaw – in the urban development and analyze the need of an urban framework. This includes urban plans – comprehensive plans, detailed plans, and other plans that might be used or at least intended in the legal framework for planning and building.

The chapter is divided into four parts: some general aspects on public governance, a case study from the island of São Vicente, Cape Verde islands, one descriptive part of the Swedish system for planning and building, and a final analysis on how the building permit can be put into an urban development framework.

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11.1 Some General Aspects on Public Governance Through Building Permission

Building permit is just one of several tools that public authorities could use in managing urban development. This permit is focused on one single building that the land developer would like to construct. The application applies for that single building and nothing else. Sometimes, the land developer could have a larger area, embracing more than one building, with an objective to subdivide and transfer each building to a client, i.e., by completing the action as land developer with transfer of real estate units with the single building for each plot.

The land developer has its counterpart in the authority at local level – the municipality – as the public actor that concedes the right to construct or formally the right to change land uses. The municipality represents the public authorities, i.e., the public actor, with its concern to cater for the public interest. The private and public actors need each other, in order to develop the urban area in the best way for both of them.

Much research, guidelines, and policies are available on urban development. We don't, and cannot, describe all of this. But for the purpose of this chapter, we will just give some general aspects and rationales for urban policies. The global objectives for development are defined in the 2030 Agenda for Sustainable Development of the UN, as a plan of action for people, planet, and prosperity. There are 17 sustainable development goals (SDG) and 169 targets. The 11th development goal – "Make cities and human settlements inclusive, safe, resilient and sustainable" – focuses on the urban environment. UN-Habitat also emphasizes that about one third of the SDG have an urban component (UN Habitat 2018a).

These development goals are by and large the concern of the public interest, while the private interest logically is concerned on the specific land development, being the focus for its business activity.

The global development goals are then further developed into the urban context, and they ought to be specified within the land development context – usually as a comprehensive plan for land use.

The more specific land/property development is described by Healey (1991) as:

> The transformation of the physical form, bundle of rights and material and symbolic value of land and buildings from one state to another, through the effort of agents with interests and purposes in acquiring and using resources, operating rules and applying and developing ideas and values.

Another definition of the property development is expressed by Reed and Sims (2015, p. 2):

> Property development is a process that involves changing or intensifying the use of land to produce buildings for occupation.

These definitions integrate the role of the private actors and their interest to property development, but they also refer to the role of the public authorities.

A comprehensive plan is usually covering a larger area, e.g., the entire area of a municipality, including its rural area. Such a plan has a strategic role in defining land use, but it does not regulate the land use in detail. Such regulations are further developed for smaller areas where private actors are active. A comprehensive plan could have a regulating role to some extent, but the degree of such regulations will depend on the role of the more specific urban development plans, such as detailed plan, development draft, etc. This is established in the national laws on planning and building.

The planning tools could be listed in a hierarchical level as follows:

- National policies, planning and building laws
- Land use/comprehensive plans at regional/municipal level
- Urban development plans at detailed level
- Building permit

There is a specific structure for each country, depending on the tradition, development of capacity on urban planning, and the role of the private actors. The comprehensive plan usually defines areas of land uses. This plan can be given a legally binding role, or it could be merely a strategic plan, while the legally binding plan can be worked out at more detailed level, and that the formal permission to change land uses is given at such a detailed level. The detailed level can also be handed over to the private actors, and thus be developed by them, though with some kind of regulating structure at the higher level, and a permission for the privately proposed development draft.

The meaning of land governance is defined in a FAO publication as follows (Sotomayor 2008, p. 8):

> Governance is the system of values, policies, and institutions by which a society manages its economic, political and social affairs trough interactions within and among the state, civil society and private sector. Land governance concerns the rules, processes and organizations through which decisions are made about access to land and its use, the manner in which the decisions are implemented, and the way that competing interest in land are managed.

A similar description of the importance of land governance is exposed in another FAO publication on land tenure (Suárez et al. 2009). They include informal arrangements, as part of the current structure. They also refer to a report of UN-Habitat on inclusive cities, with participatory decision-making in cities and devolution of power from central to local government. Such arrangements must be considered, in order to find a feasible way to include good land governance systems. However, this aspect is not further focused in this chapter.

UN-Habitat emphasizes the need of urban planning and design. They have a special theme on governance, based on planning and design. There is also a section for so-called urban initiatives. The rapid urbanization, in particular in cities of the developing world, is bringing many challenges for the authorities and the civil society to work with the urban area from a planning perspective. There are a lot of guidelines and publications on this, including how to secure public spaces, public interests, and both economic and environmental aspirations. They refer to plans for expansion and densification, mainly at local level (UN Habitat 2018b). They also call the attention to the need of an urban agenda for Africa (UN Habitat and UNECA 2015).

Bioclimatic architecture is one specific perspective of interest both for public and private actors. Land governance, as referred to above, means such a public support, and one tool for this is the building permit. It is certainly not the only tool but a relevant and well-known requirement of public governance. For this reason, we will use the building permit to check how the public governance is working – using a case study at the island of São Vicente, Cape Verde islands.

11.2 Case Study: Cape Verde Islands

Background and Methodology

A case study was done at the island of São Vicente, the main urban island in the northern part of Cape Verde. The island has an area of 227 km^2 and about 75,000 inhabitants, with about 90% living in the city of Mindelo. The local government (municipality) embraces the whole island. The city of Mindelo has doubled its population since the independence of Cape Verde in 1975 (about 40,000 inhabitants).

Interviews were undertaken in July 2018 with seven (7) professionals: architects, engineers, and one local politician. The professionals are both civil servants and private actors. The civil servants at the local government authority (municipality) of São Vicente were one architect in charge of the building permit process (municipality) since the 1980s, one surveying technician, and a previous mayor (during the period 1979–1984 mayor in the capital city of Praia and mayor in São Vicente during the period 1984–1990). The four interviewed private actors are architects with office at São Vicente (and one at Sal island) but also working with projects for other islands. This means than they have experience from several local government authorities on the building permit process.

The interviews were semi-structured, starting with a brief explanation about the idea with and the main contents of the book on bioclimatic architecture in Africa. The main issue was about how the building permit is used in order to achieve adequate solutions on bioclimatic aspects on design and construction. The focus was on the requirements by the local government (municipality) when processing and taking the decision on building permit. This means how and to what extent the process of building permit is used to achieve bioclimatic qualities in construction.

As bioclimatic architecture is not used as a specific requirement in building permits, the question was broadened to a more general perspective on how the local government is using requirements of architecture design and construction solutions as part of the building permit. Is the building permit refused, or delayed with demands on changes, due to inadequate architectural solutions? And put in a more general perspective: does the building permit play any role in correcting bad solutions in the architectural design and construction?

It could be stated that the number of approved building permits at São Vicente is about 300–500 per year (470 in 2012), though with quite some fluctuations due to market changes. In addition to these permits, there are also illegal/informal constructions, mainly in suburban areas and at the countryside. The architectural design and construction solutions for such buildings might not comply with eventual public requirements, but the owners usually search good solutions for their investment, in order to get the best output.

In addition to the building permit, there are many other issues of interest in the land development process, such as land tenure, land acquisition, development agreements, urban planning at comprehensive and detailed levels, infrastructure, access of building material, management structure of the local government (analyses, decisions, etc.), the role of central government, land and housing policies, citizen participation and consultation, financing structures, land taxes, transparency, and other issues.

The interviews were focused on the building permit process, but some other of the above referred issues were also mentioned by the interviewed persons. The most frequently mentioned issue was the urban planning process, both private planning with development drafts (*loteamento*) and public plans – detailed plans, comprehensive plans, and regional structural plans. Some other issues were also mentioned. The description is given below.

The building permit was the main focus in the interviews as it is a key issue of the land development process in every country. The urban planning might be less developed, but the process of building permit is a general requirement of the land development process, at least for urban areas. The building permit – and an approval of a detailed plan or private development draft – transfers the right to change land uses from the public authority to the private actor. Before the approval, the private actor does not have any formal right to construct a house, as it is withhold by the public authority, at least in urban areas (though bypassed in cases of illegal/informal constructions/settlements).

The description below will summarize all interviews, and it does not refer to any comment of a specific interviewed person. This means that the comments of the civil servants, previous mayor, and the private actors will all be presented as one comprehensive description, and none of the persons will be quoted separately.

Experiences and Opinions of Interviewed Persons

The building permit plays a central role for the local government to authorize construction. The building permit has to be given. The statistics indicate that five to ten permits are given per week. The architects at the municipality are the key persons in analyzing the applications, but after technical opinion, the building permit is formally approved by the mayor.

The technical analysis of the submitted application for building permit is limited to a few key issues. The following were mentioned:

- Volume characteristics.
- Conformity to the plot design (size, construction limits, number of floors). The plot map (*planta de localização*) might have a few conditions.

- Conformity to an eventual urban detailed plan or development draft (*loteamento*).[1]

Neither general requirements for construction nor specific requirements for the building permit are raised by the local government office. The application for building permit is normally given without any demand for change regarding its technical quality.

It could be mentioned that a building permit process might include an informal part – contacts between the private actor and the civil servant – as a preparatory part to finalize the formal application. However, such preceding informal contacts were not mentioned by the interviewed persons. Of course, there might be other preceding contacts between the civil servants and the private actor, in order to speed up the final decision on building permit, but this has not been focused during the interviews.

The general experience, including the perspective of the civil servants, is that there is rarely any demand by the local government in the building permit process. The demands to respect volume, number of floors, and construction limits are more obvious and rarely subject to corrections in the building permit process.

Occasionally there have been some internal municipal discussions about adequate building design and construction, depending on personal interests, but this has not been further developed into specific public sector demands.

Another aspect that sometimes is mentioned is the use of local construction material, e.g., to partly substitute concrete with pozzolana (pozzolanic ash) and to use local stones. The obstacles might be tradition in construction techniques and lack of availability at the local market. It does not seem realistic to state a certain percentage of local construction materials as a formal requirement in the building permit.

It should be mentioned that there is a National Building Code (*Código de Construção*), but it was not referred to as a practical guiding code used in analyzing and approving building permits.

The technical department at the local government office could develop a more strategic building and housing policy, but this has not been done, and it does not seem to be a concern at the moment.

Many of the interviewed persons mention the need for urban detailed plans or development drafts/*loteamento* in order to define an adequate urban structure and design, as well as specific characteristics for building design.

Why are such detailed plans not done? There might be some reasons:

- Lack of experience/know-how in preparing urban plans
- Lack of availability of the municipal architects
- Lack of funding for contracting external planning consultants (and eventually lack of experience on how to prepare such plans in the Cape Verdean context)
- Lack of a general comprehensive plan for the island as basis for urban detailed plans

One regional development plan (*Esquema Regional de Ordenamento do Território – EROT*) was prepared by consulting companies as part of international

[1] Such detailed plans are rarely available.

cooperation with Spain/the Canary Islands and supervised by the ministry – MAHOT. The report (MAHOT et al. 2012) contains five parts (*Condicionantes*, *Modelo territorial*, *Programa de Acção*, *Regulamento*, and *Relatório de ordenamento*), including regulations, maps, and description. The EROT has been submitted to the central Government in Praia for ratification (*homologação*), but this has still not been done. Without such a ratification, there is no legal basis to proceed with a comprehensive plan for the municipality (PDM – *Plano Director Municipal*), as well as detailed plans. The EROT refers to the next planning phase – the PDM – for more specific description and regulations for urban design and construction, but such a plan has still not been done.

Some development drafts (*loteamento*) are done, by private actors or by the municipality. However, these drafts are simplified plans, with a main purpose to subdivide the area in as many construction plots as possible.

The EROT has some guiding criteria for urban development, e.g., four different population density values for new residential areas (20, 35, 45, and 60 inhabitants/ha), models for residential houses (general aspects, without details), energy strategy, and water and sanitation aspects. The EROT includes regulations (*regulamento*), but for urban development, and in particular residential purposes, the section (*artigo*) 14, chap. II, is just a formal definition that there is one category of use for residential purpose. It does not define any specific criteria, except that it should be good enough for living. The EROT defines areas for different uses, including residential use, which means that the urban limit and designation of land uses are specified at this regional level. However, the land use areas are defined as *potential* uses of land (*usos potenciais do solo*), which means that they are not legally binding, not even after ratification. Some areas are identified as risk areas, such as the lower parts of valleys, with risk for inundation at rainfall. The EROT for São Vicente might have more importance for general economic planning for development of the island. The importance for construction is very limited, e.g., the building permits. There is a huge gap between the general EROT and the very specific building permit, and the interviewed persons confirmed this gap.

The idea with the regional development plan (EROT) is that there should be one such plan per island – as some islands are bigger and divided into two or more local governments (municipalities). However, for the island of São Vicente (as well as for another four islands of the country), the EROT covers the same geographical area as the PDM. But, as stated during the interviews, as long as the EROT has not been approved, the PDM cannot be elaborated nor the urban detailed plans. The development drafts (*loteamento)* are done without an approved physical plan at higher level. The legal basis for this subdivision plan was not clarified during the interviews. The general comment on such *loteamentos* was that they are prepared with the main objective to maximize the number of plots, and sometimes it results in a deficient urban design. This means that such a *loteamento* could be done as a highly densified area, without sufficient consideration on urban design.

It should be added that there is a legal structure on physical planning, with the following formal planning schemes (Table 11.1, explanations below).

Table 11.1 Physical planning documents according to the Cape Verdian planning law

National level	DNOT		
Regional level	*PEOT*	EROT	PS
	POOC		
	POT		
	POAP		
Municipal level		PDM	PIMOT
Urban area		PDU	
Detailed level		PD	

Regulamento Nacional do Ordenamento do Território e Planeamento Urbanístico (Decreto-Lei nº 43/2010, de 27 de Setembro – RNOTPU)
Explanations
DNOT Directiva Nacional de Ordenamento do Território (National Policy of physical planning)
EROT Esquema Regional de Ordenamento do Território
PEOT Plano Especial de Ordenamento do Território
POOC Plano de Ordenamento da Orla Costeira (coastal zone)
POT Plano de Ordenamento Turístico (tourist areas)
POAP Plano de Ordenamento das Áreas Protegidas (protected areas)
PS Plano Sectorial (sector plan)
PDM Plano Director Municipal (comprehensive plan)
PIMOT Plano Intermunicipal de Ordenamento do Território (joint municipal plan)
PDU Plano de Desenvolvimento Urbano (urban development plan)
PD Plano Detalhado (detailed plan)

The general comment during the interviews on this legal structure was that it does create a legal framework, but it is not applied or possible to apply in practice. One reason is the need of approval in hierarchical order, and that the lack of ratification of the EROT has stopped further planning activities.

The *loteamento* is not mentioned as a legal planning tool, but mentioned by the interviewed persons as a tool that sometimes is used. It is developed either by a private land developer or by the municipal authority. This kind of development draft is a tool in the Portuguese planning structure and legislation (with the French *lotissement* as a model) – as a tool for the private land developer. The interviewed persons refer to some examples of *loteamento* with a crowded urban structure, narrow streets, plots located in inundation risk zones in valleys, very small plots, as well as too large plots which create a segregated urban structure, etc. They find it important to initiate the land development process with some urban planning at least at neighborhood level, and not at the plot (*loteamento*) level or building permit. An urban design study has to precede the application for building permit. But this does not seem to be any current priority. So the building permit seems to be the only actually used tool for the local government authority.

The latest PDM for São Vicente was elaborated and approved in 1994, and a new PDM was elaborated in 2010, before the EROT in 2012, which has led to a vacuum and confusion, so this PDM has not been ratified by the central government. So, there has been some planning work for a new PDM, but not properly coordinated with the activities of the ministry. The national support to implement the legal structure of physical planning, according to the scheme presented above, has been insufficient. The interviewed persons describe the current situation as totally unsatisfactory, and that they just have to continue with the specific issue of building permits and occasionally some *loteamentos*. They do not expect further activities or support at local government or national levels.

But they would prefer that physical planning activities could be developed more, as the urban design is fundamental for a sustainable urban land development.

Some comments refer to the previous situation, before the democratic change in 1991, with free elections and new political parties. The physical planning situation was better during the first political period after independence (1975–1991), but limited to the two main cities of the country – Mindelo and Praia. The physical planning capacity has not improved, with exception of the touristic island of Sal.

One general aspect on the development of the land development structure is that the democratic change through the general elections in 1991, with change of political parties for government, has led to a more politicized situation, including at the municipal level. There have been several changes, both at national and municipal levels of governing political parties. These successive changes have led to shifting land and housing activities and impaired the long-term development of the urban planning capacity. Some mayors have turned land and housing development to a personal or politicized matter, and the architects and civil engineers have been more dependent on these personal or political changes. There is a need for a more long-term land and housing development, based on an improved technical capacity and responsibility.

11.3 How to Develop a Bioclimatic Architecture

The case study at São Vicente, Cape Verde islands, shows that good solutions and requirements on, e.g., bioclimatic architecture and urban design are not easy to implement. And it is not only a matter of the building permit but also the urban physical planning process.

If the national government would like to introduce better bioclimatic architecture, it has to create an urban planning structure that is feasible to implement and invest in a physical planning capacity at municipal level. The current structure of planning seems to be formally established, but the case study indicates that it has not been put in practice at municipal level.

The key question might be – is it feasible? Would it be possible to establish and implement functional working systems for urban planning and building permission? The national government and each local government authority/municipality should analyze this challenge well and try to find practical and realistic solutions.

The private actors – urban planners, land developers, architects, and civil engineers – will be able to adjust to a realistic system, and they will find their specific and a well-defined role. The current situation leaves them to an arbitrary and deficient system. They could participate in a better way, given the right and clearly defined conditions.

11.4 The Building Permit in the Land Development Process

General Framework and Some Examples from the Swedish Model

A building permit is a requirement in most countries. It could be used proactively, e.g., to improve some qualities in the urban or building design. Bioclimatic architecture is one such quality. But how could we encourage such qualities, and could some formal requirements be used with success?

A short description of the Swedish system of planning and construction will be used, in order to show how a public system can be developed, including urban planning, building permit, and construction control.

Instead of considering the building permit as the main tool for managing the urban land development process, we will start with the urban planning process. The reason for such an approach is that urban development needs to be put into an urban context and not be limited to single building development. One single construction at the countryside does not affect the surrounding area at a considerable level, while one construction in an urban area adds the building's impact to the current and forthcoming buildings. One, two, ten, and hundreds of buildings make a difference, and they create the urban environment. There is a logic change in perspective in the urban area, from the building permit to the urban planning perspective – urban plans with a formal approval.

The basis for such a perspective is stated in chap. 4, section 2 of the Swedish Planning and Building Act (PBL):

> Using a detailed development plan, the municipality must examine the suitability of a land or water area for built environment and construction works, and regulate the design of the built environment for:

1. new assembled built environment, if needed as regards the extent of construction works for which building permits are required in the built environment

The law does not state a minimum number of constructions, but in practice (based on court cases), the number is about ten constructions. In case of urban expansion, the minimum number is even lower, as the new constructions means an expansion from the current urban settlements.

The section states that the municipality plays the key role for examining the suitability of an area for built environment and construction, including the design of the built environment. Why such a demand? The basic reason is expressed as externalities – external costs and benefits. An isolated land developer – for one or several constructions – looks for the maximal benefits for his/her investment, while there might be costs for neighbors, such as pollution, scenery, access, infrastructure, and other environmental effects. It is defined as external, i.e., outside the land owned/acquired by the land developer and vice versa (from the perspective of the neighbors). This is described as the Coase theorem (Coase 1960).

The justification for a public interest in private land development is stated in PBL chap. 2, section 1:

> Where issues are addressed under this Act, consideration must be given to both *public* and *private interests*. (Italic letters – author's emphasis)

This means that any land development and construction work has to be analyzed and given permission based on the interest of both the public and private interests. There are several court cases that define the balance between the interest to construct by the private land owner and the public interest to object to or demand modifications of the planned construction. Such an objection could be raised both from urban planning perspective as from the building permit perspective. The section is described as *the principle of proportionality*, which means that the public perspective has to be considered, but within certain limits. The private land owner's interest to develop the land needs to be considered, if the external effects do not harm the public interest too much. This principle has its legal basis in the European Union Treaty, article 5.3.

The principle could be argued from both parties' perspective, i.e., both the public and private actor. Applied on building permits, it gives a rationale for the municipality to take decision that refuses a building permit for a private actor. The principle is also extended to the abovementioned requirement to prepare a detailed development plan, as such a plan will analyze the convenience for construction of an assembled built environment. The principle of proportionality is applied as such a land development will have some external effects, and the public interest is guaranteed by its active participation in the urban planning process; or it might also be considered to be an area not convenient for land development. The public interest is given priority, but the land development is not automatically refused. The key issue is that there must be balance between the public and private interest. Both have to be considered; and none of them could be forgotten.

Examples of the Principle of Proportionality in Swedish Urban Areas

Some examples of Swedish court[2] cases will be presented, in order to show how the abovementioned principles and sections of PBL are applied. Most court cases have started as claims to refused or approved building permits (by a private actor – land developer, neighbors, or other parties). The private actor has the right to appeal, and he/she is sometimes also supported by an organization of land owners, housing association, etc.

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[2] The eight cases (RÅ, MÖD, and NJA) are all from the Supreme Court, though with three different courts, due to change of court system in 2011, and some rules on special requirements for additional appeals.

Court cases on building permits:

1. One house owner changed the roof of her building in a characteristic and attractive vacation area in Smögen, at the west coast of Sweden. The municipality of Såtenäs ordered a monthly fine as long as the new roof remained due to non-compliance with the detailed plan. The previous roof was previously of roof clay bricks, and the owner changed the roof to tin plate, with some visual similarities to the previous brick roof. There was an urban detailed plan for the area, with restrictions on choice of building material. The house owner appealed but lost the case in the Supreme Court, due to the well-defined requirements in the detailed plan (Ref. RÅ 1997 ref. 77).
    (a) Conclusion: the public interest, as defined by the detailed plan, was considered more important than the costs for the private property owner.
2. An application for building permit in the township of Arild was refused by the municipality of Höganäs (southern Sweden). The detailed plan defines the area of each property unit that could be constructed, as well as the maximum area to be built. The proposed area to be built was to some extent also interfering with the plot area where construction was not allowed. The property owner submitted an appeal but lost the case in the Supreme Court, due to non-compliance with the detailed plan (Ref. MÖD P 7583-16).
    (a) Conclusion: the public interest, as defined by the detailed plan was clearly defined, and had to be fulfilled, and the private interest to bypass the detailed plan to a minor degree was not accepted.
3. An application for building permit for a fully globe-shaped house in an urban area of Gothenburg (western Sweden) was appealed by several neighbors, due to their opinion of appreciated non-correspondence/harmony to the urban area. The municipality of Gothenburg had approved the building permit, and the Supreme Court also found it acceptable and not too disturbing to the urban characteristic of that area (Ref. RÅ 2001 ref. 31).
    (a) Conclusion: the private interest was considered more important. The Supreme Court's approval considered that the external negative effects (i.e., estimated costs for the neighbors and the neighborhood area) were limited, and thus it was not justifiable to refuse the application.
4. A property owner in an attractive semi-central area of Stockholm (Bromma) applied for building permit for a planned construction work to add an 8 cm thicker wall to the house built in the 1930s, with the aim to get a better wall isolation and an increased energy-saving effect. The additional wall was to be done without changing the localization of the windows to the new outside wall alignment. The municipality of Stockholm disapproved the application due to the changed visual view of the house, being part of a characteristic urban area from the 1930s. The Supreme Court withheld the position of the municipality (Ref. RÅ 2001 not. 123).

   (a) Conclusion: the public interest of maintained characteristics of the area's buildings was considered to be more important than the extra costs for the house owner to change the location of the windows.

5. A property owner in Täby, in the northern Stockholm metropolitan area, applied for a building permit in 2013, and the municipality approved the building permit. Two neighbors submitted an appeal as they found the planned building too diverging and dominant for the specific urban area. After further appeals, the Supreme Court confirmed the municipality's approval of the building permit, as it did not diverge from the current detailed plan nor from the general requirements in the Planning and Building Act on sufficient harmonization with the local environment, as well as the design and technical quality of constructions. The detailed plan did not specify in detail how the buildings should be designed, and the application for building permit was considered to be sufficiently adjusted to this detailed plan (Ref. MÖD 2015:26).

   (a) Conclusion: the private interest was in conformity to the detailed plan that had defined the requirements for land development and construction.

6. A property owner applied in 2005 for a building permit. The property unit is localized south of but near to the urban area of Gothenburg, by the seaside. The municipality of Gothenburg refused the application with reference to the need to a detailed plan. The area is attractive for both vacation and permanent houses, within a reasonable commuting time to the center of Gothenburg. The first application for building permit, in the mid-1960s, was denied, with the same argument – the need of an urban plan. After the renewed municipal refusal in 2005, the property owner appealed, and finally, in 2010, the Supreme Court decided that such a repeated and extended refusal was not acceptable. A continued refusal to the application without starting a process of detailed planning during such a long period was considered unacceptable based on the principle of proportionality. The municipality had the right to refuse the application, but on the other hand, they cannot postpone the planning process for several decades (Ref. RÅ 2010 ref. 90).

   (a) Conclusion: the private interest was considered valid, due to the extended harm for the landowner.

7. In a similar situation at the municipality of Värmdö, southeast of Stockholm, the decision (in 2012) was to refuse the building permit, as the comprehensive plan indicated that the area will be planned after the next planning horizon – after the year 2025. Even though the municipality postponed the planning process, it was accepted as there was a specific time horizon. The private interest was not considered to suffer too much, even though the planning process was not defined in detail (Ref: NJA 2016, s 868).

   (a) Conclusion: the public interest was still considered more important, despite quite a long planning horizon, and the private interest was not too harmed.

8. A detailed plan was approved for an area in Vellinge municipality, south of Malmö. Two neighbors (one company and one physical person) submitted an appeal, as they found that the detailed plan did not clearly show the impact for the existing company on the new buildings and thus created uncertainties for the activities of this company, in particular regarding noise from the industry. The Supreme Court accepted the appeal and thus disapproved the detailed plan (Ref: MÖD P 2127-15).
   (a) Conclusion: the private interest was not sufficiently considered in the detailed plan. This means that a detailed plan must be sufficiently elaborated and evident on the consequences for the local environment, including the neighboring property units.

The abovementioned court cases show that the building permit plays a central role in land development but that the municipality has to consider the urban context and that a building permit can be refused due to the current detailed plan or the need to initiate and approve a detailed plan. The requirement to prepare and approve a detailed plan is well defined, as an urban development has to be analyzed in a broader context than a single building permit. The municipality is thus empowered with the decision on land use, both in rural areas (without the need of a detailed plan) and in all urban areas. The decision in urban areas demands more attention and coordination.

The detailed plan is not just a planning idea of an urban area, but it also means an approval of the design of the area and defines specific requirements for the building permit. That means that the analysis of building permit is by and large already done through the urban detailed plan. The focus on the approval is changed from the building permit to the detailed plan. The detailed plan can be designed with a lot of details but should not be too detailed. The Planning and Building Act states (PBL chap. 4, section 32) that it should not be more detailed than necessary considering the purpose of the plan.

Models of Planning and Building Permissions

The urban planning capacity in Sweden has been developed since the early stages of urbanization, with successive changes in and of planning and building acts. The capacity might be quite ahead the current capacity of many countries. But there is a need to have a certain urban planning capacity in every country. The current focus on building permits at Cape Verde (see the description above) might be an easy way to have some kind of public control on the urban development, but there is an obvious need to put the building permit in an urban context and thus make the analysis and approve an urban development from the perspective of the *assembled* built environment. The minimum number of houses is not easy to define, but the key aspect is when the built environment could be considered as becoming assembled. A decision of a building permit will have impacts on the surrounding area, and if there will be more than a few houses, it is logic that there is a need for an assembled analysis.

The detailed plan is not isolated from the total urban context, so the detailed plan will also need to be put in a context of a comprehensive plan. As mentioned above in the case study at the Cape Verde islands, there are some upper planning levels – PDU (i.e., the urban context), PDM (the municipal level), and EROT (the regional level). All these planning instruments demand quite some planning capacity at municipal level, and as stated by the interviewed persons, such planning capacity is lacking and to some degree just managed at central government level.

The options for planning and building development could be illustrated in four ways. See Fig. 11.1.

The options are the following:

1. The building permit is the main tool for public control, but without any real support or guiding role of other plans. The approval of the building permit might be given after a technical analysis, or just formally without any real impact. The construction control might be done in practice, just done formally, or not at all. This way is how the current situation works at São Vicente, Cape Verde, as found through the interviews (see above).
2. The building permit is the main tool for public control, but based on a physical plan at higher level. Such a plan (typically a comprehensive plan) might be just guiding or legally binding for the building permit. The approval of the building permit might be given substantially or just formally. The construction control might be done in practice, just done formally, or not at all.
3. The detailed plan is the main tool for public control and usually based on a physical plan at higher level (typically a comprehensive plan). The comprehensive plan might be just guiding or legally binding for the detailed plan. The approval of the building permit is simplified, as most aspects have been analyzed in the detailed plan, and the land developer just has to comply with the

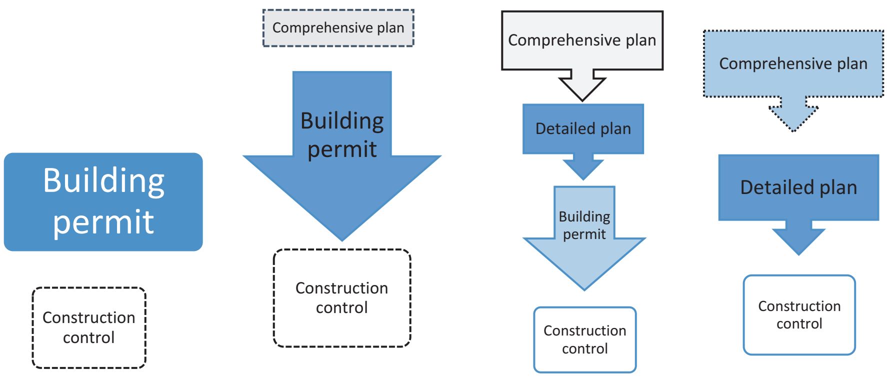

Fig. 11.1 Four ways of public control and management of land development

requirements of the detailed plan. The construction control might be done in practice, or just done formally.

4. The detailed plan is the main tool for public control and usually based on a physical plan at higher level (typically a comprehensive plan). The comprehensive plan might be just guiding or legally binding for the detailed plan. The approval of the building permit is omitted and checked as part of the construction control. The land developer is obliged to present the building design in conformity to the detailed plan, but a building permit is not required as the detailed plan and the technical requirements for constructions are available and easy to understand. The construction control ought to be done in practice, or eventually just done formally. The private actor – land developer – plays a more central role, though with some public supervision.

Please notice that the detailed plan has been used in the model. A private land development plan (such as the *loteamento/lotissement*) can be used, but such a plan has to be approved by the municipality.

The last option (no. 4) means that the technical work at the municipality could be changed from the building permit to the detailed plan or analysis/approval of the private land development plan. In an urban area, there is an obvious need to broaden the analysis from the isolated building permit to an urban environment analysis.

The land developers, including private architects, usually have sufficient professional knowledge and professional pride in proposing their clients good technical solutions, including bioclimatic aspects. But some kind of control and public requirements could be justified. The idea of construction control could be sufficient and a way to recognize and appraise their professional knowledge.

The Role of Construction Control

A further analysis will be done on how the construction control is part of the land development process. The model of the Swedish Planning and Building Act (PBL) will be presented briefly. The building permit (and the preceding detailed plan) is the main tool of the public control. The final control of the construction work is formally part of the building permit. This final construction control might be less frequent or marginalized in reality, but it is still a formal part of the building permit.

The building permit transmits the responsibility from the public authority to the private land developer. The public authority (the municipality) accepts the construction work planned and presented by the private actor. What is the need for a continued public control? The preceding permission or permissions have identified the ideas/design of the private land developer as good or at least sufficient. That means that the public authority should trust the continued construction works to be done by the private actor.

The new Swedish PBL of 2010 (the previous was enacted in 1987) changed the roles of the construction works from the public authority to an appointed private construction engineer/technician, chartered by the municipality. One reason was the lack of civil servants with civil engineering education and training to fulfill the control of all private construction works. The appointed private engineer/technician takes the responsibility for the construction works by the constructor, but has to be an independent person to the construction company.

Is such a model sufficient? This depends on the professional capacity available and how much of the construction works can be handed over to the private sector. The ultimate person – the future client/property owner – will search for the best building output from his/her invested capital and additional mortgage. And the construction company will usually try to show its quality in this professional area. For this reason, these private actors will try to get the best outcome.

But sometimes bioclimatic architecture or similar qualities might be sidestepped as a way to reduce the costs. It could also be due to lack of professional knowledge in this area. It is for this reason that the role of the detailed plan is to broaden the perspective to the urban environment, and the comprehensive plan could define further design and construction requirements than the private land developer normally would accept, based on his/her more isolated/individual perspective.

A detailed plan can define specific design and construction requirements. But the general legal basis for constructions is stated as follows in PBL, chap. 8, section 1:

A building must:

1. be suitable for its purpose
2. demonstrate a good effect of design, colour and material; and
3. be accessible to and usable for individuals with limited mobility or orientation capacity.

The technical characteristics of a building are further defined in section 4 (chap. 8):

A construction works must have the technical characteristics which are essential in terms of:

1. load-bearing capacity, stability and durability;
2. safety in case of fire;
3. protection with regard to hygiene, health and the environment,
4. safety in use;
5. protection against noise;
6. energy management and heat retention;
7. suitability for the intended purpose;
8. accessibility and usability for individuals with reduced mobility or sense of direction;
9. economical management of water and waste; and
10. broadband access.

These requirements cover quite many aspects of a good building, as a human habitat. It is the responsibility of the land developer to show how these qualities are guaranteed. Some of these qualities are presented in the application for building permit, but most are managed and controlled during the construction process, where the appointed construction engineer has the responsibility to control the land developer's construction. Much of this work is based on mutual confidence.

The public interest of a good urban and building quality is mainly channeled via the detailed plan and the general requirements on construction. For example, the requirement no. 6 above (of section 4) is a major concern in a cold country, and the technical standards have gradually become more demanding during the latest decades. This means that the constructor and its separate control engineer have to fulfil these requirements. But such requirements are rarely challenged in an appeal process. For this reason, there are no such court cases available. The private interest is mainly challenged toward the public interest in the preceding stages of the land development process, i.e., mainly about the detailed plan and the building permit. After approval of the building permit, there are rarely any reasons to challenge, as the decisions have been taken, and the responsibility has been transferred to the private actor.

The court cases described above are examples of individual property owners with objection to a positive or negative decision (approval or disapproval) of a building permit or consequences for future building permits. As mentioned above, the public requirements for design and construction are stated in the Planning and Building Act and controlled in the construction phase.

But how is the municipality developing and increasing the demands within specific areas, e.g., in sustainability? Bioclimatic aspects are usually expressed within this general term.

A general rule is that the specific demands by a municipality have to be within the limits of the Act and not extend the demands into further locally specific rules. This refers to the requirements of detailed plans as well as the construction work. However, the municipality is encouraging and shows its ambition to be ahead and progressive in sustainable urban development.

One example will be used for the new urban area of Brunnshög, situated in NE of the city of Lund (southern Sweden). The area will be developed for new research centers (ESS – European Spallation Source – and Max IV) within the area of nanotechnology, material science, etc. Except from the research centers, the area will also be developed for residential purposes. The land development starts at a comprehensive level, with the municipal comprehensive plan, and some reports with focus on this area. The main guiding document for this area was prepared and approved by the municipality in 2012 (Lunds kommun 2012), being a strategic and visionary program for the entire area (about 225 ha). This document is formally a part of the comprehensive plan of Lund, but prepared as a specific urban area program. This means that the comprehensive plan is gradually complemented with more specific programs, with its formally guiding role, not legally binding.

This program defines the more specific objectives and details for the forthcoming detailed plans. These detailed plans will be worked out in compliance with the strategic and visionary program. This urban development area is quite big, and smaller urban development areas will also be analyzed and designed from a municipal and national strategic perspective. The municipality has the key role as impulsive actor for a sustainable urban development. This is an evidence on how the public interest is manifested and worked out in practice.

Some details will be mentioned from the strategic and vision program for the urban development area of Lund NE/Brunnshög (Lunds kommun 2012).

The planning document explains (p. 51) the strategy for the microclimate, with some examples of requirements for tree plantations, design of building characteristics, street design, water areas, and vegetation cover of roofs and walls, with effects for better shadow, wind protection, and other specific microclimate characteristics.

Further, the planning document describes (pp. 69–70) how this urban development area will contribute to the achievement of national goals regarding environment (as defined in the Environmental Code), energy-saving goals, and climate and other specific goals with consequences for sustainable urban development.

This strategic document was submitted to public consultation and approved by the municipality. This means that land developers have a guiding document on the objectives of the municipality. The next steps will be the specific detailed plans, and the municipality will use the strategy document as basis for the detailed planning level. For example, the detailed plan for Solbjer (covering 13.5 ha) was prepared and approved in 2014 (Lunds kommun 2014). The detailed plan refers to the strategy document, and many details in the urban design can be identified as based on this strategy document, e.g., urban design at neighborhood level, transport system, wind and water aspects, energy values, and green areas.

There is a reference to another strategy document – environmental program for construction (*Miljöbyggprogram*) that was prepared by Lund and Malmö municipalities, and Lund University in 2009, and updated in 2012. The objective for the program is to expose the private land developers to a guiding document on requirements for construction on land provided by the municipality, i.e., the requirements of the two municipalities on construction. This is further carried out by development agreements between the municipality and the private land developer. In case of privately held land, the municipality can condition the approval of the detailed plan with an agreement based on the environmental program and other issues. The program was in force until 2018 and will be continued through development agreements as part of the implementation phase of a detailed plan.

The building permit is thus thoroughly prepared and defined in some specific design and construction details. The land developer has to prepare the application for building permit in conformity with the detailed plan, which is based on higher level plans and national requirements. The application for building permit has to be analyzed by the municipality based on these previous plans and strategies.

11.5 Concluding Analysis: The Public Permission for Land Development

How to Guarantee the Public Interest in Land Development Without a Well-Established Planning Capacity

The detailed plan of Solbjer in Lund municipality, Sweden, can be illustrated with an additional level to the model number 3 in Fig. 11.1, i.e., with an additional analysis and strategic guide for forthcoming detailed plans. See Fig. 11.2.

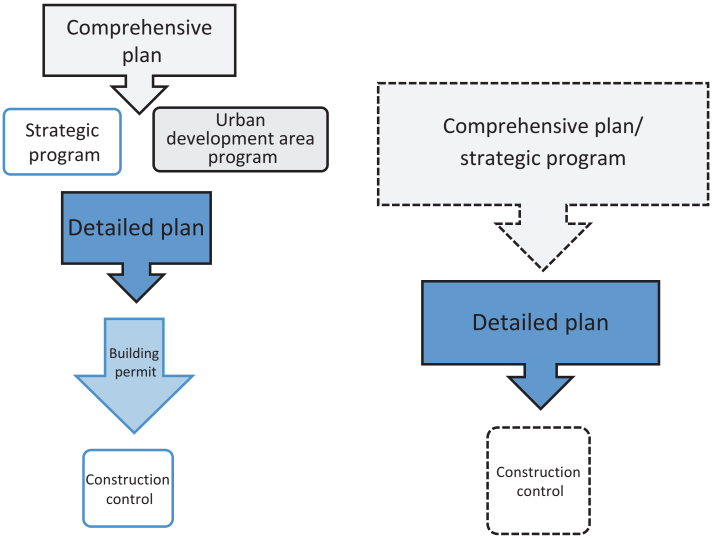

Fig. 11.2 Strategic planning as part of the land development process

This extended urban planning process, with a strategic program and an urban development area program, is not always used in Sweden, but in certain cases it might be motivated. Other land developments might be less detailed with strategies and requirements, but the national and municipal objective is to endeavor a high level of urban sustainable development.

The experiences at the island of São Vicente, Cape Verde, show that there is a planning and building framework and thus an ambition of the government to promote an economic development, including land development. The EROT for São Vicente is one such plan, with both economic and land use objectives. The subsequent physical planning documents – the comprehensive plan (PDM), urban development plan (PDU), and detailed plan (PD) are lacking, due to the hierarchy with the EROT as superordinate plan. There is a huge gap between the EROT – still not ratified – and the actual tool for control of the public interest – the building permit. The architects and engineers that analyze and prepare the application for approval by the mayor do not have any useful guiding or binding planning document as basis. Their proposal for decision by the mayor is reduced to an isolated case of one building and its suitability in such an atomic or isolated urban perspective.

There is a need to review the role of the public authority and to question the realism of an extensive planning model. The public control can still be maintained, and if there is an ambition to develop more bioclimatic characteristics in architecture design and building, there is a need to put the building permit in another context – the detailed plan.

For this reason, we propose that the extensive steps in the land development process could be reduced as described in Fig. 11.2. These two models might be extreme models, with and without a good physical planning capacity. The second model (to the right) means that the building permit has been omitted, which sometimes could be the reality, due to lack of capacity or resources, but it is still relevant to use the detailed plan as binding document for building permit. Construction in an urban area always means an urban context, and such a context needs a context approval process, i.e., some kind detailed plan. It is better to focus on the detailed plan context and start cooperating with the private land developers for the implementation phase. The building permit ought to be analyzed at the previous level – the detailed plan, where sustainable, bioclimatic, and other public interest concerns are analyzed and approved.

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Högsta Domstolen (NJA – Nytt Juridiskt Arkiv)

NJA 2016, s 868

Mark- och miljööverdomstolen (MÖD)

MÖD P 2127-15
MÖD 2015:26
MÖD P 7583-16

Regeringsrätten (RÅ – Regeringsrättens årsbok)

RÅ 1997 ref. 77
RÅ 2001 ref. 31
RÅ 2001 not. 123
RÅ 2010 ref. 90

Interviewed Professionals at the Cape Verde Islands

Civil Servants

- Anildo Silva, Architect, Local Government Authority, São Vicente (since 1987)
- Fransisco Gonçalves, Surveying Technician, Local Government Authority, São Vicente
- Nelson Atanásio dos Santos, Mayor (1979–1984 in Praia; 1984–1990 in São Vicente)

Private Professionals – Architects

- Adelino Ivo, AISA Lda, São Vicente
- Maísa Maria Santos, MS Arquitectura, São Vicente
- Mara Lima, ML Arquitectos e Urbanismo, São Vicente
- Pedro Bettencourt, Betaprojetos, Sal island

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Part IV
Energy

Chapter 12
Energy for Sustainability in Sub-Saharan Africa

Luis Alves

12.1 Energy in Sub-Saharan Africa

The African continent is witnessing unprecedented and sustained growth, and its economies are currently growing at average rates of around 4% per year. Six of the global ten fastest growing economies over the past decade are in the Sub-Saharan African continent. If this growth rate is steadily maintained, Sub-Saharan African's Growth domestic product (GDP) could increase three times by 2030 and seven times by 2050. However, to sustain such economic and social growth, a much larger and better performing energy sector is critically required. It is foreseen that Sub-Saharan African population will double in 2050, reaching two billion people. About 60% and 40% of this population will be living in the urban areas and in the rural areas, respectively.

Sub-Saharan Africa is the region with the highest energy poverty rates especially with respect to electricity. This region has a population of more than 950 million people and is the most electricity-poor region in the world, with more than 600 million having no access to electricity, and millions more connected to unreliable energy systems that do not meet their daily energy service needs. Most of the countries in this region have electricity access rates of about 20%, and two out of three people lack access to modern energy services. The average annual electricity consumption in the Sub-Saharan residential sector is around 500 kWh[1] per capita—equivalent to about 5% the consumption of countries like the United States. The IEA[2] estimates that electricity demand in Sub-Saharan Africa grew by about 35% from 2000 to 2012

[1] Kilowatt hour.

[2] International Energy Agency.

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M. C. Guedes, G. Cantuaria (eds.), *Bioclimatic Architecture in Warm Climates*,
https://doi.org/10.1007/978-3-030-12036-8_12

to reach 350 TWh,[3] and it is forecasted that total demand for electricity will increase at an average rate of 4% per year till 2040. Demand estimates that include self-generation, such as diesel generators, report even higher figures.

To meet this growing electricity demand, the region will need to significantly expand its installed generation capacity and make extensive upgrades to the power grids. At the current rate of electrification and population growths, more than 500 million people are expected to have no access to electricity by 2040, and full electricity access in the region is not estimated to be accomplished until 2080. For this reason, Sub-Saharan Africa faces a complex and persistent electricity gap resulting on a complex and persistent electricity shortage. This deficit refers both to the discrepancy between supply and demand in network regions and the lack of access in regions not served by the network. Bridging the electricity gap in the region is a multidimensional challenge, with important implications for how the energy problem of sub-Saharan Africa should be approached, in order to avoid a large majority of its population to be kept away from enjoying a healthy and productive life.

Table 12.1 illustrates the comparison between rural electricity access and urban electricity access in Sub-Saharan Africa, respectively, in 2010 and 2030, if current trends continue. The figures show that rural populations low electricity access rates will continue in the next two decades. It should be noticed that access to energy and efficient energy systems are prerequisites for economic and social development because virtually all productive activities need energy as an input. Thus, energy is very important to achieve sustainable development. Basic levels of electricity access, such as lighting, communication, healthcare and education, provide substantial benefits for communities and households. Moreover, sustained economic development requires a definition of electricity access, which postulates that energy levels should provide for basic services as well as for productive uses. And, in the case these services are based on renewable energy sources, positive environmental impacts are also added and can be achieved.

The Sub-Saharan Africa countries have large income and wealth inequalities, leading to wide differences in consumer capacity and willingness to pay for electricity. Access is also deeply unequal among individuals who are connected to the network. Some people are connected to the network but do not have economic possibilities to pay for electricity. As such, they cannot consume enough electricity

Table 12.1 Comparison of rural and urban electricity access in 2010 and 2030 (source: Africa's Renewable Future - IRENA, 2013)

	Urban without access to power (%)	Rural without access to power (%)	Rural with access to power (%)	Urban with access to power (%)	Population (million)
2010	11	47	15	27	1030
2030	5	37	14	44	1560

[3] Terawatt hour; 1 TW = 10^{12} Watt.

to make use of modern energy services. The persistent shortage of electricity undermines the region's economic growth and prevents the countries from achieving several of their health and education development goals. Among the causes of this shortage are the lack of production capacity to supply energy to networks, the lack of adequate infrastructures to supply power, regulatory impediments to the constant supply of revenues to maintain and invest in new production capacity and such as the fact that the population living in remote areas is very dispersed. The region's inability to provide reliable electricity has led to inefficient and costly production in industrial, commercial and even residential sectors. This is illustrated in Table 12.2 for all regions of the African continent.

This lack of systematic planning for the energy sector has resulted in a system with high transmission and distribution losses (an average of 18% in the region, excluding South Africa) and has created a high dependence on large dams and expensive diesel electricity production. The region's dependence on fossil fuels creates a multifaceted problem of supply and price variability, with fuel producers reducing supply in periods of low prices and consumers suffering economic losses during periods of high prices. In addition, projections indicate that climate change has a substantial impact on the reliability of sub-Saharan Africa's hydropower resources. Irregular rainfall patterns and prolonged droughts lead to hydroelectric power production reduction and long outages and blackouts. The region's contribution to global greenhouse gas emissions is the lowest in the world, but sub-Saharan countries are the most vulnerable to the impacts of climate change, such as dry and poor agricultural incomes.

This complex challenge represents an opportunity for sub-Saharan countries to design low-fuel, low-carbon energy systems based on wind, geothermal and solar energy technologies as well as to use easy and efficient demand management strategies.

The region has abundant fossil and renewable energy sources as it is illustrated in table 12.3. The immense potential of renewable energy soureces in Sub-Saharan Africa has been widely documented, and there are increasing instances of that potential to be achieved.

Table 12.2 Key energy figures for North Africa, Sub-Saharan Africa ans South Africa (source: Africa's Renewable Future, IRENA 2013)

	Population (million)	GDP (billion USD)	Electricity use per capita (kWh)	Electricity access rate (%)	Clean cooking access rate (%)
North Africa	165	407	1410	99	>95
Sub-Saharan Africa	807	557	160	29	17
South Africa	50	288	4810	77	85

Table 12.3 Sub-Saharan technical production of production capacity (source: Africa's Renewable Future - IRENA, 2013

Energy source	Potential productivity (GW)
Solar energy	10,000
Hydroelectricity	350
Natural gas	400
Total	11,000

12.2 Energy for sustainable development in Sub-Saharan Africa

What limits the development of electric power in Sub-Saharan Africa is the lack of effective technical, political and financing mechanisms that allow the development of these resources. In addition, the region's lack of network infrastructures can be transformed into an opportunity to lead the way towards better-designed, more efficient and sustainable energy systems that are not dependent of historically heavily carbon-dependent assets. There is a window of opportunity for both public and private stakeholders to determine how best to coordinate power solutions at the point of use, mini-grid and centralized grid level. Mechanisms should be implemented to facilitate the extension of the network and the deployment of micro-networks to reach regions that are not linked. Electricity distribution companies and tariff structures should be fair, stable and sustainable to ensure a reliable and cost-effective provision of services to final consumers, as well as adequate maintenance of the valuable energy infrastructures.

Bridging the electricity deficit with the integration of renewable sources into the energy systems will entail economic and environmental counterparts because of the unique combination of challenges and opportunities in the Sub-Saharan African region. A promising path to facilitate this development is through power pooling, which allows countries to pool resources and continue to expand networks beyond national boundaries, capitalizing on regional diversity in resources and demand. Energy clusters could also facilitate additional strategies to incorporate large amounts of variable renewable energy production with intermittent energy storage scenarios, such as the use of existing hydropower storage reservoirs, the deployment of new chemical and mechanical storage technologies, as for example batteries, and the adoption of generalized response programmes looking across the region. In some countries, public-private partnerships have resulted in excellent solutions for electrification of remote regions. A good example of this, is the project SESAM-ER in Cabo Verde, funded by the EU Energy Facility, to provide electricity to a small fishing village in Santo Antão Island, illustrated in Fig. 12.4. This kind of project is being replicated in the country, as well in the neighbouring country of Guinea-Bissau.

However, it is critical to design, test and evaluate different scenarios for Sub-Saharan Africa to find the ideal combination of supply, transmission, storage and demand side resources to enable development and growth in the coming decades. Countries need to develop and adopt a number of integrated, data-driven modelling tools for systems planning and operationalization, as well for financing, at an unprecedented scale. Governments need to develop partnerships with stakeholders from academia and the private sector to produce data of the quality and quantity necessary for decision-makers to have the right information for these modelling tools, to ellaborate energy master plans and design bankable projects.

Although challenging, these actions will reveal opportunities to increase the use of clean energy and to establish international and international cooperation in Africa. While the models only illustrate opportunities, there are promising signs that if access to energy and sustainable development are considered priorities across the continent, Africa will be poised for energy transformation. Some assessments and studies made in the region produced several important conclusions:

- Although Sub-Saharan Africa has significant fossil resources, many of which are the focus of domestic and international "resource runoffs" and investments in fossil fuels and their use should be very rational given:
  - The exploitation of fossil fuels, even in countries with limited energy, is often carried out without considering the development of sustainable energy sources.
  - Decades of experience demonstrate that fossil fuel-based energy development contributes little to increasing access to energy, which is lower in sub-Saharan Africa than in any other region.
- Sub-Saharan Africa has an exceptional potential for solar, wind, geothermal and biomass energy resources, both on a per capita basis and in terms of resource diversity. As such, the continent can achieve high levels of energy services with very low-carbon emissions.
- Advances in smart grids and ICT[4] will enable the region to take the most advantage of its exceptional renewable resources.
- The successful integration of a significant amount of variable intermittent renewable resources will require a high degree of flexibility on the part of the grid, which has been held back by the difficulty of operationalizing regional energy clusters and the high cost of energy storage.
- Allying operational power pools with strategic policies and actionable targets could accelerate the pace of electrification across the region.
- While these challenges are being addressed, fossil fuels, especially natural gas, are likely to continue to be part of the region's transition to a low-carbon electricity grid.

These observations lead to the following actionable conclusions:

- The lack of data is making difficult the analysis of future network projects in many countries in the region. The development of robust planning tools with relatively low data requirements will allow for a broader empowerment of renewable energy projects based on their energy, social and environmental costs and benefits.
- Investing in renewable energies is, with no doubt, a more sustainable and cost-effective way to meet the twin challenges of Africa: economic empowerment and access to energy.

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[4] Information and communication technologies.

- The clean energy path benefits significantly from well-functioning regional energy clusters. National efforts to develop clean energy transition plans as well as policies aligning the provision of energy services on and off the grid are key. However, some additional regional work—through regional energy clusters—can accelerate progress to achieve national and regional energy adequacy targets and access to energy for the entire population in Africa.
- Globally, little attention has been paid to coordinating and integrating off-grid energy systems, mini-networks and large-scale systems managed by electricity distribution companies. For African countries and individuals, the benefits of such a system can be transformative.

The Sub-Saharan African countries have a unique opportunity to expand their energy production capacity without worsening climate change due to its abundance of renewable resources. Renewable energies are the key to solve not only the problem of access to energy but also the challenges of climate change in the region. The factor that limits the development of electric power in the region is effective technical, political and financing mechanisms that allow the development of these resources. The lack of network infrastructures can be transformed into an opportunity to lead the way towards better-designed, more efficient energy systems that are not at the mercy of historically heavily carbon-dependent assets. Governments and the private sector have made concerted efforts to promote the use of micro-networks and other distributed energy resources to reach regions that are not electrified, but these efforts have inadvertently resulted in the coupling of centralized and distributed technologies as opposing efforts. However, these technologies should be seen as complementary. When centralized and distributed networks are built to integrate and link them in the future, strategic synergies can be created. To this end, effective structures to facilitate this task are essential. Finally, tariff structures and electricity distribution companies can be reformed to reflect fair and stable rates, which ensure a reliable provision of services to final consumers.

12.3 The Sub-Saharan Africa Energy Resource Potential

Sub-Saharan Africa has an enormous abundance of fossil and renewable energy resources that have not yet been adequately developed to meet the region's electricity demand. It is estimated that its potential technical production capacity is 11,000 GW, largely based on renewable energies.

Africa has considerable reserves of fossil fuels of all kinds: oil, coal and natural gas. Figure 12.1 shows an oil exploration platfrom in Cabinda, Angola. Angola is the second largest oil production country in the Sub-Saharan region, and an OPEC member. However much of this resource is either utilized outside of Africa, or some of the resource is not developed at all for use within the continent. Meanwhile, there are concerns that the future of fossil fuel use will need to take place in the context of a low-carbon development pathway. It is therefore important to explore the resource and technical challenges and opportunities associated with the expanded use of fossil fuels in Africa.

Fig. 12.1 Oil platform in Cabinda (Angola). (Photo: Laurindo Inglês)

Sub-Saharan Africa has huge renewable energy potential with some of the world's largest concentration of alternative energy resources in the form of solar, wind, hydro and biomass energy. Overall, the 17 countries in sub-Saharan Africa are in the top-33 countries worldwide with combined reserves of solar, wind, hydro and geothermal energy far exceeding annual consumption. Most of the sub-Saharan countries receive solar radiation in the range of 6–8 kWh.m^{-2}.day^{-1}, which counts among the highest amounts of solar radiation in the world. Until now, only a small fraction of Africa's vast renewable energy potential has been tapped. The renewable energy resources have the potential to cover the energy requirements of the entire continent. Solar energy can play an important role to satisfy electricity needs of a large share of the population living in remote villages, by the means of small PV power plans and individual home systems (SHS). A SHS is shown in Fig. 12.2. These systems were installed in the rural regions of Guinea-Bissau, in the frame of a project funded by the European Union Fund for Development, with some success, since they permited isolated communities and homes to have access to electricity for some basic services (light, radio, cold).

The sub-Saharan Africa region is also the home of important potential in hydroelectric power. Hydropower electricity generation is likely to grow rapidly in Sub-Saharan Africa. Hydropower represents a significant source of electricity production in eastern and southern Africa. If all the dams planned for 2030 are built they will more than double electicity generation capacity across these regions (Fig. 12.3).

Fig. 12.2 PV individual home system in Guinea-Bissau (phto by the author)

Fig. 12.3 Cahora Bassa hydroelectric power station in Mozambique (photo by Arsénio José Mindu)

Fig. 12.4 100% solar PV village—Monte Trigo (Cabo Verde)

12.4 Energy transition in Sub-Saharan Africa

a. Foster the emergence of Renewable Energy and Energy Efficiency Projects

The term “renewable energy” covers diversified sectors: resources in inventory or renewable and continuous or intermittent, more or less mature technologies, centralized or decentralized equipment and power that ranges from a few watts to several hundred MW.

In addition, a resource such as solar energy is accessible everywhere on the continent, while others are much more localized—hydroelectricity, wind and geothermal fields.

The various sectors are complementary, and the diversification of renewable supplies contributes to strengthening the resilience of sub-Saharan African energy systems, each sector carrying a particular challenge:

b. Promoting Energy Efficiency and Demand Management in the Different Sectors of the Economy

The initiatives must target different types of actors to implement measures to control energy consumption:

- The industrial sector: it sometimes consumes more than half of the commercial energy due to the use of obsolete and ineffective equipment. Process changes or marginal optimizations make it possible to act simultaneously on climate issues, energy costs and competitiveness.
- The tertiary sector: it covers various applications such as shops, offices, administrations and hospitals.
- Municipalities, managers of public buildings and urban services parks: strong stakes in urban lighting, urban transport (with co-benefits in terms of air pollution and congestion control), recovery waste energy (biogas production) and heating or cooling networks.

12.5 Reduce the Energy Divide

a. Access to Electricity

In terms of access, the regions of Africa show significant disparities. In North Africa, the electrification rate is close to 100% after the first programmes conducted 20 years ago. However, in the countries of sub-Saharan Africa, the average electrification rate in rural areas is 15%, and the urban peripheries do not systematically benefit from electricity services offered in large cities.

International cooperation and governments must support and identify national electrification policies to enable as many people as possible to access an electric service adapted to their needs. Depending on the dispersion of dwellings and their distance from the network, the solutions implemented vary:

- Small urban centres close to the network benefit from expansion and densification of the network.
- When villages are further away, isolated hybrid power plants coupled with a mini-grid are set up.
- For more dispersed habitats, individual solutions such as solar micro-kits or wired solar kits are more appropriate.

b. Domestic Fuels and Local Biofuels

Wood and charcoal are the most used fuels in rural and suburban Africa. In several countries, international institutions already finance forest or plantation management projects for fuelling cities with fuels.

It is also active in structuring biofuel pathways, ensuring their complementarity with agricultural policies and the sustainability of supplies.

c. Securing the Electrical Systems

Strengthening of national electricity grids and support for electric companies. In some countries in sub-Saharan Africa, losses, technical or non-technical (illegal connections, lack of metres), and non-payment of bills mean that in some cases, less than half of the electricity produced is paid.

As part of rehabilitation operations, there are projects that finance the replacement of obsolete equipment and technical assistance to improve commercial and financial management.

In addition, faced with a demand for electricity that increases by 5–10% per year in many regions, it is necessary to strengthen and extend the existing grids by new infrastructure (e.g. by completing the looping of several lines), in order to develop access to electricity and secure supply.

The African challenge lies in the coordinated transformation of production systems and electricity transmission and distribution networks. The modernization of the networks is an important way to integrate decentralized productions and to ensure a dynamic management of the demand.

d. Development of Regional Interconnections

Regional interconnections make it possible to evacuate electricity produced, for example, by large dams, to pool electricity production and to secure supplies. International cooperation has supported and is supporting several emblematic projects in East and West Africa.

The modernization of the networks through the introduction of intelligence in networks, as a first step for a country with a faulty electricity grid, is to have a reliable and comprehensive control centre and to introduce automation on certain systems, in order to optimize the transport and distribution of electricity. The progressive deployment of intelligence in networks (smart grids) makes it possible to answer several central concerns of the electricity companies: to reduce the technical and commercial losses and the cuts, to stabilize the network, to add intermittent renewable production capacities and to attenuate the peak of demand.

12.6 Renewable Energy: Challenges for Sub-Saharan Countries

The exploitation of renewable energies involves various issues, such as sociocultural and economic challenges.

a. Sociocultural Challenges

Reducing the gap between rural and urban dwellers and combating rural-urban migration. The electrification of villages and individual homes in rural areas far from the traditional electricity grid allows people to access lighting at night and also information services (TV and radio) and sometimes communication (mobile phones), as well as the creation of business opportunities (small shops, commerce), contributing to job increase and the fight against poverty. Access to these amenities can significantly reduce the out-migration of rural youth to the cities.

- *Improvement of the organization of social life.* Solar energy can better reorganize social life: the need for individual lighting, at the base, formerly small conflicts between women and school children can find a durable solution.
- *Reduction of the physical chore*. The introduction of solar equipment, including pumps, stoves and solar ovens, significantly reduces the physical effort of manual watering and transporting firewood for women.

b. Economic Challenges

Reducing dependency on fossil fuels. Oil prices continue to rise in global markets, and many African oil-importing countries should begin to consider other ways to reduce their dependence on oil.

- *Impact on health.* In rural areas, most health centres do not have enough drinking water because of the archaic inefficient pumping methods. The development of pumping stations operating from renewable energies (photovoltaic or wind pumping) provides easier access to drinking water in acceptable quantities in rural health centres. In addition, vaccination campaigns are numerous, especially for children, but it is often difficult to keep vaccines in rural areas. Refrigeration systems powered by solar equipment that use batteries powered by solar panels can keep these vaccines.
- *Impact on education.* Lighting in schools and teachers' homes has a clear impact on student achievement. Indeed, teachers more easily accept their living conditions slightly improved by lighting classes and their homes. They can now continue classes after a certain hour in the evening and correct students' notebooks at night. The school children themselves, can, revise the lessons quietly at home without worrying about the availability of other lighting sources.

c. Environmental Issues

- *Forest preservation.* In general, most cases of deforestation are due to the excessive cutting of wood energy by the population and overgrazing induced by pastoral needs. Solar equipment offers the possibility of considerably reducing the anthropogenic pressure on the forest cover, by substituting for wood fuels for cooking, drying and heating, among others, and by promoting an increase in the supply of biomass for energy and irrigated plantations of fast-growing trees for fuelwood, oilseed or sugar crops for biofuels, recovery of agricultural residues for making fuel briquettes, market gardening crops, etc.
- *Pollution control and reduction of greenhouse gases.* Renewable energies in general have a potential direct impact on the quality of the immediate environment. By replacing the conventional energies used by the people for their different needs, production of harmful effluents that contribute to the increase of the greenhouse effect and other forms of pollution are avoided.
- *More equal distribution of resources.* Rural populations isolated and remote from conventional power grids are disadvantaged by the fact that they do not have access to electricity in a so-called energy self-sufficient country. We can therefore speak of an unequal distribution of the country's energy resources. Better use of renewable energies would contribute to a more even distribution of energy resources and thus reduce the deep inequalities at this level.

d. Energy Challenges

The objectives of an energy policy in Sub-Saharan African countries should be based on a few guiding principles:

- Taking into account the definition of sustainable development that takes into account "the fight against poverty, the preservation of natural resources and the environment".
- The subregional scale: the objectives of the national energy policy should be in line with those of the common regional policies.
- The long term: it must be foreseen the needs of future generations and imagine scenarios of industrial development more important than the one known at the moment.
- Security and continuity of the supply of energy in several forms: electricity, biofuels but also fossil fuels.
- The reduction of the cost of energy: for the energy companies oriented towards the production of the biofuels that are put in place at the moment, it is an important stake, understood that they will want to enlarge their national market and possibly to make known outside; and for consumers who will have to control more and more costs.
- The design of sustainable energy development, that is to say, more respectful of the environment and concerned with the needs of future generations.

- Reducing inequalities, ensuring better access to energy for all the populations of the Sub-Saharan African region.

e. Technical Challenges

The popularization of renewable energy equipment during projects in Sub-Saharan African countries will result in:

- Human capacity training for innovation and research and development in national centres specializing in renewable energies.
- The creation or strengthening of enterprises and infrastructures for manufacturing, experimentation, dissemination but also equipment maintenance.

Part V
Building Materials

Chapter 13
Masonry

João Gomes Ferreira

The word "masonry" refers to a set of individual small units that are laid and arranged over each other, whether or not bound by a mortar, forming walls, bridges, foundations, etc. When this set supports the construction, it is called structural masonry.

Regarding the use of mortar for bonding the masonry units, this may be referred to as "ordinary masonry," when the mortar is present, or "dry masonry," otherwise.

The elements that constitute the masonry units may be, for example, rubble stones (rubble masonry) or regular stones arranged face to face (ashlar masonry) or bricks of different types and different materials (adobe, solid ceramic, perforated ceramic, concrete, autoclaved cellular concrete, expanded clay concrete, etc.).

Masonry walls in ordinary buildings generally have a render layer (external face of external walls) or render and plaster layers (internal face of external walls and both faces of internal walls), which is normally finished with a painting. The render layer consists of a mortar layer, which together with the surface paint protects the wall from degrading agents, contributing to their waterproofing capacity and good visual appearance. The absence of rendering causes a more rapid degradation and worse thermal insulation, mainly due to the infiltration of rainwater.

In Africa, besides clay and wooden construction, there is a predominance of structural masonry, forming the external walls of the buildings and, in the case of larger plan buildings, also some interior walls. The typology of structural masonry walls varied over time and according to the regions as a function of the economic and social level and of the materials and the constructive techniques available.

One of the most common types of dwelling in Africa is based on adobe brick walls, consisting of blocks of clay-based earth mixed with sand that are molded and compacted in wooden boxes and dried in the sun (Fig. 13.1).

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Fig. 13.1 The manufacture of adobe bricks in S. Tomé island

Fig. 13.2 Small adobe houses in S. Tomé island

This type of construction can be considered a sustainability paradigm as it uses natural materials from the region and the local workforce, does not use polluting energy sources, is economical, and respects local culture and traditions.

Besides its use in small construction in rural environment (Fig. 13.2), this constructive technique was widely used in the construction, including in larger buildings, such as those of the plantations in São Tomé and Principe (Fig. 13.3).

During the colonial period in Africa, different materials and construction techniques were introduced by the colonizers, namely, different types of walls such as the ceramic brick wall (Fig. 13.4), ordinary rubble masonry (Fig. 13.5), and the timber masonry walls similar to those of Lisbon's Pombaline type (Fig. 13.6).

Fig. 13.3 Construction of larger adobe buildings in São Tomé plantations

Fig. 13.4 Ceramic brick walls in S. Tomé

More recently, the construction with concrete blocks (Fig. 13.7) has been generally used in building walls, which are braced vertically and horizontally with reinforced concrete elements (Fig. 13.8).

Fig. 13.5 Ordinary rubble masonry walls in a S. Tomé plantation building

Fig. 13.6 Timber framed masonry wall in a S. Tomé plantation building

Fig. 13.7 Manufacturing of concrete blocks in S. Tomé Island

Fig. 13.8 Construction of a building with concrete blocks in S. Tomé island

13.1 Functional Rehabilitation of Masonry Walls

Rehabilitation of Render Layers

Painted render is, in current cases, the main protective element of the masonry walls against the agents normally responsible for its degradation. Rehabilitation of render layers or its application, where it does not exist (as long as it is compatible with the construction aesthetics), is the main way of ensuring adequate wall protection, improving its behavior and durability.

The render mortar composition should ensure physical and chemical compatibility with the wall on which it is applied. In particular, the type of sands and binders used – cement, lime, and pozzolans – as well as their dosages and the amount of water used should be taken into account.

Portland cement is a strong binder that provides higher strength, but, in return, the mortars with high dosages of cement present also higher shrinkage. Lime mortars present less resistance but also less shrinkage. Hydraulic lime presents an intermediate behavior in terms of strength and shrinkage.

The hardening process in hydraulic binders (Portland cement and hydraulic lime) occurs essentially through the reactions of the binder with the admixed water. In the case of hydrated lime, hardening occurs due to the reaction of calcium hydroxide, which is the main constituent of hydrated lime, with atmospheric carbon dioxide, producing calcium carbonate.

Natural pozzolans are materials of volcanic origin that, in the presence of calcium hydroxide (existing in lime and Portland cement), develop binding properties. The incorporation of pozzolans in the mortars reduces the amount of binder needed, which is advantageous from the environmental and economic points of view while also reducing shrinkage.

Mortars with more than one type of binder, in which the aim is to take advantage of the best qualities of each one, are called “bastard mortars”.

Wall renders are generally composed of several layers, with different functions and compositions. A traditional render for external faces usually consists of three layers.

The first layer, with a reduced thickness (a few millimeters), has the function of guaranteeing the adhesion between the support and the successive layers. This layer is usually applied with a paintbrush or a trowel, by vigorously projecting the mortar against the wall.

The intermediate layer is thicker (around 10–20 mm) and is responsible for ensuring the flatness of the surface, compensating for any irregularity that the support may present.

The finishing layer, which presents an intermediate thickness (5–10 mm), receives the final painting. The intermediate and the finishing layers are usually applied by projecting the mortar and are then straighten with a trowel. In the case of adobe walls, before applying the render layers, a paint coat with limewater is usually applied for surface consolidation.

In terms of their composition, these layers must comply with the “rule of decreasing binder content” which states that mortars should be successively less strong (have a lesser amount of binder) from wall facing (first layer) to their outer surface (finishing layer). Likewise, it is normal to use coarser sand in the first layer and a finer sand in the finishing layer.

In the first layer, for example, a volumetric dosage (ratio of the volume of the various constituents) of 1:3 (cement/coarse sand) may be used. For example, a dosage of 1:2:9 (cement/hydrated lime/regular sand) will be normal in an intermediate layer. For a finishing layer, a dosage of 1:3 (hydrated lime/fine sand) could be considered as an example. It should be noted that in the compositions presented for the different layers, although the ratio of the total amount of binder and sand is the same (1:3), the amount of cement decreases with respect to the amount of lime. The “rule of decreasing binder content” is thus respected not by the binder volume in relation to sand but by the successive reduction of the binder “strength.”

Regarding paintings, on the one hand, they must be selected in order to ensure the impermeability of the wall to the liquid water, avoiding the penetration of rainwater. On the other hand, painting layers must be permeable to the water vapor, allowing for the wall drying process at any time. Generally, environmentally friendly solutions may be used as external painting layers, such as lime paints (also known as whitewash) or water-based paints. From the aesthetical point of view, a color that respects the tradition and the local architecture must be chosen.

Thermal Rehabilitation

The thermal rehabilitation of a building, in particular with respect to the external walls, is generally achieved by increasing its thermal resistance. This technique usually involves the use of complementary insulation materials that may be disposed on the inner face or the outer face of the wall or still therein.

External thermal insulation composite systems (ETICS) have the advantages of the greater thermal inertia they ensure, the correction of thermal bridges (Fig. 13.9) and the fact that it does not decrease the indoor area. However, due to their overthickness, these systems require geometric correction of the façade, which in particular requires the replacing or correcting of doors and windows frames (jambs, sills, and heads).

The insulation systems inside the wall (cavity walls) are placed during construction, and its implementation in rehabilitation works is usually not feasible.

Finally, the internal insulation systems present a simpler application. In the case of climates with higher thermal amplitudes, the lower thermal inertia provided by internal systems may be an important inconvenient.

Aiming at obtaining more sustainable solutions, autochthonous materials should be used as a complement to the insulation. In certain regions of Africa, there are coconut palms, for example, from which coconut straw can be extracted and processed for the purpose of thermal and acoustic insulation of walls, among other applications. If this type of material is not available, common industrial materials such as extruded polystyrene or expanded polystyrene may be used.

Condensation is a relatively common problem in deficiently insulated walls, especially in regions with high atmospheric humidity, which are common in Africa. The resolution of this type of problem essentially involves the thermal rehabilitation of buildings and the implementation of adequate ventilation systems. These ventilation systems should, where possible, be sustainable, based on natural ventilation, avoiding the use of mechanical systems that consume energy and become more expensive.

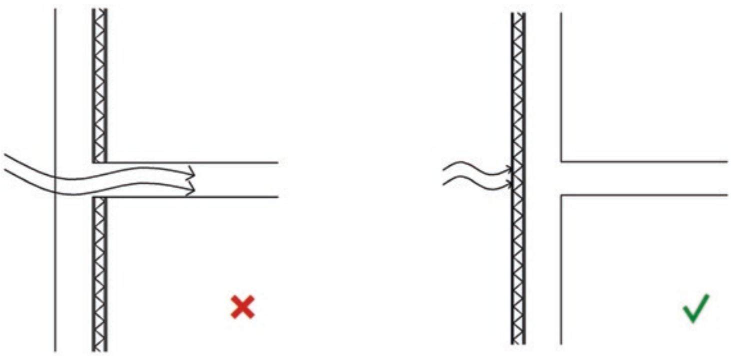


Fig. 13.9 Correction of thermal bridges with ETICS. Internal insulation – thermal bridge (left). External insulation – correction of thermal bridge (right)

Solutions for Rising Dampness

Rising dampness is one of the most common problems in masonry walls. This phenomenon corresponds to the rise of groundwater through the capillaries of the materials that constitute the masonry. In African territories where rainfall rates are high, the problem becomes particularly important.

The ascending humidity penetrates through the body of the walls and the respective renders and plasters, being able to raise tens of centimeters. Besides degrading visual appearance, rising dampness may eventually cause the mechanical degradation of the wall. The humidification and disintegration of the paints, renders, and plasters, with consequent implications on the visual appearance of the construction, firstly develop (Figs. 13.10 and 13.11). At later stages, the rising dampness causes the disintegration of the wall constituents, eventually with implications for structural strength. In addition, the humidification of the wall further contributes to the loss of the thermal insulation, also promoting the occurrence of condensations in the interior.

The problems associated with rising dampness can be solved in several ways, some more effective but more complex and costly, others less radical but more economic.

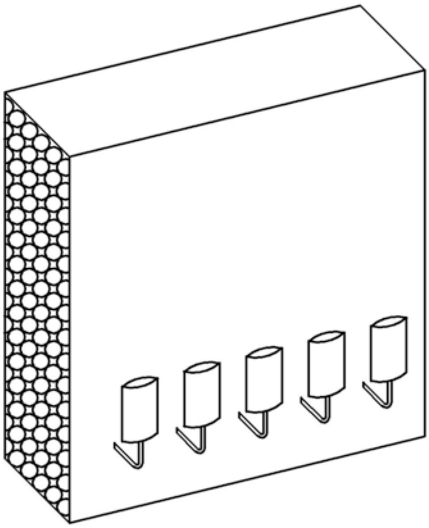
One of the possible methods for solving the problem of rising dampness is the creation of chemical barriers. This technique consists in injecting of existing pores (empty spaces between existing materials) with waterproofing materials, usually of a polymeric nature, throughout the entire thickness of the wall base.

For this purpose, drill holes with a certain horizontal spacing are executed, at the wall base, through which the selected materials are injected. The injection of the

Fig. 13.10 Effects of rising dampness in a building in S. Tomé island

Fig. 13.11 Effects of rising dampness in a building in S. Tomé island

Fig. 13.12 Creation of chemical barriers with gravitic injection



products may be carried out by diffusion (by gravity), through injection cups (Fig. 13.12) or under pressure, using a pump.

The diameter and spacing between the injection holes and the pressure to be applied depend on the masonry constitution and the products used. In the international market, different types of products are offered for this purpose, varying in their properties. These products may be divided into two types: the first type consists in pore fillers, such as epoxy-based materials, which effect mainly consists in preventing the passage of water by filling the existing voids. The other type consists of water repellent, such as those based on silanes or siloxanes, which form a water-repellent barrier.

The creation of chemical barriers is probably one of the most balanced methods between its effectiveness and its cost and complexity of application.

Another possible technique for the solution of rising dampness is the mechanical cutting with the insertion of waterproof barriers. This technique consists of carrying out, at the base of the wall, the replacement of a horizontal layer of the existing material with a layer of impermeable material. The replacement of the materials is carried out in two or three phases, by alternating drill holes, so that the wall does not lose its bearing capacity at any time (Fig. 13.13).

The material to be used for replacing the existing material, besides forming a waterproof barrier, must present adhesion to the existing materials and enough strength to resist structural loading. In this technique, properly formulated epoxy-based mortars, for example, may be applied, ensuring the required impermeability and strength.

Although the insertion of impermeable barriers may present good behavior in relation to rising dampness, it is a more complex and intrusive technique than the creation of chemical barriers, which practically do not involve the removal of existing materials. The execution of mechanical cutting with the insertion of waterproof barriers may create a discontinuity at the wall base that may cause some structural damage, especially when executed with less care, reducing the overall wall strength.

Another possible way of controlling the problem of rising dampness consists of the execution of drains in the external face of the wall. This technique consists of executing a trench all along the wall, filling it with draining materials in order to guarantee the water flow and to prevent it from accumulating and remaining in contact with the wall (Fig. 13.14). In addition, when the trench is opened, the walls must be waterproofed with suitable materials, usually based on bituminous membranes.

By avoiding contact of the wall base with soil waters, this technique, when properly executed, may efficiently solve the problem of rising dampness. However, because this is an expensive technique with a rather complex application, its advantages should be weighted in face of these two aspects.

Finally, there is another group of techniques, which mainly consists in ensuring atmospheric ventilation to promote the evaporation of the water retained in the wall. This may be achieved through the execution of atmospheric drain holes (less

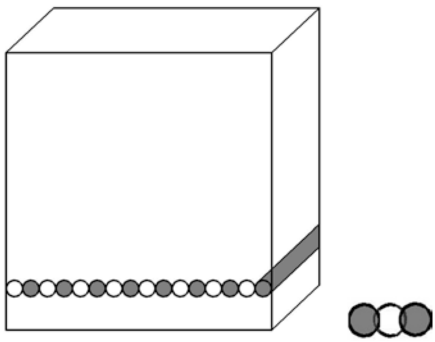


Fig. 13.13 Waterproof bareers: alternate insertion of impermeable material, first stage (white dots), second stage (black dots)

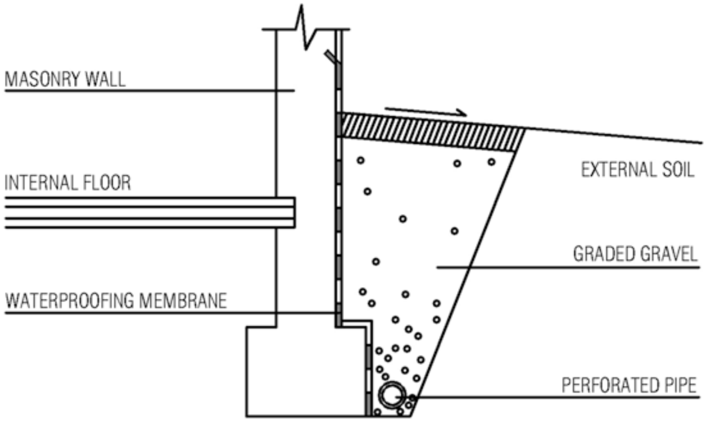


Fig. 13.14 Execution of wall drains

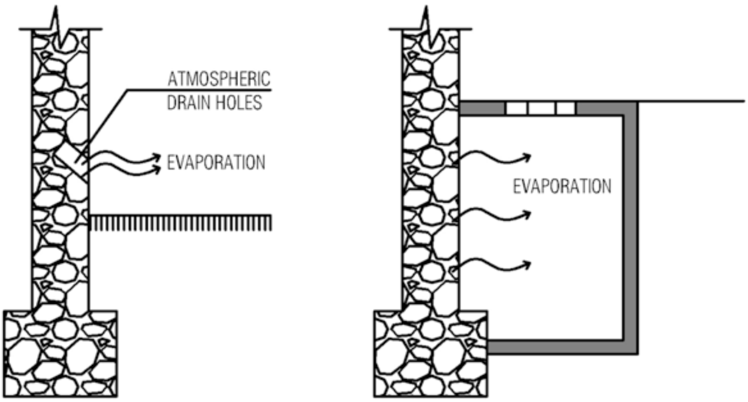


Fig. 13.15 Atmospheric ventilation. Athmospheric drain boles (left). Drain trench (right)

effective), for example, or by creating an unfilled trench along the wall base (more effective but also more expensive and difficult to execute) (Fig. 13.15).

13.2 Structural Rehabilitation of Masonry Walls

Masonry Gap Infilling

Degradation of masonry walls is often associated with the presence of voids and gaps, which may be of different dimensions. Relatively small volume losses, caused by weathering and other natural agents over time, frequently occur. In other cases, the gaps may present considerable sizes and may be associated, for example, with

Fig. 13.16 Reconstruction of an ordinary masonry wall where a doorway had been opened

poorly executed interventions, such as window or door openings that may impair the strength of load-bearing walls. In the case of small gaps, a current repair mortar with controlled shrinkage may be used.

In the case of larger gaps or even suppression of extension zones of the masonry wall, those areas should be rebuilt with suitable materials, compatible with the existing ones, namely, rubble stones, ceramic bricks, repair mortars with controlled shrinkage, etc. (Fig. 13.16).

Consolidation of Masonry Walls with Grout Injection

The consolidation of masonry walls by grout injection consists of infilling the existing voids and integrating the existing mortars in the admixture.

This technique may be implemented in walls with high disaggregation, severe cracking, or significant void ratio. These pathologies may be localized or generalized and originate in the construction or induced by deterioration over time.

The best form of grout injection, with regard to the materials used, composition, and execution technique depends on the type of masonry and the degradation stage.

Grout injection (Fig. 13.17) is generally performed through plastic tubes inserted in holes drilled in the wall to at least half their thickness. The spacing between holes depends on the execution conditions, namely, the grout workability and the wall permeability. The spacing between the holes increases with the void ratio and with void interconnection and with the grout workability. In the case of walls where the voids do not constitute an intercommunicating network, the grout injection is generally infeasible or at least of much slower and more complex application.

Grout injection may be carried out by pouring or under pressure, depending on the masonry permeability to the grout used and on grout's workability. For better control of masonry infilling, pressure injection should be performed from the bottom up using the injection tubes immediately above the injection line for purge control. In this case, the injection is terminated in each tube as the grout begins to flow at the tubes above the injection level (Fig. 13.17).

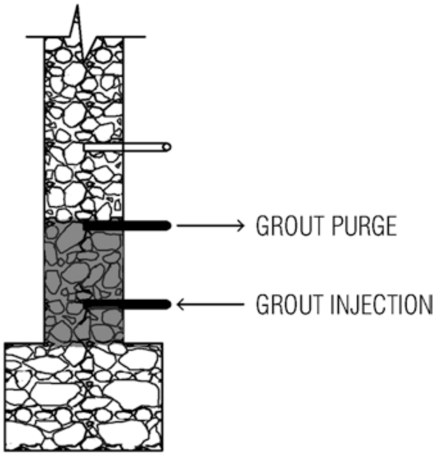


Fig. 13.17 Grout injection in masonry walls

The materials to be used in grout injection may be diverse, with a preference to those with the highest physical and chemical compatibility with the existing materials. Thus, inorganic binders may be used, namely, lime, either hydrated or hydraulic, cement, and pozzolans. Grout compositions must be studied in each case in order to ensure compatibility with existing masonry. Although there are some formulations in commercial solutions based on organic binders, namely, epoxy resins, these are generally less compatible due to the different nature of the materials involved when compared to those of the original wall.

Before performing the grout injection over a large wall area, tests should be performed in localized areas to optimize the execution procedure (pressure, spacing between injection tubes, grout composition and workability, etc.) to ensure the best results. Likewise, post-execution tests should be carried out, which may be as simple as the sound proof, which consists of evaluating the sound emitted by hammering the wall.

Crack Injection

Cracking in masonry may be of structural or nonstructural nature.

The less severe form consists of nonstructural cracking, which is, in most cases, due to thermohygrometric effects, in particular to shrinkage of mortars used in wall renders and plasters. This type of situation, although it can affect a wide wall area and harm its visual appearance, generally corresponds to only superficial, small opening and irregular cracking, usually called mapped cracking, as seen in Fig. 13.18. This cracking is not particularly severe and may generally be corrected through a suitable paint scheme.

On the other hand, structural cracking is a more concerning pathology and generally involves both the masonry core and its finishing. This type of cracking is usually more expressive, corresponding to cracks with specific location and orientation

Fig. 13.18 Mapped cracking in wall render/plaster

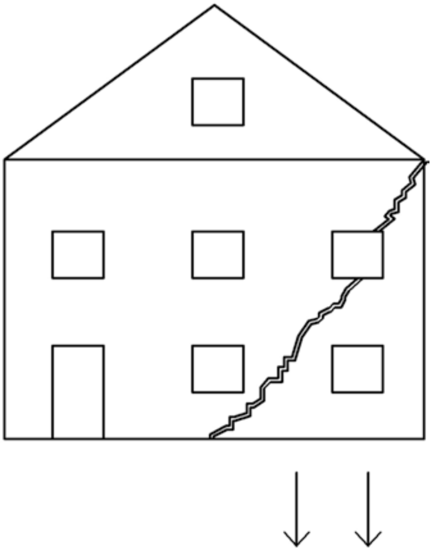


Fig. 13.19 Diagonal cracking due to support settlements

and with greater opening. This cracking is usually associated with problems of a mechanical nature, such as support settlements (Fig. 13.19), poor functioning of the roof structure (e.g., unbalanced horizontal impulses), or stress concentration (often occurring near the doors and windows).

One of the main aspects to be analyzed in the case of structural cracking is whether it is in progress or has already stabilized. In the case of stabilized cracking where the analysis of the situation shows that the structural problem is overcome (e.g., foundation settlement), the repair of the crack itself is sufficient.

In the case of non-stabilized cracking, the original pathology must firstly be solved (support settlement, roof impulses, etc.), and afterward the cracks are repaired. The structural problem has to be analyzed on a case-by-case basis in order to solve it effectively and economically. In the case of foundation settlements, for example, the problem may arise from different causes such as the quality of the soils, the effect of the percolating water with entrainment of fine particles, or from an inadequate constitution of foundation masonry.

Crack injection allows restoring the integrity of the affected masonry and contributes to the best visual appearance and waterproofing. Crack injection should be carried out with materials chemically and physically compatible with the existing ones, and it is therefore generally preferable to use inorganic grouts based on inorganic binders of the same type: hydrated or hydraulic lime, pozzolans, or cement. The grout composition must be studied specifically for each situation and, in the case of larger cracks, may contain fillers (quartz powder, sand). The use of synthetic materials, such as those of an epoxy base, should only be considered when strong bonding effect is needed. This may be appropriate, for example, for cracking in larger stone blocks of ashlar masonry.

As well as in grout injection, the injection of vertical or diagonal cracks (Fig. 13.20) should be performed from bottom to top through tubes inserted into previously drilled holes. The upper injection tubes function as purge control when injecting the tubes immediately below. In the case of horizontal cracks, the injection should take place from the center to the periphery, alternately to each side. Normally, the crack surface should be sealed with mortar prior to the injection operation, in order to prevent reflow of the slurry and ensure correct infilling of the crack.

In the more severe cases where the stability of the wall may be affected by cracking, the addition of mechanical connections may be considered in order to "sew" existing cracks.

These mechanical connections correspond to slots open on the walls transversally to the cracks where metallic elements are then introduced and connected with an appropriate mortar (Fig. 13.21). In these cases, where a stronger binding is needed, mortars with formulations comprising synthetic binders, in particular based on epoxy resins, may be used.

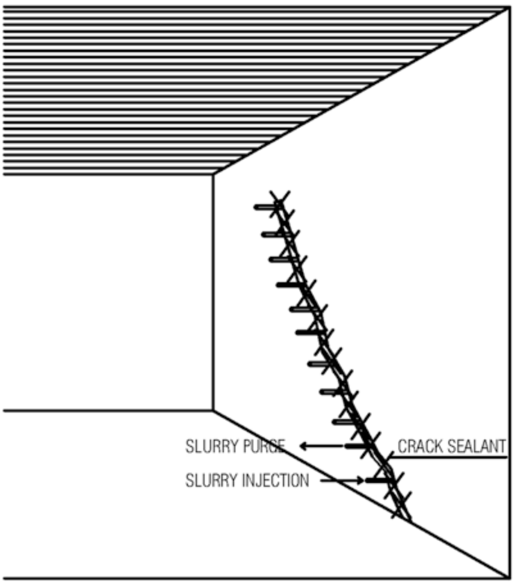


Fig. 13.20 Crack injection in masonry walls

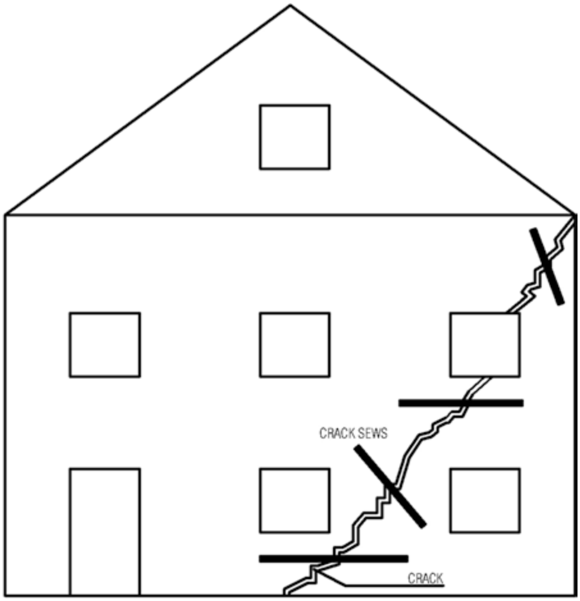


Fig. 13.21 Cracks "sewed" with metallic elements

Ring Beams and Ties

Masonry buildings erected after the emergence of reinforced concrete (end of the nineteenth century) according to good building practice usually have horizontal peripheral beams, referred as ring beams, at least at floor and roof levels. These beams provide an overall confinement of the structure promoting a global group behavior of the walls, limiting their deformations and increasing the overall building strength.

However, in many cases, these confining peripheral beams simply do not exist, or they have been poorly executed. In these cases, new ring beams in reinforced concrete may be created in grooves executed on the walls (Fig. 13.22).

Alternatively, steel profiles may be used, which simultaneously provide a longer support to the timber floors (Fig. 13.23) or roof elements.

One of the most serious structural problems in masonry buildings regards the tendency for walls to "open" globally and disconnect from each other. These problems are usually associated with deficiencies of the construction, such as the inadequate constitution of the corners: lack of interlocking masonry elements, for example, Fig. 13.24, or uncompensated impulses in roofs, Fig. 13.25. In other situations, these problems arise from unpredicted actions on the structure, such as excessive vertical loading, foundation settlements, or earthquakes.

One of the most effective forms of intervention to deal with these situations is the walls' tying. There are several types of tying systems. One of the most common types consists of using passive non-adherent steel cables or steel rods, crossing the

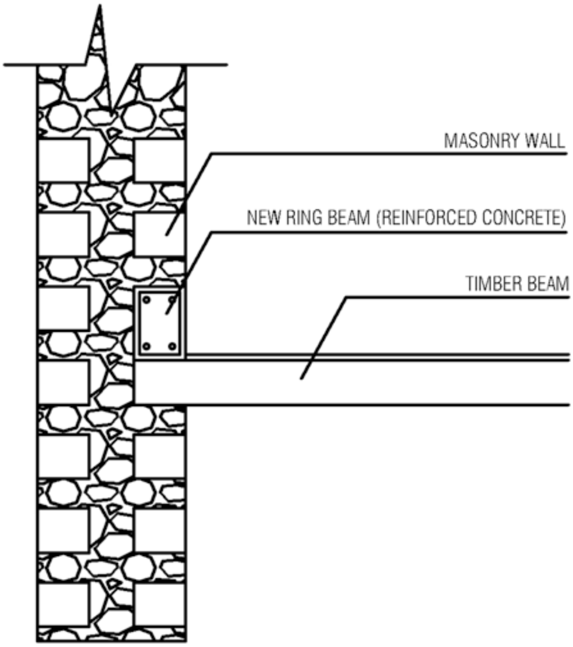


Fig. 13.22 Execution of a ring beam in reinforced concrete

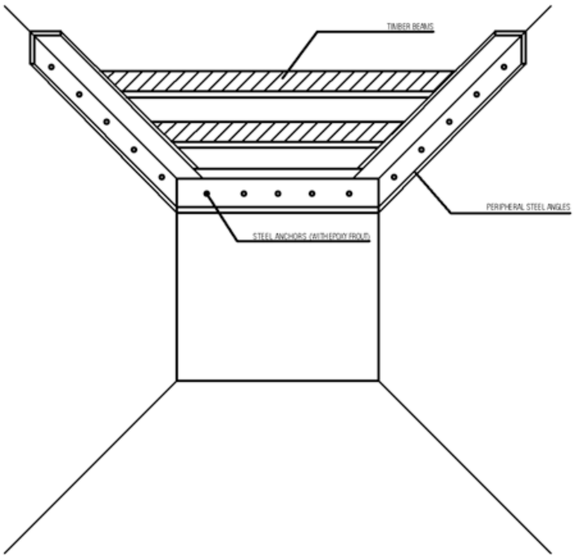


Fig. 13.23 Execution of a ring beam in steel profiles

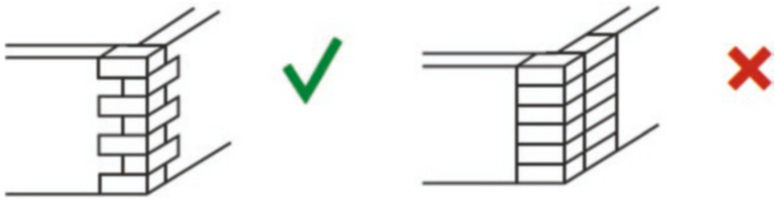


Fig. 13.24 Lack of interlocking in corners

Fig. 13.25 Uncompensated impulses in roofs

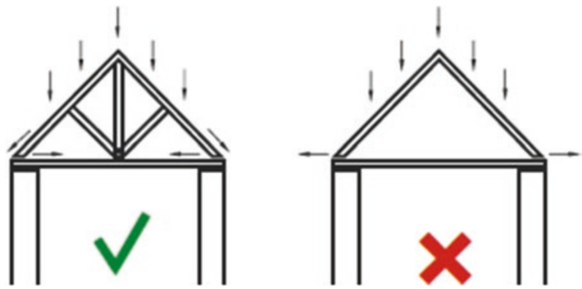
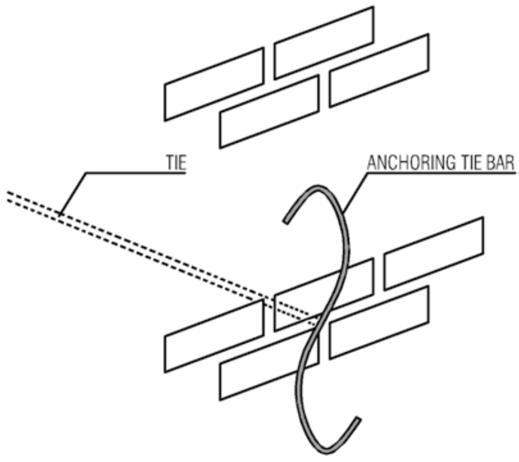


Fig. 13.26 Traditional anchoring tie bar



entire building and connecting the opposing external walls. In these cases, it is necessary to take care of the anchoring zones in the walls to avoid creating stress concentrations that could damage the masonry and even lead to its punching in those zones.

The anchoring tie bars (Fig. 13.26) should consist of elements, such as steel plates or steel bars, with a sufficient contact area to ensure adequate stress transmission between them and the walls. The tying elements are usually placed near the ceilings for functional and mechanical reasons, namely, to avoid obstructing the passageways and to take advantage of the floors stiffness.

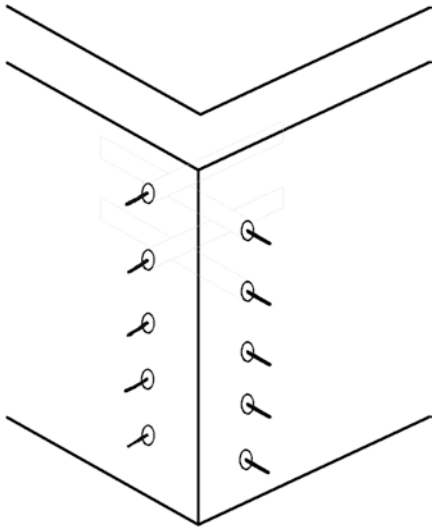


Fig. 13.27 Injected sleeve ties

Another way to improve the behavior of walls or their connections is to use injected sleeve ties. After holes have been drilled in the masonry walls, steel rods with injectable sleeves are inserted in them and then sealed with a cement grout. The injected sleeve ties may be disposed along the wall or perpendicularly to it, to be used, for example, to sew wall corners by connecting the perpendicular walls thereon (Fig. 13.27).

Chapter 14
Timber

Helena Cruz and José Saporiti

Of all materials used in building construction, timber is the only fully renewable raw material, continuously produced by nature.

But since natural forests are not inexhaustible and natural regeneration may be too slow compared to consumption, sustainable use of timber implies continuous replacement of the felled trees. Thus, sustainability of timber constructions implies, first of all, the use of timber from sustainable forests, planted and properly managed in particular in view of timber production.

The production and processing of wood have low energy consumption, much lower than that associated with most building materials.

Timber is produced from trees at the expense of solar energy. Therefore, the (fossil fuels) energy incorporated in the initial phase of the life cycle of this material is essentially due to forest planting and management, felling and cutting the logs, possible drying and preservation, if any, and transportation between the various processing stages till placing on site.

With regard to transportation, the use of local species should therefore be favoured in order to minimize costs and the corresponding carbon footprint.

Drying is an essential aspect to take into account as, when harvested, timber moisture content is excessive for nearly any use. Drying is therefore necessary to reduce its weight and the consequent transportation costs, to reduce the immediate risk of biological attack by fungi and by certain insects and to allow timber transformation and use in construction.

To a great extent, timber drying occurs spontaneously after felling, first rapidly, then slower and slower as its moisture content tends to equilibrium with the surrounding environment. Natural drying generally does not bring moisture content of timber below the range 14–18%, depending on the environmental conditions

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(air relative humidity and temperature), and it may take several months to reach this value, which may not be acceptable for the building works.

Frequently lower moisture contents (often between 10% and 14%) are required for industrial uses (e.g. production of wood-based panels, furniture or joinery) or for certain construction applications such as flooring. The application of timber on site with moisture content higher than the equilibrium moisture content will lead to drying on site and consequent shrinkage, splits and distortion. Thus, the need for kiln drying is often unavoidable. Nevertheless the corresponding costs will be minimized if a first natural drying is carried out, followed by kiln drying until the target moisture content is reached.

If the durability of a given wood is insufficient for the intended application, preservative treatment with chemicals may be considered. These correspond to the incorporation of more energy in the building material, due to this specific operation and through the energy already incorporated in the manufacture of preservatives. In addition, one should take into consideration the possible environmental impact of preservative products during fabrication and the use and disposal of construction timber at the end of its life cycle.

Whenever possible, other options should be considered to protect the timber and prolong its life, by choosing more durable timber species and/or by reducing the risk of biological attack through proper detailing. Design, application and maintenance are therefore crucial to extend the life of timber, thus delaying the moment when the carbon dioxide sequestered during its growth is released back into the atmosphere by decomposition.

As concerning the comfort and economy of energy of timber buildings, it should be taken into account that the thermal conductivity of timber and the thermal inertia of timber buildings are low, resulting in an inner temperature variation closely following the exterior temperature. In such conditions, the adoption of passive strategies for inner temperature control is particularly important in order to limit the energy consumption for heating in winter and especially for cooling in the hot season.

14.1 Use of Timber in Construction

Timber has been widely used in building construction, especially in traditional/vernacular architecture, where it is frequently the main material, but also in "colonial architecture", used mainly in roofs, floors and windows. Timber has also been increasingly adopted for modern buildings, both for residential and touristic purposes, frequently as the main structural material.

The way in which timber was used in the past was mainly a result of the local availability of this natural resource, knowhow and building requirements dictated by climatic conditions and culture, which determined a variety of building traditional uses.

Nowadays, other reasons influence also the use of timber, such as the social and individual concern towards the use of renewable raw materials and the reduced environmental impact associated with its production and use, especially if grown locally, as well as good aesthetic qualities, the integration into the natural environment and the versatility of architectural solutions that timber allows.

Sustainable architecture involves the use of local resources, including materials and manpower. But it is also about the choice of robust and durable constructive solutions, based as much as possible on passive protection measures, which act mainly to reduce exposure to degradation agents.

In summary, it is essential to use this important resource in a rational way, which implies:

- Appropriate choice of wood species in order to take advantage of the specific aesthetic characteristics, mechanical strength, dimensional stability and durability of each
- Specifying the quality and moisture content appropriate to each application in order to obtain more uniform batches and to reduce the development of cracks and on-site work
- Correct design and detail options so as to reduce the risk of degradation, thereby extending the life of structures with low maintenance costs
- Architectural solutions that take into account the specificities of the wood, allowing a good energy efficiency of the constructions, as much as possible through passive strategies to control the environmental conditions.

14.2 Suitability of African Species for Building Construction

Being a natural material, wood presents great variability in terms of colour, density, dimensional stability, mechanical strength and durability. The greatest source of variability has to do with the forest species, although differences may also be noted depending on the geographic region and condition where the tree grows, the area of the trunk from which the wood is obtained, grain direction and the presence of knots.

Good judgement of service requirements and use conditions are fundamental, as a poor choice of material or inappropriate application will certainly shorten its service life or compromise its performance, or both.

Extensive information on African timber are published, mainly studies from sources from the twentieth century. A short overview of the characteristics and typical uses of some common species produced in Africa is presented in Table 14.1. Some species very well appreciated by the market but classified as “endangered” or higher grade by the Union of the Conservation of Nature (IUCN) Red List of “Threatened Species” are not included (e.g., Wenge, *Millettia laurentii*, or Agba, *Gossweilerodendron balsamiferum*). The use of timber from sustainable managed sources displaying certification should be encouraged.

Table 14.1 Characteristics and typical uses of common wood species from Africa

Wood species	Trade name	Main region	Characteristics					Main end uses
			Colour	Density (kg/m^3) (EN 350 2016)	Mechanical properties, see Table 14.2 (Bolza and Keating 1972)	Dimensional stability[a] (Lincoln 1986)	Durability (Bolza and Keating 1972; EN 350 2016), see Table 14.3	
Afzelia spp.	Afzelia	Central and eastern Africa	Yellow to brown with high tendency to turn darker with exposure	820-880-930	S2 to S3	Small movement	1–2 (1/D)	Structural uses; joinery: flooring
Albizzia spp. *(principally A. ferruginea)*	West African Albizia	Western Africa	Red-brown to chocolate brown	500-600-650	S4 to S6	Small movement	2–3 (2/D)	Structural (building and marine constructions)
Aucoumea klaineana	Okoumé	Western Africa	Pinkish-brown. It can show grey-black steaks	430-440-450	S6 to S7	Medium movement	3–4 (4–5/S)	Nonstructural (plywood, furniture, moulding, panelling)
Baillonella toxisperma	Moabi	Western Africa	Pinkish-brown to rich red-brown	770-800-830	S2 to S4	Small movement	1 (1/D)	Nonstructural (furniture, flooring)
Cedrus spp.	Cedar	Northern Africa, Middle East	Light brown	510–570[b]	S5 to S6	Medium movement	1–2 (1–2/D)	Structural (house building) or nonstructural (joinery and furniture)
Khaya spp. mainly *K. ivorensis*	African mahogany	Western and central Africa	Darker reddish-brown	490-520-580	S5 to S6	Small movement	3 (3–S)	Nonstructural (furniture, decorative veneers)
Lophira alata	Ekki	Western Africa	Dark red-brown to dark brown	950-1060-1100	S1 to S2	Large movement	1 (1–2/D)	Structural (bridge and decking, marina construction) and nonstructural

Nesogordonia papaverifera	Danta	Western Africa	Dark red-brown	710-730-760	S3 to S4	Medium movement	2 (3v–D)	Nonstructural uses (joinery, flooring)
Ocotea usambarensis	East African camphorwood	Eastern Africa	Brown	460–570[b]	S5 to S7	Small movement	1–3 (no data)	Light structural and nonstructural (flooring, panelling, joinery)
Pericopsis elata	Afromorsia	Western and central Africa	Golden brown to reddish-brown	680-690-710	S2 to S3	Small movement	1 (1–2/D)	Nonstructural (flooring, joinery, panelling)
Piptadeniastrum africanum	Dahoma	Western and central Africa	Light to golden brown	600-700-800	S4 to S5	Medium movement	2–3 (3–2)	Structural uses (building construction) or nonstructural (flooring, joinery)
Pterocarpus angolensis	Muninga	Central and eastern Africa	Golden brown to dark brown	510-720[b]	S4 to S5	Small movement	2–3 (no data)	Nonstructural (furniture and panelling)
Terminalia ivorensis	Idigbo	Western and central Africa	Pale to brown or pinkish	520-550-560	S5	Small movement	2 (2–3/S)	Nonstructural (furniture, joinery)
Terminalia superba	Limba	Western and central Africa	Light yellow-brown	550-560-600	S4 to S8	Small movement	4 (4–S)	Structural and nonstructural
Turraeanthus africanus	Avodiré	Tropical western Africa	Pale to golden	540-550-560	S4 to S6	Small movement	4 (5–S)	Nonstructural (joinery, panelling)

[a]Movement – sum of radial and tangential dimensional change when changing from 90% to 60% relative humidity, at 25 °C temperature. Small, under 3%; medium, between 3% and 4.5%; large, over 4.5%
[b]From Bolza and Keating (1972)

Table 14.2 Strength group defined by clear wood specimens tested at 12% moisture content (Bolza and Keating 1972)

Strength and stiffness				
Strength group	Bending strength (MPa)	Bending modulus of elasticity (MPa)	Compression strength parallel to the grain (MPa)	Shear strength parallel to grain (MPa)
S1	158	18,700	81.3	18.7
S2	134	16,300	71.0	16.7
S3	114	14,200	62.0	15.0
S4	93.7	12,400	53.4	14.1
S5	79.2	10,700	46.2	11.7
S6	67.2	9100	40.0	10.3
S7	56.8	7920	34.4	9.1

Table 14.3 Natural durability

<table>
<tr><td colspan="4">According to Bolza and Keating (1972), resistance to decay for heartwood in ground contact under average conditions</td></tr>
<tr><td>Class</td><td>Description</td><td colspan="2">Service life expectancy (years)</td></tr>
<tr><td>1</td><td>Very high</td><td colspan="2">25–50</td></tr>
<tr><td>2</td><td>High</td><td colspan="2">15–20</td></tr>
<tr><td>3</td><td>Moderate</td><td colspan="2">8–15</td></tr>
<tr><td>4</td><td>Low</td><td colspan="2">1–8</td></tr>
<tr><td colspan="4">According to EN 350 (2016)</td></tr>
<tr><td colspan="2">Decay – for heartwood in ground contact</td><td colspan="2">Subterranean termites</td></tr>
<tr><td>Class</td><td>Description</td><td>Class</td><td>Description</td></tr>
<tr><td>1</td><td>Very durable</td><td rowspan="2">D</td><td rowspan="2">Durable</td></tr>
<tr><td>2</td><td>Durable</td></tr>
<tr><td>3</td><td>Moderately durable</td><td rowspan="2">M</td><td rowspan="2">Moderately durable</td></tr>
<tr><td>4</td><td>Slightly durable</td></tr>
<tr><td>5</td><td>Not durable</td><td>S</td><td>Not durable</td></tr>
</table>

The uneven distribution of forest lands and corresponding disproportion of timber resources availability combined with the different stages of forest management governance provide different risks to the sustainable use of wood (Barrow et al. 2016). In this respect, the exploitation of nontraditional species or secondary forests can be considered as alternatives that may help in reducing commercial pressure on most common (well-known) forest species. The suitability for the use of new species may be verified by laboratory tests to assess mechanical properties, dimensional stability, natural durability, ease of drying, suitability for gluing and finishing, etc., to establish the best uses for each timber.

14.3 Hygroscopicity and Dimensional Stability

Timber is a very hygroscopic material that continuously absorbs or loses water vapour to the surrounding environment, depending on the temperature and relative humidity of the air. These causes its dimensional variation – which depends from the species and the direction considered in the material (tangential, radial or longitudinal). Variation of the environment surrounding the timber, either due to annual climatic cycles or accidental actions (accidental wetting), results in drying-wetting cycles and consequent cycles of shrinkage-swelling, respectively.

Dimensional variations related with moisture movement are relatively unimportant along the fibres of the timber but may be very relevant in the directions perpendicular to the fibres (being approximately twice in the tangential direction than in the radial direction) and likely to cause splits and distortion (Figs. 14.1 and 14.2).

The choice of more stable timbers is recommended when the exposure of the building elements to highly variable environmental conditions is unavoidable, and the resulting dimensional variations will have unacceptable implications.

Careful design and detailing, by adopting constructive measures that limit the access, absorption and retention of water by timber, will also contribute to the good performance and durability of timber structures.

Timber applied on site with moisture content higher than the equilibrium moisture content with the site conditions will dry and shrink afterwards, with evident damages (Fig. 14.3). In order to limit shrinkage, cracking and distortion of the finished elements (Fig. 14.4) drying should be carried out to near the expected equilibrium moisture content, which can be estimated from the abacus shown in Fig. 14.5, as a function of predicted air temperature and relative humidity.

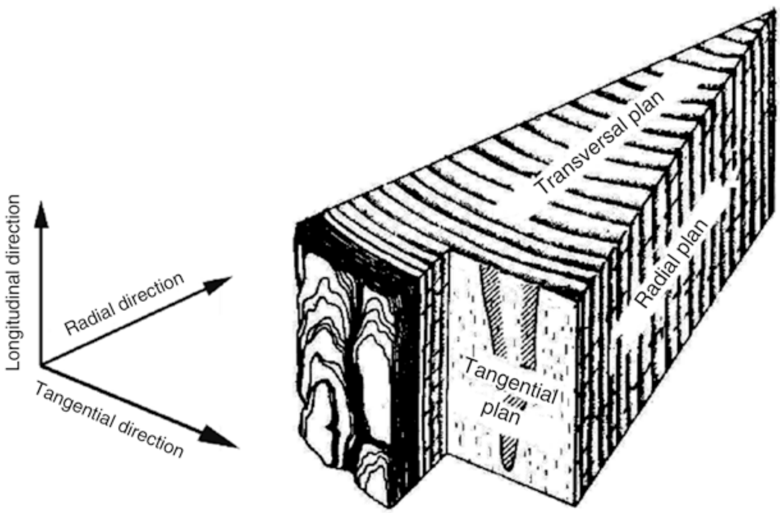


Fig. 14.1 Timber principal directions

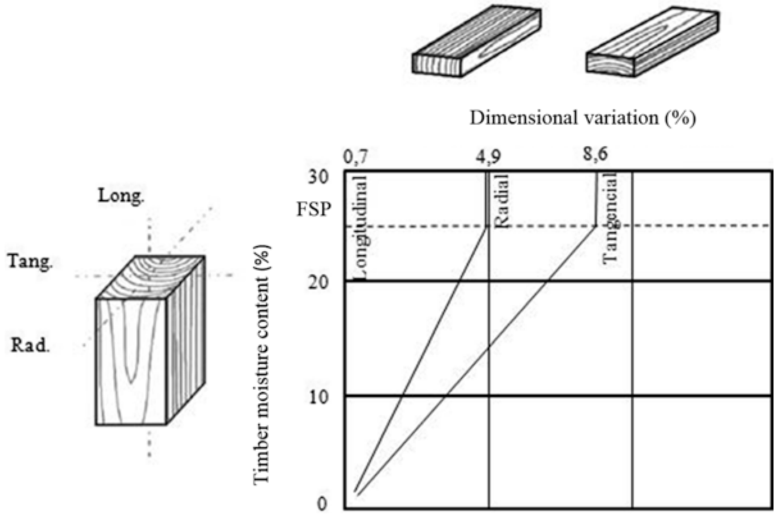


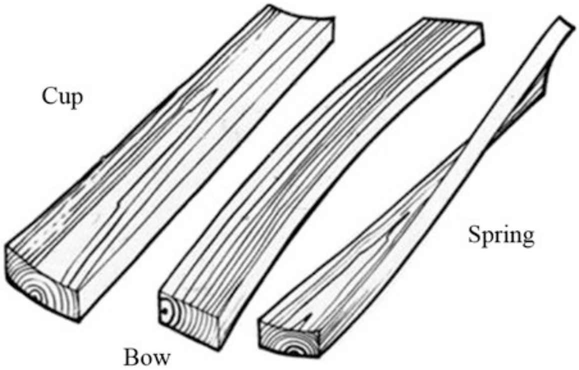
Fig. 14.2 Variation of timber dimensions resulting from variation of moisture content

Fig. 14.3 Swelling of timber flooring after application

14.4 Biological Deterioration of Wood

Timber is susceptible to degradation, due to biological agents that feed on it (notably fungi and insects in terrestrial environment and marine xylophages in salt water), due to the action of fire or even due to weathering, especially when fully exposed to the sun, rain and wind. Timber elements may also be damaged as a result of excessively high stress, or wear in service, if subjected to heavy use.

Fig. 14.4 Distortion



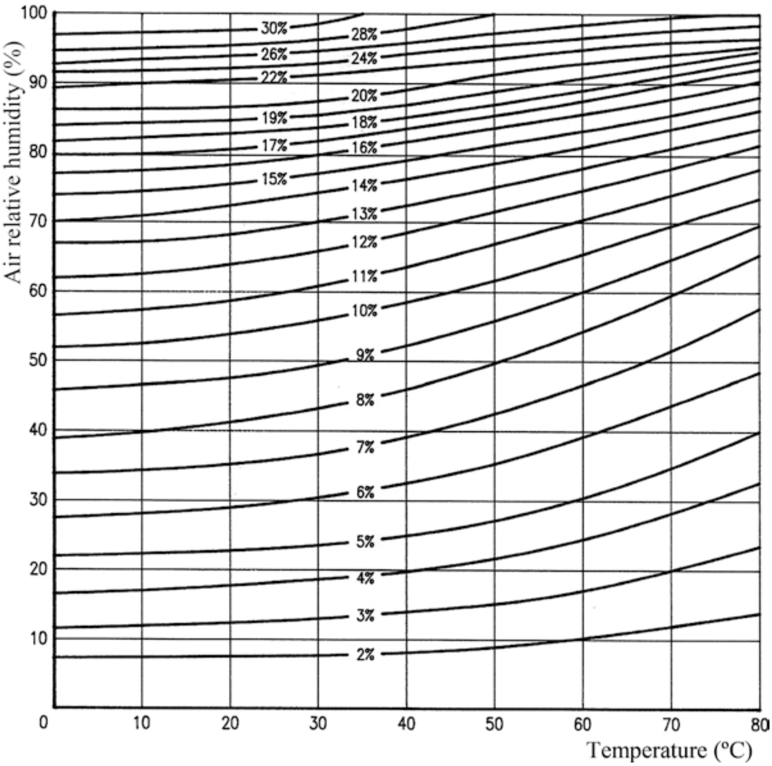


Fig. 14.5 Hygrometric curves

The life of the material on site depends on the actual risk of attack associated with the conditions of use but also on the susceptibility of the particular species to the attack by these agents.

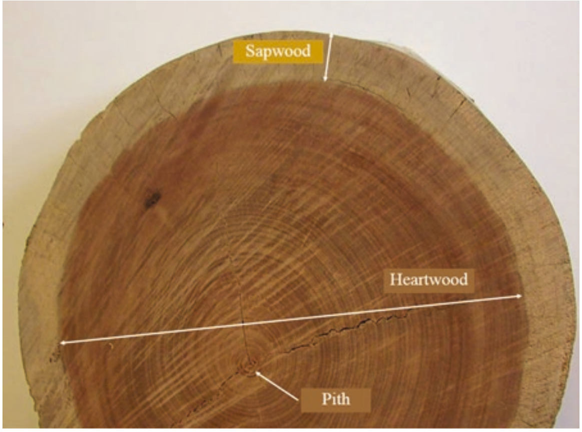


Fig. 14.6 Heartwood and sapwood

The natural durability of a species depends on its level of susceptibility to each of the various agents. Moreover within each species, heartwood is usually more durable than sapwood (Fig. 14.6). This difference may be very pronounced, especially in some tropical hardwood species.

EN 350 (2016) lists, for most forest species of commercial interest in Europe, (i) their durability against rot fungi (heartwood classification, since sapwood is always non-durable against fungi); (ii) durability against subterranean termites (heartwood classification, since sapwood of all species is susceptible); and (iii) durability against beetles (in this case, the durability of sapwood, since the heartwood is assumed to be durable, unless otherwise indicated). This standard covers most common degradation agents in Europe. For agents and species, other than the ones listed in this standard, specific literature should be consulted or specific laboratorial or field trials conducted.

Table 14.1 includes information regarding the natural durability of a number of common species produced in Africa.

Although dry wood may be attacked by some insects, for many other insects and for rot fungi to attack and digest the wood, it must have relatively high (but not saturated) moisture levels. The risk of wood attack by rot fungi is considered to be low for moisture content values lower than 18–20%.

Based on the preferred conditions for the various biological agents to degrade timber, a set of use classes was established, based essentially on the greater or lesser probability that the wood will reach and maintain high levels of humidity on site (EN 335 2013).

Table 14.4 presents the use classes considered in Europe (regarding the risk of biological attack) and some examples. It is necessary to stress that in other regions, especially tropical regions with a wide diversity of wood-degrading agents, this information should be completed with data concerning the specific insects present in that region.

It is the responsibility of the designer to identify the risk corresponding to each element of the construction and to adopt appropriate protective measures.

Table 14.4 Use classes[a] and relevant attacking biological agents

Use class	General use situations	Illustration	Application examples	Moisture content of timber	Relevant attacking biological agents
1	Interior dry		Floors, panelling, interior cladding	Dry, not above 20%	Dry wood insects
2	Interior or under cover not exposed to the weather		Roof structures, wall structures	Occasionally >20%	Dry wood insects
	Possibility of water condensation				(*Medium risk*) Wet wood insects Rot and mould
3	Exterior, above ground, exposed to the weather		Exterior doors and windows, decks without ground contact, pergolas, exterior wood cladding	Frequently >20%	(*High risk*) Dry wood insects Wet wood insects Rot and mould
	May be divided in: 3.1 limited wetting conditions 3.2 prolonged wetting conditions				
4	Exterior in ground contact and/or fresh water		Decks in ground contact or in contact with swimming pools	Predominantly or permanently >20%	Dry wood insects
			Foundations in fresh water, fence poles, poles for transmission lines		(*Very high risk*) Dry wood insects Rot

(continued)

Table 14.4 (continued)

Use class	General use situations	Illustration	Application examples	Moisture content of timber	Relevant attacking biological agents
5	Permanently or regularly submerged in salt water		Pontoons, piers, foundations in salt water	Permanently >20%	Marine xylophagous + (*Very high risk*) (= CU4, for the part of the elements above water)

[a]Adapted from EN335 (2013)

Damage Caused by Rot Fungi

Fungi may attack timber with moisture content generally higher than 18–20% but not saturated with water (they do not attack timber permanently immersed in water). In terrestrial environment, such high values may be reached as a result of occasional or frequent humidification or when exposed to the rain or ground contact.

Inside buildings, fungus attack may only be expected as a result of construction deficiencies, such as rainwater infiltration (e.g. from poorly designed or poorly maintained roofs or window frames), rising of ground water, defective water pipes, condensation, lack of ventilation, etc.

Sapwood of all timbers is considered non-durable as concerning rot fungi; heartwood may vary from very durable to non-durable, depending on the forest species.

Rot fungi cause the loss of mass and mechanical resistance of the timber, and, under favourable conditions, they may completely destroy the elements. Since fungi development is related to high humidity in construction, decay is often a serious but local problem, affecting specific areas of the structure, such as the ends of floor beams sitting in exterior walls, elements under the eaves and other singular points of the roof, near chimneys or roof windows, for instance.

Damage can be detected by the presence of mycelium growing on the timber surface, plaster or rendering and by a marked loss of the timber resistance to the penetration of a cutting object (knife or chisel); after drying, the timber may have the characteristic appearance referred to as "cubic brown rot" or "white fibrous rot".

The severity of attack by rot fungi is not always easy to quantify, and there may be significant loss of resistance even with minor mass losses. It is prudent to assume that, in the sections affected by rot fungi, the effective strength of timber is null, requiring these sections of local replacement or adequate reinforcement.

Damage Caused by Termites

Termites are social insects that live in colonies. Knowledge on the specific species existing in each region, their food preferences and nesting and infestation strategy is crucial in order to adopt correct protection and remedial measures.

Subterranean termites nest in the soil and attack timber with water content generally above 20% but not saturated, mainly in the outside in contact with or near the ground and inside the buildings, especially in the ground floors. Like rot fungi, indoor infestations normally occur only in buildings or parts of buildings where various deficiencies in the construction allow the occurrence and maintenance of high humidity levels in the materials.

The identification of an infestation may generally be done by the observation of termite nests (in some cases aerial and highly visible above ground), galleries of earth on the timber or masonry, resulting from the activity of the colonies, or by the observation of winged adult insects, which constitute forms of dissemination of the colonies. However, the detection of infestations is often only done in advanced stages of degradation of the structures, since the identifying signs are not always readily recognized.

Sapwood of all timber is considered susceptible, and heartwood may be classified as durable, moderately durable or susceptible, depending on the forest species (see EN350-2).

The severity of damage by subterranean termites depends on the loss of section caused, which may be locally very important, with serious consequences for the safety of the structure.

Damage by Woodboring Beetles

Woodboring beetles are insects with complete larval cycle, being in the larval stage that they cause destruction of the timber where they live and of which they feed, digging galleries. Near the end of their life cycle, insects exit the timber, leaving a characteristic circular or elliptical hole known as the exit orifice. The emergence of adult timber insects may give rise to new infestation of the same or other accessible (and susceptible) timber elements by females laying large numbers of eggs.

Heartwood of most timber species is durable regarding the attack by woodboring beetles, while timber sapwood can be durable or susceptible, depending on the species (see EN 350-2).

Woodboring beetles attack timber in interior and exterior conditions, generally without special requirements regarding its moisture content, although they frequently prefer dry timber. Their presence is usually denounced by the exit holes, possibly accompanied by sawdust.

Infestations are usually generalized to large zones of a structure or compartment by the ease of propagation between nearby elements. Behind an exterior layer of timber, apparently intact, severely attacked timber may be grooved by galleries and powdery. Destruction is generally limited to the sapwood material, which may be small in many tropical species.

Damage by Weathering

Sunlight, in particular ultraviolet radiation, causes the chemical decomposition of lignin, one of the main constituents of timber. It begins to darken, intensifying its characteristic colour, subsequently evolving into a grey tonality, which we usually associate with "old" timber.

Cycles of intense sunlight exposure followed by rain and wind accelerates damage, as these remove the deteriorated surface layer exposing the underlying material.

Damage caused by atmospheric agents is very slow, affecting only the outer layer of the elements, with consequences that are mainly aesthetic and can be minimized by the application of coating products such as paints, varnishes or stains capable of reflecting or absorbing ultraviolet radiation, in addition to water-repellent action.

Exposure of timber to successive cycles of wetting and drying also leads to the development of drying fissures or cracks and distortion, which is a form of degradation but in most cases do not cause significant loss of strength.

14.5 Strategies to Extend the Life of Wood Constructions

Extending the life of timber in service can be achieved in a number of ways.

The best strategy is the selection of forest species with suitable natural durability in view of the expected risks (see use classes) in service.

In many regions of Africa, there is an extensive supply of hardwood species, many of which produce timber with high natural durability.

If it is not feasible to obtain timber with adequate natural durability, it may be advisable to treat it with preservative products, chemicals which increase the durability of the wood (acquired durability) or thermal treatments. However, besides the additional costs, many preservative products may not be able to protect the timber effectively during the intended life of the structure, thus requiring regular reapplications which may not be feasible after construction. Low treatability (permeability) of certain timbers may also hinder suitable penetration and retention of the product.

Trapping techniques have been used, for instance, for termite control. Treatment solely of the key members of a structure is normally a good strategy, contrary to the systematic treatment of the entire structure as was often recommended in the past.

An alternative approach, more interesting at all levels, is to reduce the risk of use by adopting appropriate design concept and constructive details. Although this strategy may not be always viable or enough, protection by design should always be a priority towards a clean and durable form of protection.

Through proper design and detailing of structures, it is possible to reduce the pressure of biological agents on timber, thereby reducing the durability requirements (and possible treatment needs) concerning timber elements. In a very simplified way, by eliminating the contact of timber with the ground, risk will move from use class 4 to 3; furthermore, by sheltering the timber members, the risk may jump from use class 3 to 2; by further preventing wetting, it can reach use class 1.

Proper detailing and execution should protect the end grain surfaces (generally the tops) of the timber pieces, where liquid water and moisture are most easily absorbed by wood fibres. Detailing should also allow quick water run-off and surface ventilation to promote rapid drying. It should also enable joints between elements

Fig. 14.7 Glulam arch support on concrete shoe with ventilation and metal capping of top surface

to accommodate any unavoidable swelling of the wood as, if restrained, these can cause damage to the confining materials.

Water absorption and retention will cause its swelling and (above certain levels) increase the risk of attack by some insects and fungi. The variation of environmental conditions also causes distortion and cracks.

In case of occasional and slight wetting, a member with a large cross-section will increase moisture content less than a smaller section member under the same conditions. However, under frequent or abundant wetting, massive cross-section elements will take longer to dry out and will therefore bear a greater risk of biological attack.

Likewise, surface coatings (paint, varnish or stain) may in the first stage reduce the absorption of water, but they also hinder drying out should water manage to enter through drying fissures, joints or ends. For this reason, less "permeable" finishes may be preferable, besides requiring easier maintenance.

A further aspect to be taken into account is that larger dimensions usually lead to more visible distortions, thus lengths and cross-sections should be limited (especially in the tangential direction, where shrinkage is maximum).

Direct contact of the wood with the ground should be avoided by fixing it on concrete or masonry foundations, keeping the wood at least 30 cm away from the ground. Detailing should also avoid accumulation of water and promote the aeration of the timber, especially in the ends or end joints (Fig. 14.7).

On ground floors of buildings with rising humidity, water-repellent materials (screens or bituminous felts) should be interposed between wood and concrete or masonry.

Fig. 14.8 Metallic capping of a top

Fig. 14.9 Metal washers for spacing between surfaces (top view)

Direct exposure of the timber ends to the rain should also be avoided, which may be done, for example, by metal capping (Fig. 14.8) or a top layer of treated wood or sacrificial wood (to be replaced). Detailing to prevent water retention between both materials may include the creation of drippings and ventilation spacing.

Repeated application of sealant or water-repellent products on the tops can also reduce water and moisture exchange with the environment, limiting absorption and cracking.

Large contact surfaces between wood elements can also retain water by capillarity. If likely the accumulation of dust or debris, which contributes to water retention, spacing thicker than 5 mm is recommended. Otherwise, this spacing may be reduced to about 2 mm and be obtained, for example, by interposing suitable metal washers (Fig. 14.9).

Horizontal contact surfaces may be more difficult to deal with effectively. Spacing, water drippers, water-repellent and, in certain cases, wood preservative treatment may have to be considered.

14.6 Maintenance

Provisions should be made to assure suitable performance of the load-bearing structure and of non-accessible components during the entire intended working life of the construction.

For construction parts that do not play a key role and are easy to replace, it may be acceptable to aim for a shorter service life, provided that it is accepted by the building owner and a maintenance plan including replacements is established. Repairable or replaceable components and materials may include claddings, roofing materials, exterior trims and integrated components such as windows and doors.

Maintenance is obviously essential in the case of timber structures and should be planned from the beginning in order to assure good performance, safety and durability of buildings. Adequate inspection and maintenance plans can detect and correct at an early stage any deficiencies and potentially anomalous situations.

Conservation measures are designed to prevent degradation of materials or to stop ongoing degradation and may be followed by measures to restore original safety and functionality or to reinforce structures and to adapt them to use.

Since the attack of timber by different agents of degradation requires favourable conditions for their development, an effective way to prevent or stop certain types of degradation is to change the conditions that allowed the installation of such agents.

The elimination of moisture sources in the building, for example, by repairing defective roofs or piping and by promoting ventilation, may solve problems when they are due to agents preferring moist timber. Conservation actions should therefore begin with drying and cleaning. However, this is not always feasible or quickly effective, as in the case of rising water from the ground or thick masonry walls.

If it is not possible to dry the timber quickly and permanently, specific measures should be taken, which may include replacing decayed elements with naturally durable or preservative treated timber.

Timber with clear signs of rot (fungal attack) should be considered as having negligible strength, as well as the adjacent sections, about 0.5–1 m long on each side of the rotting timber, and desirably removed from the site. It may be advisable to apply a preservation fungicidal treatment to the remainder structure, should they stay wet for a while.

Fighting termites involves careful consideration of the situation in order to recognize the extent of the attack and possible location of the colonies, which may involve the systematic treatment of the timber at risk with a preservative product of recognized termiticidal action or – preferably – the placement of physical barriers. It should be borne in mind that infestations by termites are difficult to definitively eradicate, since the execution of works often leads to the temporary escape of insects, which will return later if global measures are not taken with lasting effects. In this way, it is very important to keep clean and periodically monitor the possible access points of the termites to the structures, namely, the pillars and walls in the ground floors, as well as to keep roofs in order, avoiding the accumulation of soil or organic debris as branches or foliage. Specific measures other than these may be necessary, depending on the infesting species.

In the case of woodboring beetles, which infestation is normally limited to the superficial sapwood layer, the attack ceases when these insects exhaust the available food. In tropical timbers with a small percentage of sapwood, the loss of strength to a structural member caused by woodboring beetles is usually of little significance.

The outer layer of very degraded and powdery material may then be removed, if this can be considered acceptable from the aesthetic and historic point of view.

All timber used in reinforcement or replacement operations shall have durability appropriate to the corresponding effective use class.

Levels of Intervention

Repair and restoration aim at the recovery of the main original functioning and characteristics of the structure. It may include the maintenance of the original materials or constructive techniques (maintaining both the original materials and techniques may not always be possible), as well as some regeneration and possible improvement of the existing systems, without substantial alteration of the structural behaviour. Involved are general actions of cleaning and curative and/or preventive treatment of timber, the punctual replacement of elements or sections of deteriorated elements, the repair of drying fissures, the repair or improvement of structural connections and the general solidarity of the structure.

Strengthening and rehabilitation of a building aim to improve its durability, serviceability and/or strength. It may include local replacement of damaged members with different materials or constructive solutions, the introduction of new materials and layers (e.g. thermal insulation, lining, bracing), as well as substantial reorganization of architectural or structural functioning, in order to resolve deficiencies of the original structure, its inadequacy to a new use or to current safety standards.

General Solidity of the Structure

Even in the case of light interventions, and in the absence of biological damage, care must be taken to correct any obvious deficiencies of the structure, even if they do not reflect into obvious anomalous behaviour.

These shortcomings may be due to structural design or assembly errors, such as missing or misplaced fasteners, lack of structural bracing or eccentricity of loads on nodes. They may also result from inappropriate alterations throughout the life of the building, such as removal or cutting of elements without due replacement or fixing. Shortcomings may also derive from the natural settling and ageing of the structure, such as sagging members due to creep, lack of contact between members at joints due to shrinkage, twist or crushing of the timber or corrosion or even failure of fasteners and connectors.

Connections should be carefully checked with a view to restoring or possibly improving their performance, wherever possible without significantly altering their functioning. If the functioning of a joint is to be altered (e.g. by drastically increasing its rotation stiffness), possible implications of this in global structural performance should be checked.

Consolidation of connections usually involves tightening of fasteners and filling the gaps at notches. Although these are quick and simple operations, they can substantially improve the performance of connections. Replacement of metal ties or plates should also be considered, if broken or otherwise markedly deteriorated. This normally implies the need to increase the number and/or diameter of the associated fasteners (nails or screws). The length and state of conservation of the supports of trusses and rafters to the walls should also be inspected and possibly improved.

Roof repair operations are an opportunity to improve or correct the load-carrying structure, as regarding the number, cross-section and position of girders, especially if bending stresses are too high. Redistribution of the loads transmitted by the roof to the trusses may also be obtained by introducing additional girders, properly positioned on the nodes of the trusses.

Whenever necessary, diagonal and longitudinal bracing elements should also be introduced to increase the roof structure stiffness perpendicular to the trusses' plane. This operation is relatively simple, but able to significantly improve the roof structure response to wind and earthquakes.

All metal elements used, such as nails, bolts, plates and washers, must have adequate dimensions and sufficient protection against corrosion, for example, by galvanizing.

Repair of Drying Fissures and Cracks

Most old timber structures have drying fissures and cracks: the more noticeable, the greater the temperature and humidity variations to which the timber has been subjected. Although drying cracks are a natural and unavoidable occurrence, certain timber species are particularly prone to cracking, especially if subjected to sudden drying.

It is important to distinguish between drying fissures or cracks (Fig. 14.10) and mechanical failure (Fig. 14.11), since the latter indicate that the element's strength capacity has been exceeded, thus requiring always appropriate intervention. Drying cracks follow the wood grain and develop in radial planes causing the timber member to split open. Mechanical failure may run across the wood fibres at various points, have an irregular profile and often arise in the proximity of defects like knots; it may also cause the fibres to slide along the failure surface.

The following paragraphs only apply to drying fissures. Mechanical failures require specific diagnosis, careful assessment of consequences and appropriate remedial measures.

Attention should be paid to deep or thru drying fissures (travelling thru the cross-section of the member), especially when they develop near the connections, as they reduce the timber ability to hold the fasteners. Careful consideration should also be given to fissures occurring in sections with high shear stresses or tensile stresses perpendicular to the wood grain, as well as those associated with other defects such as large knots or slope of grain.

Fig. 14.10 Drying fissures

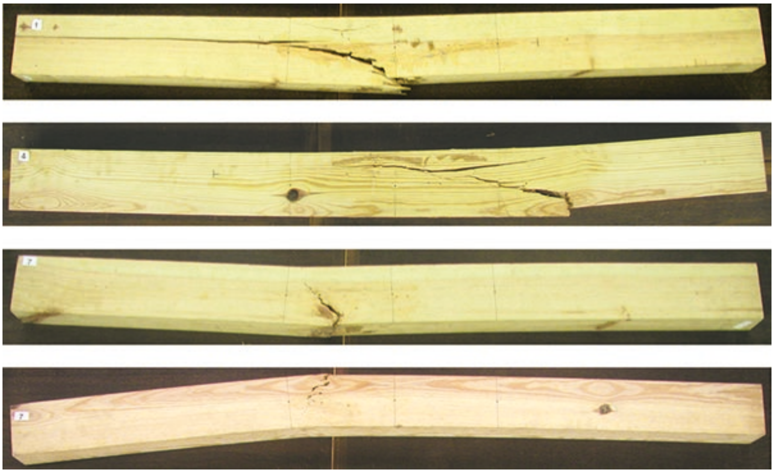


Fig. 14.11 Some examples of mechanical failure

Fresh fissures or cracks (usually with "fresh" appearance, revealing the inner lighter-coloured timber) should be carefully examined, as these may indicate progressing situations requiring immediate action. It should be noted, however, that fresh fissures are likely to appear during particularly dry hot spells or when the environment inside the building changes drastically, for example, due to the introduction of air conditioning or certain equipment on site.

The traditional methods used to repair fissures consist of the following: applying metal ties surrounding the member (Fig. 14.12); applying driving nails, screws

Fig. 14.12 Fissures repair with traditional method (ties)

or bolts across the fissure; and applying metal, timber or plywood splices to both surfaces perpendicular to the fissure. Although these methods fail to close the fissures, they may prevent their progression. Splices have the added disadvantage of hiding the fissure, therefore preventing its monitoring. Except for the direct nailing of timber, all these interventions have great visual impact.

The use of bolts across the fissure that tighten the split member through steel plates applied to opposite faces or edges allows subsequent retightening. To avoid the "wedge" effect when securing the timber in the position in which they were driven, specific partially threaded bolts should be used.

Repair of Damaged Supports

Damage of trusses and beam ends is a frequent problem. This is often caused by the activity of biotic agents, particularly when in contact with wet masonry. Damage of the ends may also result from shear failure due to original undersized timber members or overloading resulting from the change in use of the structure.

The complete replacement of the damaged element is normally unnecessary and should only be adopted in the last instance. In addition to preventing the use of the structure during such a heavy intervention, it requires the removal and replacement of large construction zones, with loss of the original materials and consequent historical value of the structure.

Another option widely used is to keep in place the whole original element, applying timber, plywood or metal splices to one or to both sides of the damaged section (Fig. 14.13). This solution has the advantage of limiting the intervention only to the deteriorated section and does not involve removal operations, which take longer and almost always require propping of the structure. The reinforcement should extend

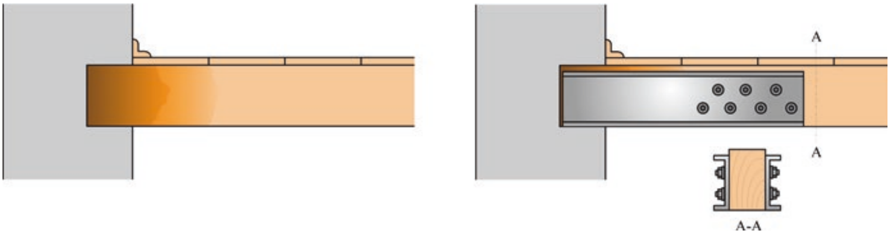


Fig. 14.13 Beam end repair by splicing

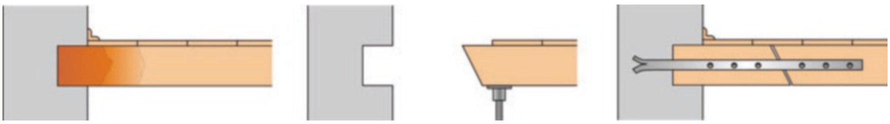


Fig. 14.14 Repair of a beam end using a timber prosthesis connected with metal plates and bolts

between 0.5 and 1 m beyond the deteriorated zone, mobilizing clearly sound timber with adequate strength. Its main drawback is the impossibility to follow the state of the piece of timber inside the splice.

Another option consists of the removal of the damaged length of the member, replacing it with an identical prosthesis (Fig. 14.14). The connection between the original and the new length is done using metal plates applied to the surface of the timber and bolts, possibly conjugated with notches. The timber used in these replacements should be durable. This technique implies propping of the elements and the impossibility of maintaining the structure in service during the intervention.

Reinforcement of Elements

Reinforcement of elements (floor beams or truss members) may be necessary for a number of reasons. The most frequent is the insufficient strength and/or stiffness of these elements for the intended use.

Reinforcement may also be necessary due to the loss of cross-section of the elements caused by insect attack or even their mechanical failure resulting from poor quality and strength of a particular element or from excessive loading.

As in the case of repair work, solutions to increase strength and rigidity of the elements must be considered on a case-by-case basis, taking account of the specific characteristics of the work, such as access to the elements and possible requirements concerning visual impact of the intervention, and the objectives to be attained.

A commonly adopted solution for the reinforcement of elements in service is the application of steel plates or profiles, adequately protected against corrosion, generally bolted to the element to be reinforced. These profiles can be inserted into slots inside the timber, applied on both vertical faces, or on the upper face, lower face or both.

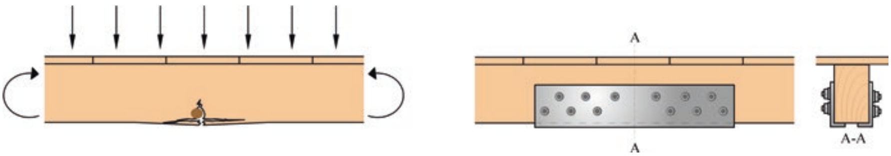


Fig. 14.15 Local reinforcement through the application of exterior steel plates

The stiffness or strength increase of an element generally implies reinforcement along its overall length or at least along the most stressed part of the element span, thus sharing the applied loads. In the correction of a local deficiency, local reinforcement may be considered (Fig. 14.15), but it should be ensured that the metal parts are secured on sound timber (without biological degradation) with adequate mechanical properties (without large defects likely to affect its performance). In these cases it is important to ensure that the transition between the reinforced and non-reinforced sections does not occur in areas with high stresses, which could lead to failure in the transition zone.

Changing Structural Functioning

One way to solve a poor structural performance is to change the way the structure or the specific structural system (e.g. floor) works. This may involve changing the load paths to relieve the defective system, by redistributing loads by adding new elements to the system or by changing its support conditions or load application points.

A simple solution involves the introduction of new elements (e.g. beams or trusses) interspersed between the existing elements (parallel to these), thus maintaining the existing structural functioning while increasing the load-bearing capacity. This operation involves the removal of the floor and/or ceilings for the introduction of the new elements. In the case of roof structures, the addition of extra elements usually implies removal of the roofing. Another difficulty of this approach is the need for geometric compatibility, since the existing elements are often irregular and deformed, requiring careful levelling in order to load both the new and old elements. A balanced load distribution also implies similar stiffness of the various elements operating in parallel, which is not always the case, with the stiffer elements taking up the greater percentage of the load.

Bracing elements (such as billets between floor beams), as well as the roofing and ceiling load-bearing structures between trusses, allow the distribution of loads, namely, by transferring part of the load applied to an element to the adjacent elements and increase the overall stiffness of the structures. The introduction of bracing or improvement of these systems and connections can thus contribute substantially to increasing the load-carrying capacity of the structure.

Reduction of beams span may be suitable to improve its response. This can be done, for instance, by placing timber or steel beams, under a floor system, perpendicular to its axis.

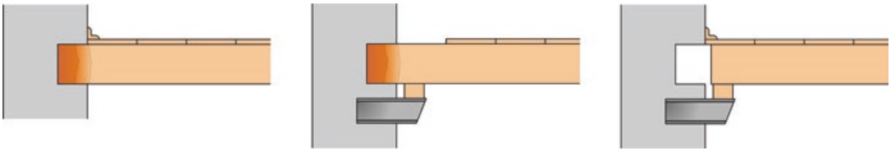


Fig. 14.16 New supports

Another common intervention, also suitable to deal with decayed beam ends, involves the enlargement or creation of new beam supports along the wall or protruding from the wall, (in timber, masonry or steel profiles) allowing support of beams away from decayed ends (Fig. 14.16).

These reinforcement solutions allow the (almost) integral use of the original materials. Main disadvantages are the increase of the structural mass and the alteration of the distribution of stresses in the structure, which have to be properly analysed.

14.7 Inspection and Evaluation of Timber Constructions

All structures must undergo periodic inspections and maintenance to detect any deficiencies at an early stage, thereby minimizing damage, and to maintain an adequate level of performance.

Strength assessment may be required in the case of malfunctioning structures or whenever there are doubts as to its safety conditions, especially in view of a possible change in the use of the building.

In general, after a preliminary or qualitative inspection, which gives a general idea of the problem, detailed inspection should be carried out to estimate the strength of the structure and to establish appropriate remedial and reinforcement measures. Besides reinforcement or replacement measures, specific treatment and protection may be needed that aimed to prevent recurrence of problems.

Certain malfunctions observed in the building (e.g. roof sagging, high floor vibration, detached plastering, damaged window frames, wall cracks) may indicate reduced load-bearing capacity of the structure or the existence of conditions favourable to timber damage associated to water intake, which must be confirmed by detailed visual inspection. Even in the absence of obvious signs of alarm, the usual critical points of a building should be inspected to check the timber conditions. These critical points correspond to likely wet areas, like the ends of floor and roof beams in exterior walls, cellars, kitchens and bathrooms' floors.

Once the overall assessment of the situation has been completed, a detailed inspection should be carried out, which should cover the entire building as far as possible. It is important to accurately identify the possible degradation agents, as well as the extent and severity of the degradation they caused, to identify the timber species and quality, as well to understand the functioning of the structure.

At all points reportedly deficient or suspect, it is essential to uncover, for direct observation and measurements, the timber structure, by removing floors, linings or plasters, starting with a small section that will widen according to the extent of the identified problem.

The inspection should also enable detection of possible structural problems, not necessarily resulting from the biological damage of timber, such as mechanical failure of elements, excessive deformation, rotation at the supports and slipping of joints.

Being critical in the evaluation of the structural functioning is essential, since there may have been deficiencies in the design and execution of the original structure, which should be corrected.

It is not essential to have sophisticated means to carry out an effective inspection. Careful inspection of the timber elements and some expeditious measurements (effective or remaining member cross-section after attack by insects or loss of strength due to decay), made with the help of a knife, will provide the essential information.

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Chapter 15
Bamboo: An Engineered Alternative for Buildings in the Global South

Edwin Zea Escamilla, Hector Archilla, Denamo Addissie Nuramo, and David Trujillo

15.1 Bamboos of the World

Bamboo is the only *Graminea* adapted to the life as forest. Bamboos can be found around the globe and are naturally occurring in Africa, America and Asia in tropical, subtropical and warm temperate areas around the equator. Bamboos are giant grasses that propagate rapidly by the expansion of underground rhizomes. In general, bamboos are known for their rapid growth with a rate of up to 25 cm/day in certain species of woody bamboos such as *Guadua angustifolia* Kunth (bamboo). Although there are some species of solid bamboos, morphologically bamboo can be generally described as a hollow tapered tube (culm), with internodes separated by nodes, which is supported by an intricate rhizome system (Fig. 15.1). The culm is the main organ of the aerial part of bamboos, which is also comprised of branches, sheaths and foliage leaves, with flowering occurs sporadically. The rhizome and culm neck form the subterranean part. Culms store about 80% of the carbohydrates required by young plants for their growth, whilst rhizomes store the remaining 20%.

The growth process of a bamboo culm differs of that of a tree. Firstly, a bamboo culm will experience a rapid growth phase in which the cane will reach its maximum height and diameter in about 9–12 months. Secondly, the culm starts a process of consolidation of tissues which occurs by secondary cell thickening until maturity,

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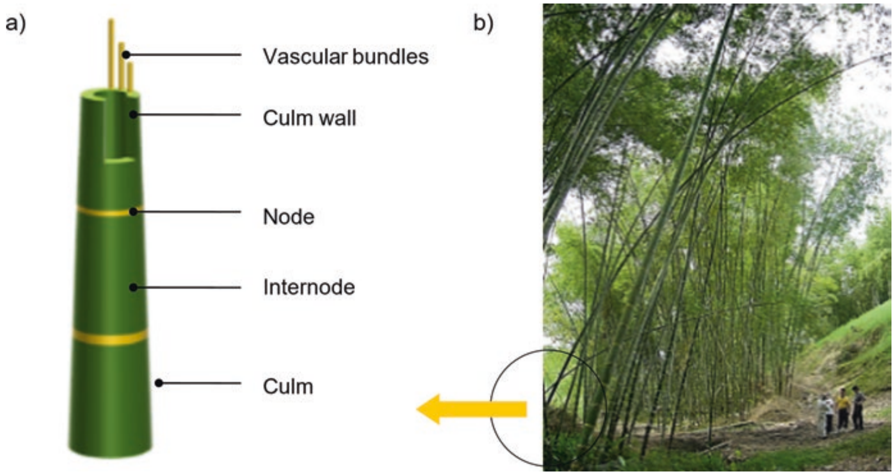

Fig. 15.1 (**a**) Part of the culm, (**b**) bamboo plantation (Archila Santos 2015)

which results from the deposition of lignin (lignification) of acquired cell wall layers (polylamellation). This lignification of fibre cell walls increases bamboo's density, but not its diameter or height. The plant reaches maturity in 3–5 years and what follows is a natural process of decay. Bamboo clumps can grow for 50 years or more, but flowering results in the death of the whole plant in some species (Liese 1998; Hidalgo-López 2003). Such delay in the flowering process is attributed to the considerable energy demand of this fast-growing plant (Vorontsova et al. 2017 cited by Lybeer et al. 2006). This, together with the resulting high biomass production, gives bamboo an advantage over other renewable resources in terms of yield.

Thanks to their wide availability and renewability bamboos have been used around the world for millennia for many applications ranging from food to furniture and construction. More than 1600 species of herbaceous and woody bamboos have been catalogued (Vorontsova et al. 2017), and about 20 species of woody bamboos are considered as key species for construction purposes (Ramanuja Rao and Sastry 1996). For instance, the sympodial species bamboo is used for construction in South and Central America; it has large vascular bundles (Fig. 15.1) with fibre bundles of variable sizes that confer it with a coarse finish. In contrast, the monopodial *Phyllostachys heterocycla pubescens* (Moso) endemic to Asia is more suitable for smooth finishes for parquet, furniture and decorative applications (Liese 1998). This is due to its smaller vascular bundles with fairly even distributed fibres around the conductive tissue. Some species such as *Oligostachyum* sp. and from the genus *Indocalamus* are classified as amphipodal, which combines sympodial and monopodial rhizomes.

It is estimated that bamboo forests cover an area around 37 million hectares which amounts to about 4% of the world's total forest coverage (Phimmachanh et al. 2015). From this total coverage, it is estimated that Africa has more than 40 bamboo species covering more than 1.5 million hectares (Phimmachanh et al. 2015).

Studies in utilization of bamboo in Africa have indicated that the resource is less valued than wood products, and its uses are mainly traditional, and only a few manufacturing firms are reported so far (Endalamaw et al. 2013; Ingram and Tieguhong 2013). All around Ghana bamboo culms are used both in rural and urban areas for construction purposes including fencing; scaffolding; as frames for mud houses, props, rafters and roof material; for binding thatch in roofing houses; and for construction of livestock pens (Obiri and Oteng-Amoako 2007). Moreover, processed bamboo products comprising plywood bamboo, ceiling panels, flooring, window blinds, doors and furniture are produced and used in Ghana (Obiri and Oteng-Amoako 2007). In Nigeria bamboo is distributed widely in the south and middle-belt regions where the average diameter of the bamboo culms ranges from 3.2 to 9.1 cm (Atanda 2015). It is reported that the rate of use of bamboo in Nigeria is low (Atanda 2015). Traditionally, bamboo is used for scaffolding, shade houses, fencing and furniture making (Ladapo et al. 2017). It is also used in rural areas to construct mud houses where bamboo culms serve as structural frames (Atanda 2015). Other uses of bamboo for construction in Nigeria include structural element for buildings, bamboo-based panels and furniture (Ladapo et al. 2017). There are two indigenous bamboo species in Ethiopia covering more than 1 million hectares of land. In the rural areas of Ethiopia where bamboo grows, people use bamboo culms for construction of houses, construction of fences and furniture making (Desalegn and Tadesse 2014). Whilst Ethiopia has a huge bamboo resource, its utilization for construction purposes has been limited to hut construction, fencing, furniture and handicrafts (Kindu 2010).

15.2 Bamboo Use

Bamboo uses can then be classified depending on the degree of transformation of the raw material and the manufacturing process to which it has been subjected. Three material transformation stages are identified, non-processed, moderately processed and highly processed, in Fig. 15.2. This figure illustrates the processes applied to bamboo and the transformation stage attained for certain applications. Overall, traditional uses require less intensive processing, whilst industrialized uses require high levels of transformation.

Non-processed raw bamboo is commonly used for low added value and short-term applications (temporary shelters, scaffolding, handcrafts, food, etc.) usually where the material is abundant and durability is not a concern – because rotten material can be easily replaced. Moderately processed mature bamboo is preserved and dried mainly for its use in traditional construction in countries where bamboo building systems (bamboo) are regularized (e.g. Colombia, Ecuador, Peru and Mexico). In addition, some handcrafts and furniture applications make use of this type of bamboo in which manual and non-intensive industrial processes are involved (hybrid). Engineered bamboo products (EBPs) are highly processed bamboo products that add high value to the plant through different transformation processes

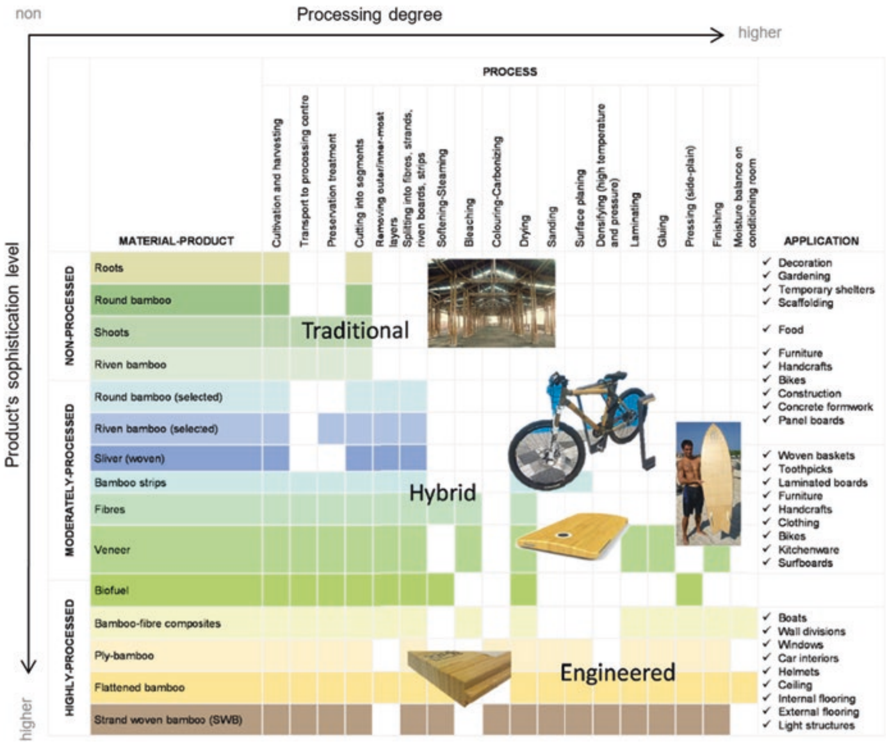

Fig. 15.2 Uses of bamboo depending on its transformation degree (Archila Santos 2015)

resulting on consistent, straight-edged products. Some of the most popular engineered bamboo products used in construction are flooring (e.g. flattened bamboo), architectural surfaces (e.g. bamboo plywood or Plyboo) and exterior decking (e.g. strand woven bamboo, SWB). The Chinese industry is the main supplier of these products with Moso bamboo as the raw material. Finally, some hybrid bamboo products are made by combining different processing stages to achieve aesthetic appeal.

15.3 Traditional Bamboo-Based Construction Material

Although non-processed bamboo canes (culms) are broadly used in construction, these should not be considered as construction material in itself. It is estimated that more than a billion people live in bamboo houses worldwide. In Bangladesh alone, more than 70% of the houses use non-processed bamboo culms in walls and roof structures in a temporary fashion.

Bamboo culms are the main input for all the bamboo-based construction materials and can be processed into five distinctive types of bamboo-based construction

Fig. 15.3 Bamboo-based construction materials

materials. They can be roughly divided between moderately industrialized materials (e.g. (i) preserved and dried bamboo poles; (ii) flattened bamboo, *esterilla*; (iii) woven bamboo mats; and (iv) strips) (Zea Escamilla and Habert 2015; Liu et al. 2015). These categories are presented in Fig. 15.3.

(i) Bamboo poles are derived directly from the bamboo culm and are usually trimmed in sections between 3 and 6 m and treated against fungi and pest using boric acid (H_3BO_3 or $B(OH)_3$) and borax (sodium borate) for 7–10 days. Poles are then dried until its moisture content is below 20%. The poles are then transported from the treatment plant to either a distributor or to an intermediate processing facility. This transport is generally local with a range between 4 and 120 km (Zea Escamilla and Habert 2015). Preserved and dried bamboo poles can be used directly in construction as columns, beams or struts and are also the main input for the production of flattened bamboo, woven mats, strips, slivers, strands and other starting materials for engineered bamboo products (Zea Escamilla and Habert 2015; De Flander and Rovers 2009).

(ii) Flattened bamboo is a handcrafted construction material. To produce flattened bamboo, a bamboo pole is split open with an axe and its innermost part and internodes are removed. During this process some fibres are broken making the material flexible, but still able to maintain its 'mat-like' shape (Zea Escamilla and Habert 2015; Liu et al. 2015). The main application of flattened bamboo is in load-bearing wall systems, where it is used between bamboo poles in order to support the soil cement mortar with which the walls are plastered.

(iii) Woven bamboo mats are produced by manually or mechanically splitting a bamboo pole into strips with widths between 2 and 4 cm. These strips are then reduced by hand or in a slivering machine into thinner elements with thicknesses between 0.5 and 3.5 mm (Liu et al. 2015), which are then woven to form a mat (Liu et al. 2015). The entire process is usually done manually in small rural communities. The woven bamboo mats are generally used as lightweight walls, but recently they have also been used to produce panels of EBP in India (Zea Escamilla and Habert 2015) (although their manufacturing process is still labour and glue intensive). Flattened bamboo and woven bamboo mats are commonly manufactured in facilities very close to the point of extraction and/or treatment.

15.4 Engineered Bamboo

Bamboo can be engineered to form products with improved and/or standardized mechanical, physical and aesthetic properties. The transformation of naturally variable bamboo culms into engineered products with predictable properties and generally rectangular shapes facilitates the mainstream use of bamboo in construction. In general, engineered bamboo products (EBP) are scarce and require intense processing. Their development started with the manufacture of bamboo panel boards in China around 1940; however, it was not until the end of the last century, during the 1980s and 1990s, that research and commercial interest in this type of materials increased (Ganapathy et al. 1999). Currently, the use of the bamboo species *Phyllostachys heterocycla* pubescens (Moso) for the production of EBP is widespread. Liu et al. (2015) and Trujillo and Archilla (2016) classify EBPs into three main types: (i) laminated bamboo, (ii) densified bamboo and (iii) bamboo boards.

As illustrated in Fig. 15.4, commercially available EBPs such as glue-laminated bamboo strips (a) and (f), densified strand woven bamboo or SWB (b) and bamboo boards such as those made out of flattened half bamboo poles (c), fibres (d), flattened mats (e) and bamboo strands or particles are industrially manufactured mainly in China through several processing stages and possess distinctive mechanical properties (Table 15.1). Due to their elevated degree of transformation, these EBPs are referred to as highly processed bamboo products in Fig. 15.2.

Currently, the most widespread practices in the manufacturing of EBP are the machining and lamination of longitudinal strips and the hot pressing of fibre strands under elevated temperatures (Table 15.1). The former refers to the process undertaken to manufacture laminated bamboo products and the latter the process undertaken for SWB, a densified bamboo product.

Fig. 15.4 Engineered bamboo products. Laminated bamboo: (**a**) ply bamboo and (**c**) flattened half bamboo poles (MOSO International B.V.) and (**f**) glue-laminated bamboo beams (www.agenciadenoticias.unal.edu.co). Densified bamboo: (**b**) SWB and other EBPs developed using Moso and bamboo, respectively: (**d**) bamboo plastic composite (www.bambooindustry.com), and (**e**) glue-laminated flattened bamboo boards

During the strip lamination process, the round culm is first split into six to eight concentric sections; secondly, the trapezoidal-like section of the strips is sanded down into a rectangular form after removal of about two thirds of the total material, and finally the strips are longitudinally oriented and glue laminated into beams, boards or flooring slats. One of the biggest drawbacks of this process is the high amount of material discarded. Usually, the strongly consolidated outer layer of the bamboo culm with the highest specific gravity is removed, and its mechanical properties are no longer comparable to steel. The negative influence on the mechanical properties of bamboo due to removal of the outer skin as well as the considerable material wasted through the strip lamination process has been highlighted by Nakajima et al. (2008), Tanaka et al. (2008) and Archila (2015). These studies have undertaken modifications to the cell structure of bamboo by thermal softening: the first without pressure, the second with elevated temperature and pressure and the third with moderated heat and pressure. These types of heat and pressure treatments are currently applied to bamboo with the aim of achieving flat sections of high density and hardness. Some of the resulting mechanical properties of lamination and heat and pressure processes applied to bamboo are presented in Table 15.1.

15.5 Bamboo-Based Buildings

Bamboo has been used as a construction material for centuries all over the world, and traditional bamboo building systems have been widespread mainly in Africa, Asia and Latin America (Archila Santos et al. 2012; Correal 2016). Earthquake-prone

Table 15.1 Processes involved in the manufacture of some engineered bamboo products and their mechanical properties (Sulastiningsih and Nurwati 2009; Mahdavi et al. 2010; Vogtländer et al. 2014; Correal et al. 2014; Nugroho and Ando 2000; Huang et al. 2013)

	Product	Density kg/m^3	Species	Process	MOE Bending GPa	MOR Bending MPa
Lamination strips	Sulastiningsih and Nurwati[a]	710–750	G. apus/*G. robusta*	Cold press + clamped	7–10	39–95
	Mahdavi et al.[b]	510	Moso	Cold press	9	77
	Ply bamboo (Plyboo)[c]	666	Moso	Cold press	–	135
	Laminated Guadua[d]	728–796		Cold press	–	82
	Xiao et al. (2013)[e]	800–980	Moso	Hot press	9	99
Hot pressing fibre strands	Flattened bamboo[c]	850		Stem + hot press	–	–
	LBL (zephyr mat)[a]	940	Moso	Roller crushing + hot press	10.1–11.6	66.5–81.2
	Bamboo scrimber[f]	1240	*Melocanna baccifera*	Roller crushing + glue impregnation + hot press	15.2	266
	Huang et al.[g]			Hot press	13	89
	SWB outdoor[c]	1200	Moso	Hot press	–	–

[a]Sulastiningsih and Nurwati (2009)
[b]Mahdavi et al. (2010)
[c]MOSO International BV (Vogtländer et al. 2014)
[d]Correal et al. (2014)
[e]Xiao et al. (2013)
[f]Nugroho and Ando (2000)
[g]Huang et al. (2013)

countries such as Colombia, Ecuador and Peru have adopted bamboo culms as a structural material within their building codes for walling and framing systems of up to two storeys (AIS 2004; Mena et al. 2012).

According to a study by INBAR (van Dam et al. 2018), utilization of bamboo as a construction material in Ethiopia relates to the construction of traditional or rural housing where only 2.5% of those housing units are constructed from bamboo. Studies have shown that there were more than 500,000 units of houses constructed out of bamboo in Ethiopia in 2007.

Ethiopia has a rich tradition of constructing houses with bamboo using traditional techniques. Below are pictures of some of the traditional bamboo houses in Ethiopia (Figs. 15.5 and 15.6).

Fig. 15.5 Dorze bamboo house

Fig. 15.6 Sidama bamboo house

Plastered Cane Building System (Bahareque Encementado)

The plastered cane building system is the most common structural bamboo system. It consists of load-bearing bamboo walls that are plastered with cement mortar for weathering protection, structural integrity and improving its fire performance (Zea Escamilla et al. 2014). This structural wall framing system with bamboo for one- and two-storey dwellings was firstly normalized by the Colombian construction code, today known as NSR-10. It is defined as a system composed of a bamboo or bamboo and timber skeleton and a sheathing made out of flattened bamboo (Fig. 15.5), nailed to the skeleton and covered with a cement render applied over a steel mesh (AIS 2004). Both elements together result in a shear wall response.

This system uses bamboo intensively (approx. 12 linear metres per sq. metre) where 50% of the material is round bamboo used for the skeleton (frame) and the other 50% is riven bamboo boards used for the sheathing. Different configurations of walls depend on their function and structural performance. Structural braced walls are designed to resist vertical, horizontal and wind loads and must be located on the corners of the building and at the ends of every set of structural walls. Non-braced structural walls withstand vertical loads and must not be located at the ends of the wall system. In addition, nonstructural walls are used as divisor walls and must not bear any shear or vertical loads (do not need to be continuous or to be anchored to the foundations). A series of images in Figs. 15.7 and 15.8 depict the building process with this bamboo wall framing system.

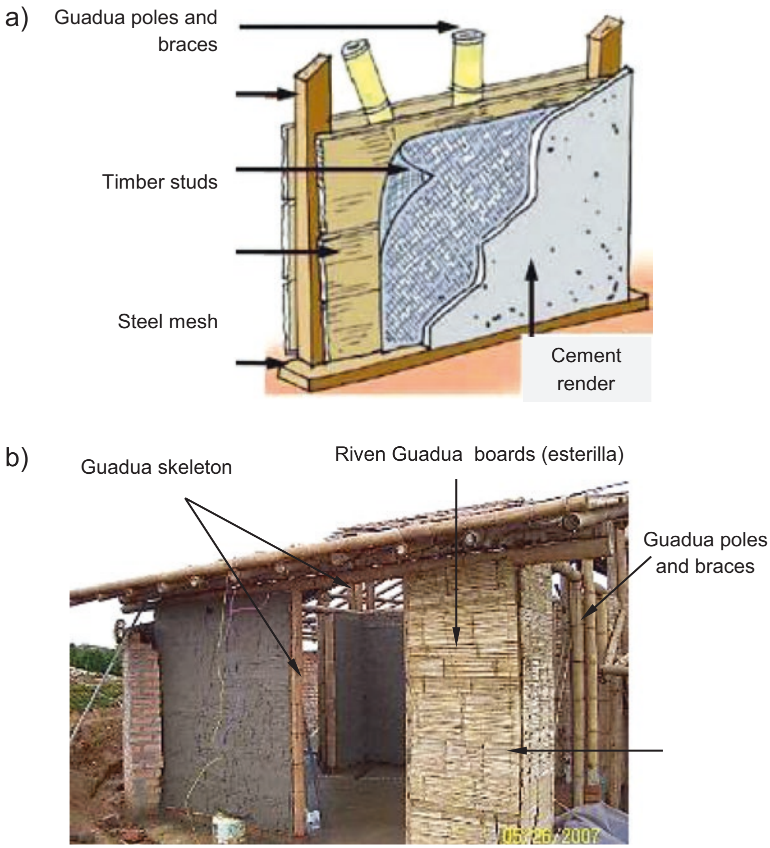

Fig. 15.7 Plastered cane wall framing system with parts diagram. (**a**) Typical frame section with timber and bamboo elements. (**b**) Typical wall-roof framing with bamboo. (Image (**a**) taken from (Farbiarz et al. 2002))

Fig. 15.8 Construction process of the plastered cane wall framing system (picture (**h**) by Arme Ideas en Bamboo Ltd). (**a**) Foundations. (**b**) Anchorage. (**c**) Framing and bracing. (**d**) Sheathing with riven bamboo. (**e**) Rendering. (**f**) Roofing. (**g**) Finishing. (**h**) Final product

Within the frame structure, head and sole plates in timber are strongly recommended instead of bamboo due to crushing perpendicular to the grain (see Fig. 15.7); these constitute the horizontal elements. The studs must be separated by between 300 and 600 mm, and the diameter of bamboo must not be less than 80 mm. The diameter of the steel wire mesh nailed to the flattened bamboo must not exceed 1.25 mm (curtain mesh). The sheathing of the wall skeleton should be applied to both sides.

Overall, this system has been conceived to (a) minimize the effect of collapse during strong seismic events of low probability, (b) ensure low damage during moderate seismic events and (c) avoid any damage from minor seismic events of high probability. Therefore, slab, roofs, columns and additional structural elements must be designed to contribute to the stability of the main load-bearing system, following the requirements for each variation considered within the Colombian Code for seismic-resistant construction. As stated previously, this system is restricted to two-storey buildings.

However, the three main limitations of this system are (a) its current maximum height limitation to two storeys and (b) that it uses a significant amount of cement, aggregates and steel for the reinforcement and plaster of the walls, and (c) the use of whole bamboo culms makes construction processes labour intensive (Zea Escamilla et al. 2014; Murphy et al. 2004). These points render it unsuitable for multi-storey buildings that can cope with the need for high-density construction in growing urban centres, whereas the latter corresponds to about 50% of the total environmental impact of the construction, which increases its overall carbon footprint.

Framing Systems for Large Structures with Bamboo

The infill of bamboo internodes with a cement mortar (Fig. 15.9) has led to increased rigidity of the connections, which otherwise will fail by shear parallel to the grain or crushing perpendicular to the grain.

This gain in rigidity has allowed the construction of large structural frames for commercial and institutional buildings and hybrid structures for holiday houses such as those in Fig. 15.10a and b, respectively.

Other structures have demonstrated the potential of round poles of bamboo as an engineering material for large structures using infilled internodes and comparable structural concepts to the traditional collar and tie initially introduced by Simón Vélez. These include the replica of the Indian Pavilion for the Shanghai Expo 2010 (Fig. 15.11) recently built in Bogotá, the Zeri Pavilion for the Expo Hannover in 2001 and a pedestrian bridge in Holland.

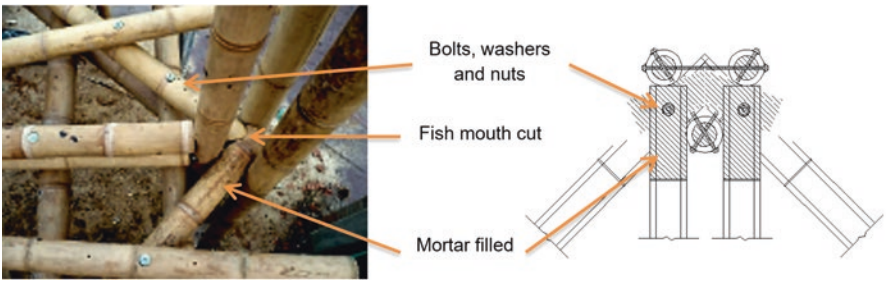

Fig. 15.9 Detail of connections in a bamboo structure

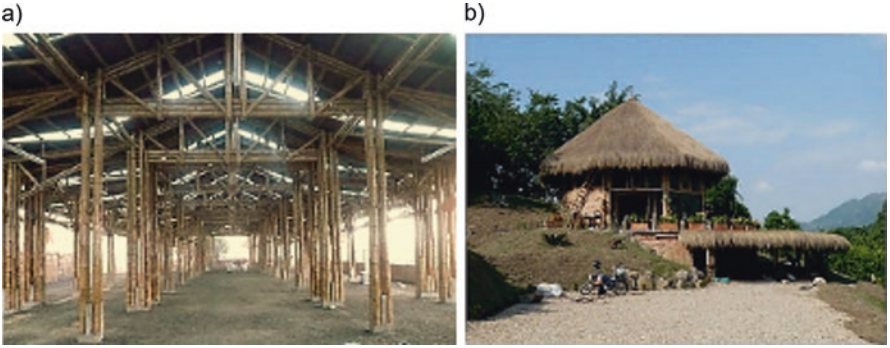

Fig. 15.10 (**a**) Warehouse in Bogotá, Colombia, by Hector Archila. (**b**) Bohio, holiday cottage in Villeta, Colombia, by Hector Archila

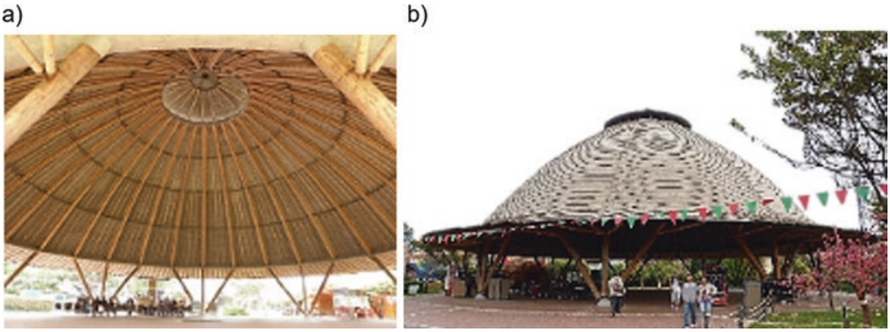

Fig. 15.11 Replica of the Indian pavilion for Shanghai Expo 2010 by Simón Vélez in Bogotá, 2015. (**a**) Interior view of the structure. (**b**) Exterior view

15.6 Environmental Issues

The current practices in the construction sector make use of increasingly larger amounts of energy and are responsible for the depletion of natural resources (Bribián et al. 2011). The levels of extraction of construction minerals have also reached new levels in the twenty-first century, highlighting not only the problem of the availability but also the accessibility to those resources (Steinberger et al. 2010). For instance, the production of construction materials such as cement and aggregates is using 30–40% of global energy production (Dean et al. 2016), and under the current practices, it means that their production process releases 30% of global GHG emissions (Di Placido et al. 2014; Pearce and Ahn 2013). Therefore, it is imperative to explore the potential environmental benefits from the use of low-carbon alternative construction materials, amongst these bio-based materials such as bamboo and timber. Bio-based construction materials are renewable, and with adequate management, their production can be sustained over long periods of time. Moreover, during their growth phase, they capture atmospheric CO_2 and store it in their tissues (Riaño et al. 2002; Asif 2009). If these materials are used in durable products, such as buildings and their constituent materials, then the release of the captured CO_2 can be delayed as long as the buildings are in service (Tellnes et al. 2014). In the case of bamboo, due to its heterogeneous growth, only 25% of the culms are harvested annually (Riaño et al. 2002). As a result, a plantation is always standing, capturing CO_2 and producing readily feedstock for its potential use as construction material (Riaño et al. 2002).

The environmental impacts of bamboo-based construction materials increase in relation to their level of industrialization (Zea Escamilla and Habert 2015). A significant difference in environmental impact can be observed between industrialized and handcrafted products. The environmental impact of bamboo pole is, for example, five times smaller than the impact associated with glue-laminated bamboo. In the cases of handcrafted materials such as flattened bamboo and woven bamboo mats, the environmental impacts increase only due to the material demand associated with their production. To better understand the environmental impacts presented here, it is necessary to look at the relative contribution of the different processes involved in a material's production. Flattened bamboo and woven bamboo mat are handcrafted from bamboo poles and thus have only one input. Consequently, they have only one process contributing to environmental impact. For the low industrialized materials, the contribution of the raw material production, the growth of bamboo culm, represents less than 10% of the total impact as presented in Fig. 15.12. The drying process is the major contributor with 35%, followed by the electricity used for trimming with 25% and the treatment for insect

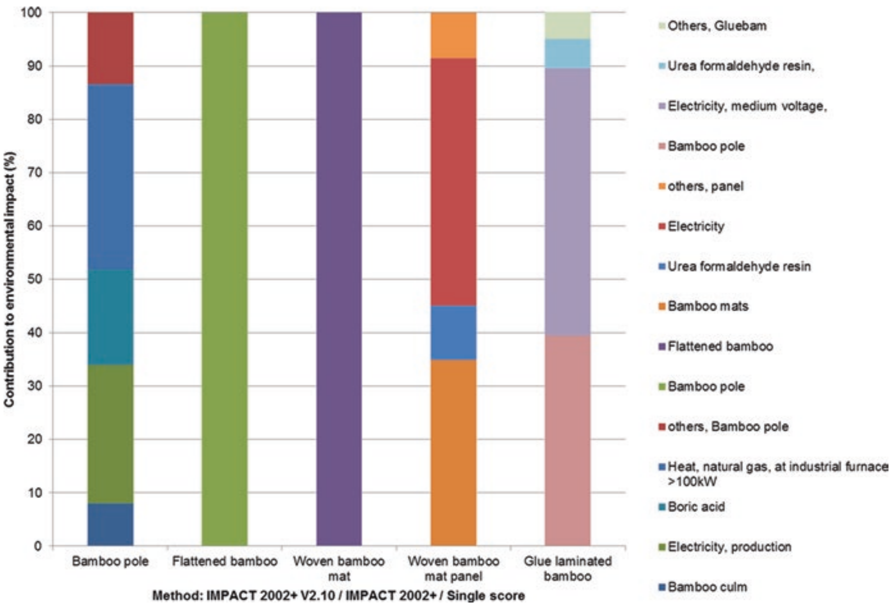

Fig. 15.12 Contribution to environmental impact

resistance with a 15% share of the total. The contribution associated with infrastructure and machinery is much higher for the low industrialized materials than for the highly industrialized ones, with contributions to the total impact of 12% and 2%, respectively.

In order to compare the environmental impact of different construction materials, it is necessary to do it at the building level. This is due to the differences in services that a unit of materials can provide. The work of Zea et al. (2016) has shown that bamboo-based buildings using either handcrafted or engineered bamboo products withhold great potential to produce lower environmental impacts than those constructed with mineral-based materials, as shown in Fig. 15.13.

These environmental benefits go beyond the reduced emissions from the production of materials and construction of buildings. If the whole life cycle of the bamboo-based building is assessed, from bamboo plantation to recycling of the building's material, it becomes that bamboo withholds a great potential as storage of CO_2. As an example, the CO_2 flows associated with the execution of industrialized bamboo-based housing solutions are presented in Fig. 15.5. This figure shows two types of temporary CO_2 storage (captured in the plantation and stored in buildings) and two types of avoided CO_2 emissions (avoided from electricity generation by using material by-products and the recycling of demolished construction materials). The implementation of an industrialized bamboo-based housing program exerts positive effects on the environment by capturing and avoiding over 10^8 tCO_2e emissions over 130 years.

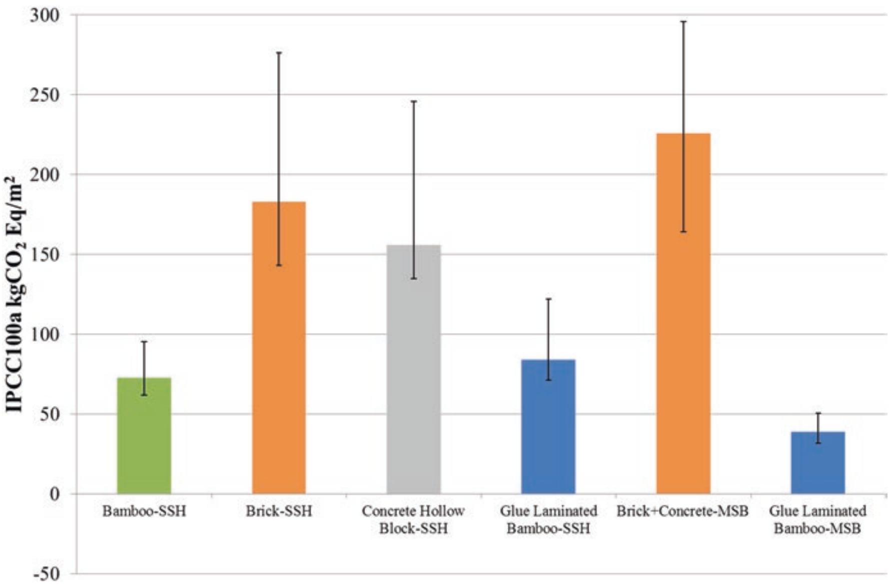

Fig. 15.13 Environmental impact $kgCO_2Eq$. *SSH* single-storey house, *MSB* multi-storey building

The use of bamboo in construction can support the regenerative development of the regions in which they are applied, leading to sustained improvements in their environment and economic stability.

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Part VI
Water, Sanitation and Drainage

Chapter 16
Water, Sanitation and Drainage

Filipa Ferreira

Around the world, nearly 800 million people don't have access to safe drinking water, and more than one-third of these people live in sub-Saharan Africa countries. According to WHO/UNESCO (2010), although access to water supply and sanitation in sub-Saharan Africa has been steadily improving over the past two decades, the region still faces considerable problems: access to improved water supply has increased from 49% in 1990 to 60% in 2008, while access to improved sanitation has only risen from 28% to 31%.

This situation has a great impact in terms of public health, life expectancy and poverty. Every day across Africa, over 650 people die from diseases related to diarrhoea. In infants and children under 5, 85% of all diseases are related to water. Furthermore, it is estimated that around 5% of the gross domestic product in sub-Saharan Africa is lost every year as a direct result of polluted or contaminated water, lack of water or poor sanitation. It is also commonly referred that every $1 spent on water and sanitation generates at least $4 in increased productivity; thus investing in infrastructures that increase access to safe water is one of the most effective instruments in promoting health and reducing poverty.

In 2015, in sub-Saharan Africa, 58% of the population used improved sources of drinking water (that required no more than 30 min per trip to collect water), and 14% of the population had limited drinking water services (used improved sources that required more than 30-min collection time) (WHO/UNICEF 2017). The same report refers that 28% of the population used improved sanitation facilities (those designed to hygienically separate excreta from human contact) that were not shared with other households. Of this population, only 7% had access to sewer connections. Further 18% of the population used improved but shared facilities (classified as limited sanitation services). In addition, in 34 out of 38 African

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Fig. 16.1 Sustainable Development Goals (United Nations 2015)

countries with data, less than 50% of the population used basic handwashing facilities in 2015, which contributes to severe health problems.

The Sustainable Development Goals (SDGs, summarized in Fig. 16.1) express the United Nations concerns related to these and other interconnected problems, covering social and economic development issues that include poverty, hunger, health, education, global warming, gender equality, water, sanitation, energy, urbanization, environment and social justice. Of the 17 global goals set by the United Nations in 2015, Goal 6 ("Ensure availability and sustainable management of water and sanitation for all") is directly related to water safety and sanitation, emphasizing the following objectives:

- Ending open defecation
- Achieving universal access to basic services (adequate and equitable sanitation and hygiene for all, paying special attention to the needs of women and girls and those in vulnerable situations)
- Achieving universal access to safely managed services

Nevertheless, achievement of Goal 1 (No Poverty), Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-Being for People), Goal 5 (Gender Equality), Goal 8 (Decent Work and Economic Growth), Goal 11 (Sustainable Cities and Communities) and Goal 12 (Responsible Consumption and Production) is also connected to the water sector.

In this context, the importance of water distribution and sanitation in sub-Saharan Africa is evident. This chapter will cover aspects related to the abstraction, treatment, reservation and distribution of water in African countries. In addition, sanitation approaches will be detailed, considering dry sanitation, faecal sludge management and conventional sanitation. Finally, some major concerns related to stormwater drainage in urban areas are presented.

16.1 Water Supply

General Considerations

Nowadays, several countries in Africa experience water stress, and within the next few years, others are expected to reach this critical point. Like most other parts of the world, agriculture and mining are responsible for Africa's water strain, and climate change is probably going to aggravate the situation. Water shortage affects humans (one of the main restrictions to improve the quality of life of populations is the shortage or lack of potable water for human consumption), but it also affects nature (many native species are critically endangered).

As previously mentioned, the average life expectancy in African countries varies greatly depending on the water condition for that particular country, and infant mortality rates are directly correlated to water safety. In 2011, the highest child mortality rates were observed in sub-Saharan Africa, where one in nine children died before the age of 5. Cholera and hepatitis are the most common waterborne illnesses that affect Africa population, but malaria, dengue and other similar diseases are also a concern.

In addition, according to WHO/UNICEF (2008), women in Africa shoulder the largest burden in collecting water. In fact, 72% of water collection is made by women, 14% by men, 9% by girls and 5% by boys. Gender segregation is evident in these matters.

In Africa, generally, water supply systems reflect low production problems, as well as lack of storage, coverage and transmission systems. A significant part of urban areas are not covered by water supply systems, some of which are densely populated. Serviced areas frequently suffer from poor operational conditions: low pressure, intermittent services, high percentage of real water losses (usually higher than 40%) and high levels of non-revenue water (which economically compromises the necessary development of the water supply system). Since water safety and quality are fundamental to human development, it is of the utmost importance to improve access to safe water and reduce the referred problems, so as to increase public health and reduce poverty.

Water Abstraction and Treatment

In sub-Saharan Africa, two-thirds of the 159 million population still rely almost completely on surface water. Generally, cities main supply of water are surface freshwater from rivers, either abstracted directly from the river or after the construction of a dam, sometimes located several kilometres away from the city (as illustrated by Fig. 16.2), and water needs to be pumped through considerable distances.

In rural areas, typically the only water sources are located at great distances from housing clusters and in places of difficult access. There are many situations of

Fig. 16.2 Surface water abstraction of Figueiras, Santo Antão, Cape Verde

Fig. 16.3 Groundwater abstraction of São Vicente, Santo Antão (on the left) and borehole drilling (on the right) in Cape Verde

children and adolescents who spend part of their time finding and transporting water for their families. This problem contributes to school drop-out and, consequently, to perpetuate poverty.

Some regions rely on groundwater abstracted trough wells or drilled boreholes (as illustrated in Fig. 16.3). However, frequently wells produce disappointing results of hard and saline water, particularly in coastal areas. Innovative pump systems, including handpumps and "Play Pumps", aid communities in drawing clean water from wells. The handpump is the most basic and simple to repair, with replacement parts easily found, while "Play Pumps" combine child's play with clean water extraction through the use of a roundabout.

Water purification processes commonly include filtration and disinfection with bleach (sodium hypochlorite), an efficient and affordable option (Tumwine 2005).

The process is simple: after filtration, two drops of bleach are added per litre of water, remaining in rest for about 20 min before use. Boiling is usually not an option in developing countries since it consumes a lot of energy and wood and other biomass fuels are not always available (and are very expensive).

Seawater desalination is one of the water sources considered in islands like Cabo Verde, which are supplied mostly through this method, despite the significant costs of the process.

Another water resource with potential but still not properly explored in most African countries is rainwater harvesting.

Water Storage and Distribution

Improved water supply systems have the potential to deliver safe water by nature of their design and construction. These include piped supplies (such as households with tap water in their dwelling, yard or plot or public standposts) and non-piped supplies (such as boreholes, protected wells and springs, rainwater and packaged or delivered water). In peri-urban areas, water quality and reliability is usually poor, and distribution is provided by vendors, kiosks or neighbours.

Water distribution systems include large-scale storage tanks (as presented in Fig. 16.4). Countries such as Ghana and Zambia have high levels of water storage per capita, but they present a limited capacity to mitigate contamination risks (WHO 2013). Due to the fact that water distribution systems operation is intermittent,

Fig. 16.4 Large-scale water storage tank in Tete, Mozambique

Fig. 16.5 Domestic water storage tank in Cape Verde

domestic water storage tanks are very frequent (Fig. 16.5). However, water contamination during storage at home presents a serious risk to health for millions of households in developing countries. Several studies have shown an increased risk of diarrhoea because of inadequate water storage (Knight et al. 1992).

The water requirements associated with a distribution system are calculated based on the areas served by each tank, the network coverage, population and per capita demands. In Africa, household water use averages 47 L per person. In urban areas, per capita demands are strictly related with people's access to water: in average, street taps consumption is 25 L/inhab/day; households with tap water consumption is 60 L/inhab/day; in city centres water consumption is 85–100 L/inhab/day; luxurious residences have a consumption of 150 L/inhab/day.

It is important to take into account that a substantial amount of the water produced (typically 50–60%) in African cities is lost through leakages and an additional 10–20% is usually lost through unauthorized use, illegal taps and unbilled consumers. Proper conception of water supply systems should prevent water losses, especially in countries where the resources are scarce.

Water Loss Control

In most water distribution systems of undeveloped countries, operational conditions are limited. Water quality is poor, low pressures are common and the services are intermittent, also as a way to control water losses (the rate of water losses increases along the transmission mains due to prevailing pressures).

Water losses include real losses (due to breakdowns or leakage in storage facilities, trough mains and water service lines) and apparent losses (due to meter inaccuracies or unauthorized consumption). To determine water losses in large systems, leak detection surveys based on district metering areas should be implemented. Pressure management, inspection of water mains, rehabilitation and replacement of problematic infrastructures, GIS mapping of system components (in order to quickly

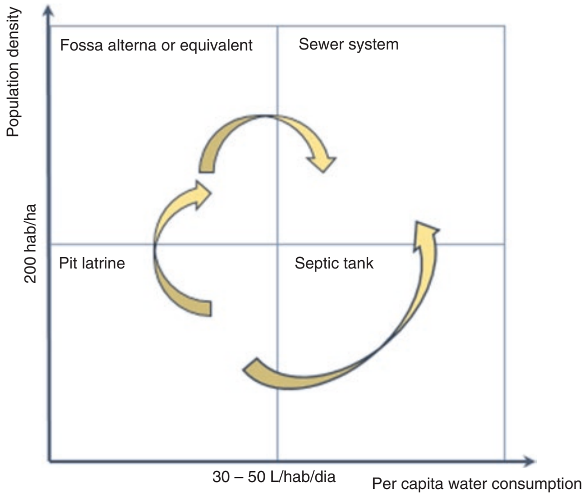


Fig. 16.6 Evolution of the sanitation service type in function of population density and per capita water consumption

find valves to isolate main breaks), and periodically checking operation and control of pumps used to fill storage tanks are management activities that may contribute to reduce real water losses.

16.2 Sanitation

General Remarks

Improved sanitation facilities are those designed to hygienically separate excreta from human contact, and both wet and dry sanitation technologies are acceptable, depending on population density and per capita water consumption. Generally, households are classified as having safely managed sanitation services if the toilets are not shared and the wastes undergo at least a minimum level of treatment.

When analysing wastewater and faecal sludge drainage and treatment solutions, on-site and off-site solutions should be considered. On-site sanitation facilities are the main form of improved sanitation in urban as well as rural areas of Central Asia and Southern Asia, Oceania and sub-Saharan Africa and are specifically designed to facilitate safe management of excreta. Off-site sanitation facilities can be connected to sewer networks or to on-site storage and treatment facilities such as septic tanks.

As presented in Fig. 16.6, the construction of sewer networks is justified when water consumption and population density are sufficiently high. In the remaining cases, on-site solutions should be preferred. Thus, in the case of high population density (over 200 inhabitants/ha) and per capita water consumption over 30–50 L/(inhab.day), the typically most adequate and economic solution is a gravitational sewer network conveying wastewater to the WWTP. That situation results from the available areas being insufficient to accommodate more septic tanks, especially when a high water consumption is registered. In areas with individual septic tanks and where water consumption tends to increase, small diameter gravitational sewer networks (settled sewerage) or condominial sewerage (gravitational with smaller diameters than conventional systems) can be used.

However, when water consumption is high but occupation density is very low, the use of septic tanks is usually the best option from a technical, economic and environmental point of view. For low water consumptions, latrine solutions prevail, either with or without emptying and biosolids (sludge) transport to treatment, depending on the territory's occupation density.

Faecal Sludge Management and Sanitation Services

Overview

Faecal sludge management represents a major challenge for peri-urban sanitation on most of sub-Saharan cities (Muximpa and Hawkin 2013). According to these authors, the faecal sludge service chain (presented on Fig. 16.7) comprises three main stages:

- Containment: the excreta is contained in the toilet or latrine and stored in septic tanks or latrines (where part of the liquid content is discharged, usually in the soil), and the remainder undergoes a partial digestion process during storage.

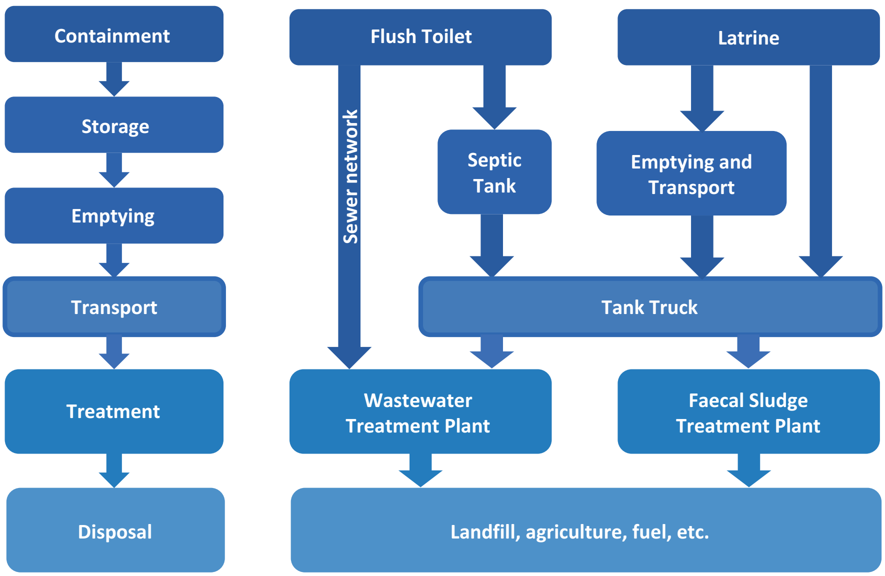


Fig. 16.7 Sanitation service chain. (Adapted from Muximpa and Hawkin 2013)

- Emptying and transport: the emptying and transport options strongly depend on the characteristics of the sanitation infrastructure and on accessibility. Emptying services are usually provided by small private operators like manual emptiers or small companies that combine emptying and sludge transport. In most extreme (but not infrequent) cases, manual emptying is the only possible option, due to the location and characteristics of the latrines, septic tanks or its content.
- Treatment and disposal: collected faecal sludge should be subject to treatment in appropriated faecal sludge treatment plants (FSTP), which promote the dewatering and stabilization of sludge, as well as their subsequent valorization.

Sludge Containment Solutions

On-site dry sanitation technologies typically include the infrastructures described in the following paragraphs.

Ventilated Improved Pit (VIP)

The VIP design can be used for both single and double pits. A single VIP is similar to a single pit latrine with addition of a vertical vent pipe (Fig. 16.8). The single VIP is a ventilated improved pit in which airflows vent continuously through the ventilation pipe, minimizing odours, or even, if well-designed and maintained, eliminates it completely (smell-free). Single VIP can reduce, as well, fly nuisances, since a fly screen is placed at the top of the pipe, trapping the flies as they escape towards the

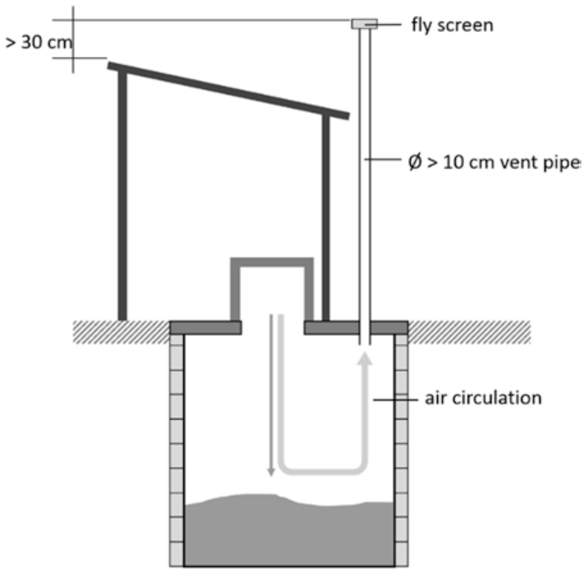


Fig. 16.8 Schematic of a single ventilated improved pit. (Adapted from Tilley et al. 2014)

light. A raised pit can be built, but usually the pit is dug at least 3 m deep and with 1–1.5 m in diameter, depending on the number of users. In this case, the liquid percolates from the pit and migrates through the soil, where the degree of removal of pathogens and organic matter depends on the soil type, moisture, distance travelled and other environmental aspects. The treatment processes in the single VIP (aerobic, anaerobic, dehydration, composting, or otherwise) are, therefore, limited, and the reduction on pathogens or organic matter is not significant. Nevertheless, since the excreta are confined, pathogen transmission to the user is restricted, being a significant improvement over single pits or open defecation. To further limit exposure to microbial contamination, a minimum horizontal distance of 30 m between a pit and a water source and 2 m between the bottom of the pit and the groundwater table is typically recommended. When the single pit is full, it can either be emptied and the sludge can be treated and reused or the old pit is covered and decommissioned, which is only advisable if land area is available. As opposed to the single VIP, by using two pits, one pit can be used, while the content of the second rests, drains, reduces in volume and degrades. When the second pit is almost full (the excreta is 50 cm from the top of the pit), it is covered, and the content of the first pit is removed. Due to the extended resting time (at least 1 or 2 years after several years of filling), the material within the pit is partially sanitized and humus-like.

Fossa Alterna

Fossa alterna is a short cycle alternating, waterless (dry) double pit technology, as shown in Fig. 16.9. This technology only works correctly if the two pits are used sequentially and not simultaneously. The full pit degrades, while the second pit is filling, which, ideally, should take from 1 to 2 years (guaranteeing its decomposition), depending on its size and the number of users. The material in the full pit will degrade into a dry earthlike mixture that can be safely and easily removed manually and can be used as a soil conditioner, which makes it a useful technology for rural and peri-urban areas with poor soil. The fossa alterna is excavated to a maximum depth of 1.5 m and entails a constant input of cover material (soil, ash and/or leaves), which should be added after defecation and not urination.

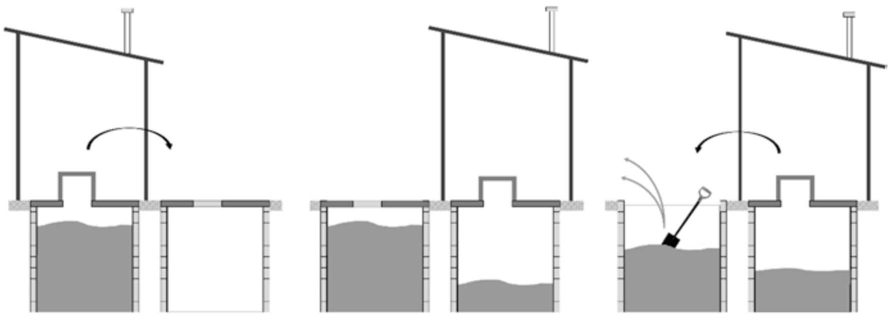


Fig. 16.9 Schematic of a fossa alterna. (Adapted from Tilley et al. 2014)

The cover material introduces not only a diversity of organisms, which help in the degradation process, but allows, as well, for aerobic degradation, since pore spaces increase. Fossa alterna should be used for urine, but water should not be added, since water boosts the development of vectors and pathogens and fills the pore spaces, reducing the degree of aerobic degradation. Since cover material is used to continuously cover the excreta, smells and flies are reduced. To reduce the smells even further, a ventilation pipe can be added. They are not as deep as single pits but may yet cause environmental contamination, when the groundwater level is high. In this case, as well as in flood-prone areas, the fossa alterna could be raised or built entirely above ground.

Ecological Toilets

Ecological toilets (Fig. 16.10) include two chambers which are used alternately to store faeces, while the urine is collected separately, in an impervious container. These types of on-site solutions are laid above ground and are specially adequate where groundwater table is high and the soil is rocky making excavation difficult or in areas prone to flooding. The faeces are slowly dehydrated and stabilized and should be periodically removed.

Sludge Emptying and Transport

Sludge emptying and transport is usually provided by informal operators (that perform manual emptying using shovels and buckets), base communal organizations service providers or micro-companies (Strande et al. 2014). Mechanical emptying

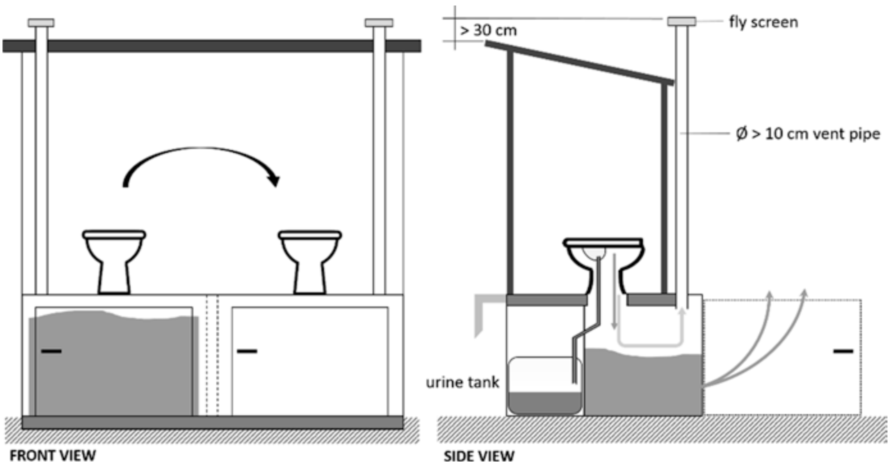


Fig. 16.10 Schematic of an ecological toilet. (Adapted from Tilley et al. 2014)

Fig. 16.11 Vacutug (on the left) and vacuum trucks (on the right) operating in Maputo, Mozambique

solutions may use manual operated pumps, like the Gulper, the diaphragm pump Fig. 16.11 and the MAPET.

Motorized equipment that runs on electricity or fuel includes the Vacutug, developed by UN-HABITAT, and vacuum trucks (Fig. 16.11). Vacuum trucks can receive sludge carried by a Vacutug, therefore shortening the travel time until the treatment facilities.

Informal service providers are frequently perceived as undignified and degrading workers. Therefore, in areas with no accessibility to sludge collection heavy vehicles, it is recommended to collect sludge from septic tanks and latrines through micro-operators using “Vacutug”-type tanks or equivalent. The sludge should be temporarily deposited in a sludge transfer station (STS), located in a place accessible to heavy motorized vehicles. Afterwards, a secondary sludge collection will be carried out, from the STS to the FSTP.

Faecal Sludge Treatment

Combined treatment of faecal sludge with wastewater is not recommended due to the increase in organic load, which may compromise the WWTP efficiency, resulting in the occurrence of bad odours. These difficulties may be mitigated if faecal sludge is conveyed, not to the WWTP headwork, but to the preliminary sludge process unit, in a faecal sludge treatment plant (FSTP), that may be located (or not) in the WWTP (Peal et al. 2014).

Faecal sludge treatment plants should include dehydration processes (that lower the sludge’s volume and weight, as well as, the transport and final treatment costs), mineralization, stabilization and drying of the sludge. These processes promote pathogen reduction and nutrient and organic material stabilization, thus contributing to the protection of public health and the environment. It is recommended to have screening as pretreatment in order to remove solid waste that may exist in the sludge. The processes described in the following paragraphs should be considered.

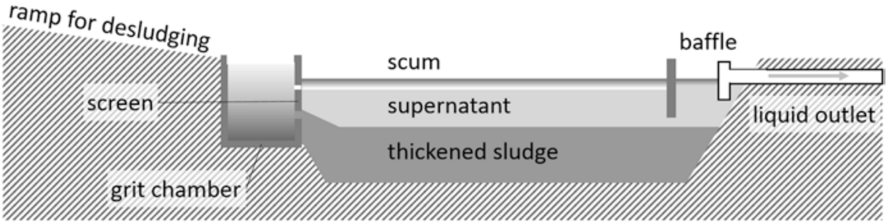


Fig. 16.12 Sludge disposal in sedimentation/thickening pond. (Adapted from Tilley et al. 2014)

Sedimentation/Thickening Ponds

These ponds are used to achieve separation of the liquid and solid fractions of faecal sludge, allowing for 80–85% reduction of the sludge volume (Fig. 16.12). The effluent is removed and treated (for instance, in lagoon systems), while the thickened sludge can be further treated during the solid-phase treatment process implemented downstream. As the sludge settles and digests, the supernatant must also be decanted and treated separately in the liquid-phase treatment process. The thickened sludge can then be dried or further composted. Long retention periods (e.g. up to a year) are required to ensure sludge's anaerobic digestion and pathogen reduction, and sludge subsequently use as soil conditioner/fertilizer. This technology is a low-cost option that can be installed in most hot and temperate climates, as long as there is available and inexpensive area, preferably located at the outskirts of the community. The thickened sludge is still infectious, although it is easier to handle and less prone to splashing and spraying; therefore trained staff, for operation and maintenance, is essential to safeguard correct functioning.

Unplanted Drying Beds

Unplanted drying beds consist in rectangular tanks (two or more tanks) with permeable bed, in which sludge is deposited for natural dewatering (Figs. 16.13 and 16.14). The leachate percolates the bed and is collected through perforated pipes (for instance, PVC pipes with 150 mm in diameter), located at the bottom of the bed (with a slope of 1–2%), and conveyed for further treatment. On top of the pipes are layers of gravel (with diameters between 40 and 70 mm and a maximum depth of 50 cm) and sand (uniform sand with diameters between 3 and 10 mm and a maximum depth of 10 cm) that support the sludge and allow the liquid to infiltrate. When the sludge is dried, it must be separated from the sand layer. The sludge volume drains off as liquid or evaporates, and the sludge achieves moisture content between 50% and 70%, if it remains on the drying beds long enough (about 1 month, on average). The drying ensures pathogen reduction, but the dried sludge

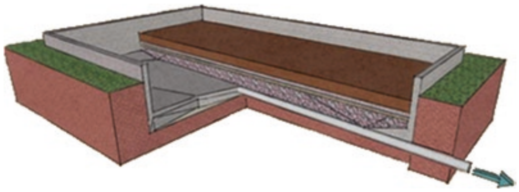


Fig. 16.13 Schematic representation of an unplanted drying bed

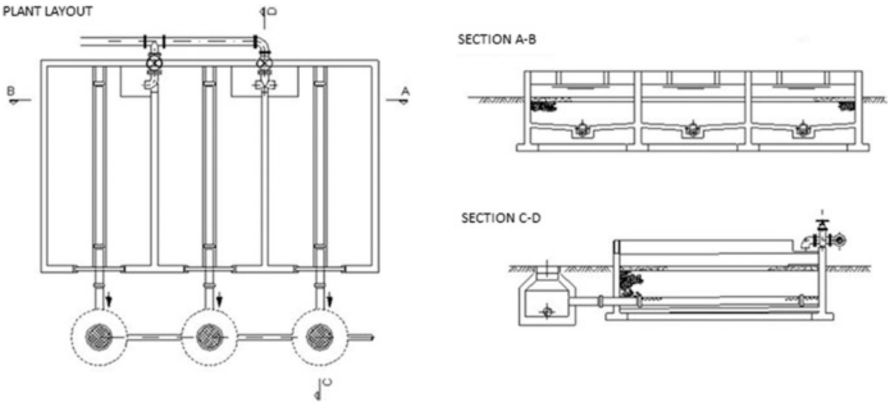


Fig. 16.14 Plant layout and sections of unplanted drying bed

is not effectively stabilized or sanitized if not conveyed for further treatment (e.g. composting). This technology is also not effective at stabilizing the organic fraction. This technology is, however, an effective way to decrease the volume of sludge, which is particularly relevant when it has to be transported elsewhere for further treatment, end-use or disposal.

Planted Drying Beds

Planted drying beds differ from simple drying beds due to the presence of macrophytes (Fig. 16.15) and to the larger volumes and depths of the beds. They are aesthetically interesting and easily accepted by the communities, have high dehydration efficiencies, low investment costs and require low maintenance. The treatment processes include dehydration, mineralization and faecal sludge stabilization, thus promoting odour and pathogen reduction. The dehydration efficiency, in tropical climates, generates a dry matter content superior to 30%. In general, beds are emptied every 5–10 years and the compost is transported into its final destination (typically agriculture).

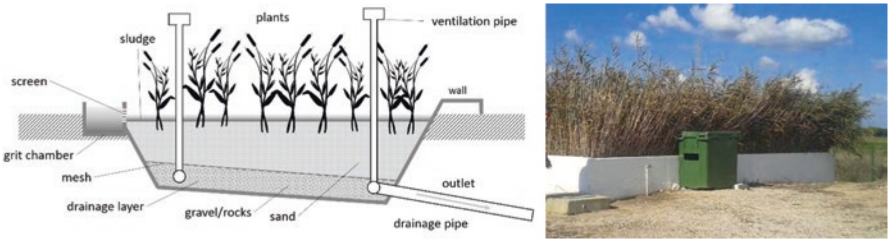


Fig. 16.15 Planted drying bed schematic representation and installation

Besides the previously described faecal sludge dehydration processes, FSTP may include chemical stabilization, by addition of hydrated lime, to ensure pathogen removal. Sludge co-composting may also be considered, using a mixture of faecal sludge and organic solid waste, taking advantage of the high nitrogen content of the sludge and the low moisture content of solid wastes. Sludge that has already undergone dehydration is especially suitable for this process. The total co-composting process takes between 6 and 8 weeks to destroy pathogens. It is necessary to frequently mix the composting piles in order to ensure aerobic conditions, control temperature and the moisture content of the mixture.

Final Destination and Faecal Sludge Valorization

Depending on the treatment type and quality, digested or stabilized faecal sludge should be regarded as a resource, as it might be valued in landscaping and agriculture, replacing the use of chemical fertilizers and contributing to the improvement of soil's productivity. Usually, agricultural valorization of sludge is less expensive than its disposal.

The use of treated faecal sludge may not present risks, since it should not have any chemical inputs, namely, hydrocarbons or heavy metals. However, sludge that originates at large-scale wastewater treatment plants is more likely to be contaminated with those chemicals, since it receives industrial and domestic wastewater, as well as surface water run-off.

The main constraint to agricultural valorization of faecal sludge is its acceptance by end-users. Nevertheless, even when sludge is not easily accepted by farmers, it can still be used in municipal projects and actually provide noteworthy savings (e.g. mine reclamation).

Wastewater Drainage and Treatment

Overview

Technically eligible wet sanitation technologies and treatment solutions for small agglomerates include (a) individual or collective septic tanks and appropriate final disposal (land infiltration through leach fields or soak pits or filtration through sand

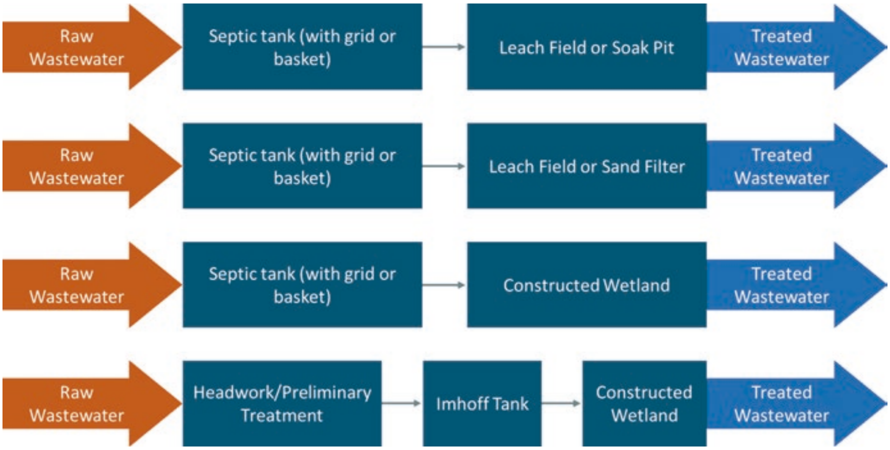


Fig. 16.16 Eligible treatment sequences for small agglomerates

filters or constructed wetlands) and (b) Imhoff tanks followed by constructed wetlands and sludge drying beds. Examples of eligible treatment sequences for small agglomerates are shown schematically in Fig. 16.16.

If the effluents are intended to be reused, in particular for irrigation, the treatment must be complemented by a disinfection system (usually filtration followed by chlorination).

Regarding the proper treatment process for the solid phase, this depends in part on the type of treatment adopted for the liquid phase. For systems with septic tanks, sludge and surface scum are subject to biological action (anaerobic digestion or septic fermentation), with the degradation of organic matter into mineral matter. Sludge removal must be done at least every 2 years. The sludge should be transported by a vacuum truck to the nearest WWTP with sludge treatment or to a FSTP. Alternatively, in order to guarantee autonomy, drying beds can be installed, even in the case of septic tanks.

Drainage Systems

In urban areas served by sewer networks, it is environmentally important to avoid direct discharges of domestic and industrial wastewater into the receiving environment. Therefore, separate systems should be constructed whenever it is possible. In case of combined systems, it is necessary to divert dry weather flows to a domestic main trunk sewer which transports wastewater to the WWTP. The diversion can be done through weirs positioned as downstream as possible, to maximize the intercepted domestic wastewater, but at an elevation above tidal influence.

Besides conventional separate systems, simplified small diameter systems (settled sewerage systems) or "condominial systems" might constitute an adequate technical solution.

Wastewater Treatment

Wet sanitation technologies typically used in wastewater treatment include the following infrastructures:

Septic Tanks

A septic tank is a watertight chamber made of concrete, fibreglass, PVC or plastic, through which raw wastewater (black water and grey water) flows for primary treatment through low retention times (between 1 and 3 days), promoting both physical treatment, by settling and flotation, and biological treatment, through anaerobic digestion and septic fermentation, reducing solids and organics. Liquid flows through the tank and heavy particles sink to the bottom, while scum (mostly oil and grease) floats to the top. Over time, the solids that settle on the bottom are degraded anaerobically. However, the rate of accumulation is faster than the rate of decomposition, and the accumulated sludge and scum must be periodically removed. Generally, the removal of 50–60% of solids, 30–40% of BOD and a 1-log removal of *E. coli* can be expected in a well-designed and maintained septic tank, although efficiencies vary greatly depending on operation and maintenance and climatic conditions.

A supplementary treatment device, like soak pits, constructed wetlands, leach fields or sand filters, must be installed downstream of the septic tank.

This technology is most commonly applied at the household level. Larger, multi-chamber septic tanks can be designed for groups of houses and/or public buildings (e.g. schools). A septic tank is appropriate where there is a way of dispersing or transporting the effluent. If septic tanks are used in densely populated areas, on-site infiltration should not be used; otherwise, the soil will become oversaturated and contaminated, and wastewater may rise up to the surface, posing a serious health risk. Instead, the septic tanks should be connected to some type of conveyance system, through which the effluent is transported to a subsequent treatment or disposal site. Even though septic tanks are watertight, it is not recommended to construct them in areas with high groundwater tables or where there is frequent flooding. Because sludge must be regularly removed, a vacuum truck should be able to access the location. Often, septic tanks are installed inside the household, under the kitchen or bathroom, which makes emptying difficult.

Septic tanks must be inspected annually or biannually in order to verify that scums have not reached the discharge device and to verify that the distance between them and the bottom sludge has not been greatly reduced: the thickness of the bottom sludge must not exceed 30–40% of the liquid level in the tank, and the thickness of the scum layer below the free surface of the liquid shall not exceed 20–30% of the liquid mass level in the tank. In Fig. 16.17 is presented a schematic representation of a two-compartment septic tank.

The sludge removal is carried out by pumping, by inserting a hose into both chambers of the pit through the openings in the upper slab. Sludge is usually stored

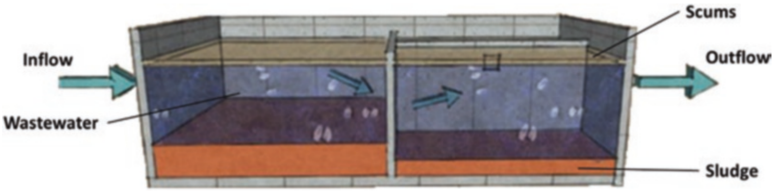
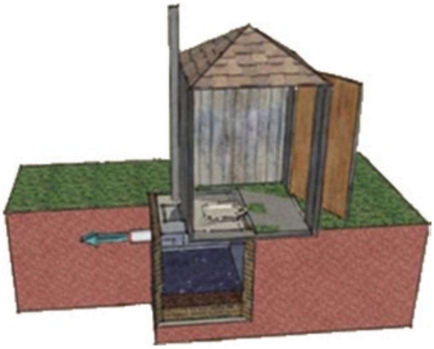


Fig. 16.17 Schematic representation of a two-compartment septic tank

Fig. 16.18 Cleaning operation of a septic tank using a vacuum tank

Fig. 16.19 Representation of a micro septic tank located under an isolated sanitary facility



in a tank (with 3–12 m^3 capacity) and transported to an appropriate treatment plant. Figure 16.18 represents, schematically, the cleaning operation of a septic tank and a typical vacuum truck.

In the case of individual septic tanks, simple single chamber solutions can be installed directly below the sanitary facility, as shown in Fig. 16.19 which must have a ventilation pipe, protected by a net to prevent the entrance of insects.

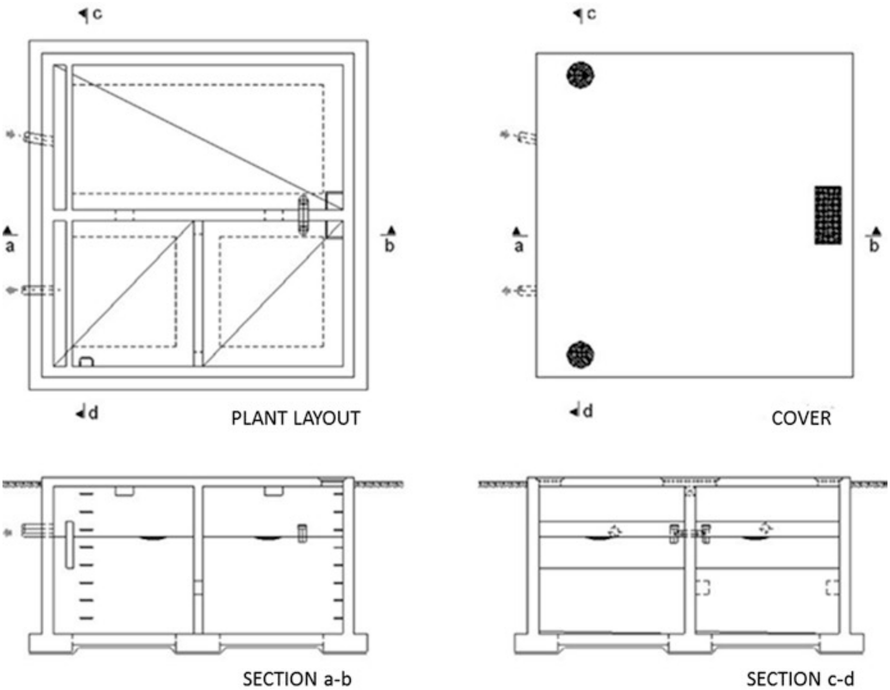


Fig. 16.20 Schematic representation of a septic tank with three compartments: plant layout and sections

In the case of collective septic tanks, it is recommended the use up to three compartments, as illustrated in Fig. 16.20. Septic tanks must have openings (one per compartment) for control, repair and discharge of sludge.

Imhoff Tank

The Imhoff tank is a primary treatment technology for raw wastewater, designed for solid-liquid separation and digestion of the settled sludge. It consists of a V-shaped settling compartment (primary settling chamber) above a tapering sludge digestion chamber with gas vents, as represented in Fig. 16.21. The settling chamber has a circular or rectangular shape with V-shaped walls and a slot at the bottom, allowing solids to settle into the digestion chamber, while preventing foul gas from rising up and disturbing the settling process. The sludge accumulates in the sludge digestion compartment, being compacted and partially stabilized through anaerobic digestion.

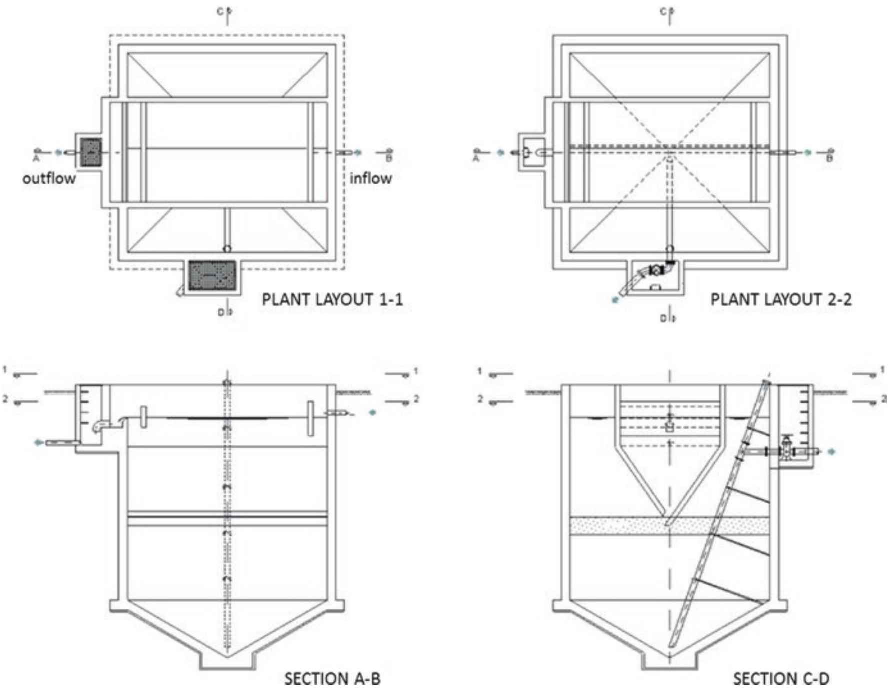


Fig. 16.21 Schematic layout and sections of an Imhoff tank

The Imhoff tank is a robust and effective solution that promotes a suspended solids reduction of 30–70%, COD reduction of 25–50% and BOD_5 reduction of 25–40%, leading to potentially good sludge stabilization. Imhoff tanks can cope with high organic loads and are resistant to organic shock loads. They do not have mechanical equipment, are simple to operate by non-specialized personnel and do not consume electrical energy, requiring reduced maintenance. As mentioned, the Imhoff tank is a primary treatment unit, and the effluent must be conveyed to a secondary treatment, namely, to constructed wetlands.

The digested sludge must be periodically discharged to drying beds, preferably by hydrostatic pressure, and the operation is controlled by a valve installed in the digested sludge extraction chamber.

Constructed Wetlands

Constructed wetlands are treatment systems that, when properly designed, reproduce the naturally occurring processes of a natural wetland, marsh or swamp, to improve water quality (Fig. 16.22). The naturally or artificially impermeable basin usually contains water, a substrate (drainage material, such as gravel, and filter

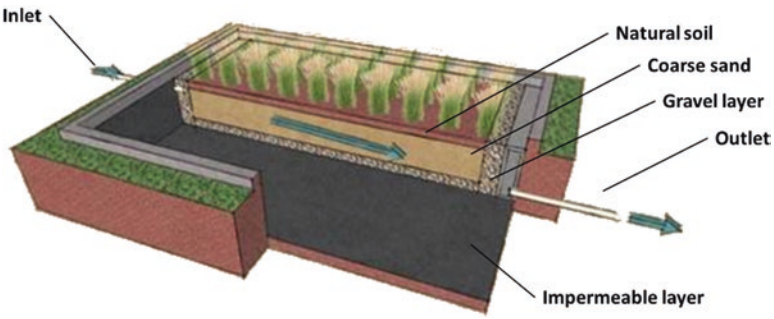


Fig. 16.22 Constructed wetland schematics with subsurface flow

material, such as coarse sand, covered by natural soil), and, most commonly, vascular plants (macrophytes). As the water slowly flows through the wetland, physical, chemical and biological processes occur simultaneously: the heavier solid particles settle out, which also removes the nutrients attached to them, and plants (and the microorganisms that exist on the roots and stems) take up nutrients like nitrogen and phosphorus. Pathogens are removed by natural decay, predation from higher organisms and sedimentation and due to UV irradiation. Although the soil layers present anaerobic conditions, the plant roots release oxygen into the immediately surrounding area, thus creating an environment suitable for complex biological and chemical activity. Macrophyte plants play also an important role in the evapotranspiration and ensure the maintenance of the porous structure of the filter layers (decreasing its clogging). Constructed wetlands are commonly used when land is available and low-priced and present the following advantages: reduced operation and maintenance costs (energy and supplies); technical requirements for operation and maintenance are low; flexibility to adapt to sudden variations in flow and organic loads; significant decrease of suspended solids, CBO_5, COD and pathogenic microorganisms; and reduced risk of septicity of the liquid mass and odour release. These technologies can also fit harmoniously into the landscape and are an environmentally sensitive approach that is favoured by the general public.

Soak Pits

A soak pit, soakaway or leach pit, is a covered, porous-walled chamber that allows water to slowly soak into the ground, as shown in Fig. 16.23. As wastewater percolates through the soil from the soak pit, small particles are filtered out by the soil and, if existing, the filter material (usually coarse rocks and gravel) and organic material are digested by microorganisms. The soak pit should be between 1.5 and 4 m deep but, as a rule of thumb, never less than 2 m above the groundwater table, to avoid groundwater table contamination. Soak pits are appropriate for rural and peri-urban settlements but always downstream of grey water or black water primary treatment (to avoid clogging). As the treatment depends on soil absorptive capacity,

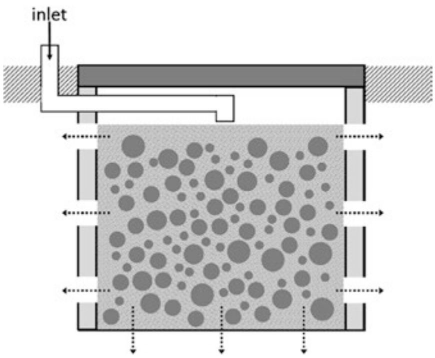


Fig. 16.23 Soak pit schematic representation. (Adapted from Tilley et al. 2014)

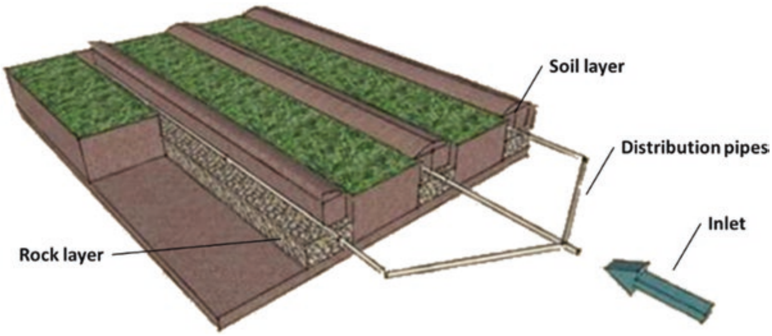


Fig. 16.24 Representation of leach field, composed by three trenches

the soak pits are best suited for soil with good absorptive properties; clay, hard packed or rocky soil is not appropriate. They are not appropriate for areas prone to flooding, and pits should also be located at a safe distance from a drinking water source (preferably more than 30 m).

Leach Field

A leach field, or drainage field, is a network of perforated pipes that are laid in underground filled trenches to distribute the effluent from septic tanks, which can be used whenever the terrain offers good permeability conditions and the water table elevation is low, not presenting contamination risks (Fig. 16.24). The trenches consist of narrow ditches dug into the ground, with depths between 0.3 and 1.5 m and 0.3–1 m wide. The bottom of each trench is filled with about 15 cm of clean rock, and a perforated distribution pipe is laid on top, also covered with rock. A layer of geotextile is placed over the rock layer to prevent small particles from plugging the pipe. A final layer of sand and/or topsoil covers the geotextile and fills the trench to the ground level. Additionally, the trenches should not be longer than 20 m and at

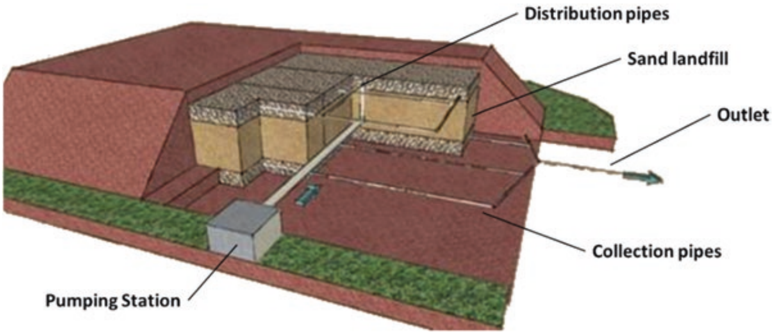


Fig. 16.25 Typical sand filter schematics

least 1–2 m apart. To prevent contamination, they should be located at least 30 m away from any drinking water source.

Leach fields guarantee the treatment of the effluent through filtration (mechanical action) and aerobic processes ensured by bacteria present in the upper layers of the terrain (biological action).

Sand Filters

Sand filters are complementary treatment facilities built on natural land, which are a final disposal option to be considered when the land is difficult to excavate or if the water table is too high and does not permit the safe use of leach fields.

A sand filter is composed by a sand landfill implanted above the natural terrain in which the effluent is subjected to biological filtration. The effluent from the septic tanks is distributed over the landfill through pipes covered with draining material and collected by a lower pipework. It is common, at the upstream of a sand filter, to have a small pumping station because, generally, the septic tank from which the effluent is taken is not at a sufficient elevation to guarantee a proper gravity flow. In Fig. 16.25 is schematically represented the layout of a sand filter.

16.3 Stormwater Drainage

Most sub-Saharan Africa urban areas do not have adequate stormwater systems. When existing, these systems are usually limited to the city centre and were often built 40–50 years ago, not presenting enough hydraulic capacity to respond to intense rainfall events. The fact that population in urban areas is rapidly increasing, leading to unplanned urban growth and imperviousness areas upsurge, contributes to the problem aggravation. In addition, rainfall has a large impact in soil erosion and soil nutrient loss.

Intense rain events frequently result in floods, with negative social, economic and environmental impacts, and are a vehicle to disperse faecal matter stored in septic tanks or latrines, leading to cholera and diarrheal diseases spread.

For stormwater drainage in urban areas, several types of solutions may be considered according to the characteristics of the area to be drained:

- Improvement or reinforcement of existing infrastructures, considering the design return periods rain events
- Expansion of infrastructures, namely, sewers and drainage ditches or open channels
- Construction of infiltration basins or retention basins and other source control infrastructures, mostly in the upstream catchment areas
- Definition of floodable areas in which uses of soil that condition the natural flow of waterlines are forbidden

The preservation of reserved areas should be included in the territorial management and urban planning, in order to minimize floods risk associated to future urban expansion.

Rehabilitation of existing roads that lack regularization and proper drainage is also an important measure to prevent or mitigate floods.

For new urbanizations it is recommended that, whenever possible, the streets have a similar orientation to that of the natural drainage lines and are provided with systems of ditches and culverts to assure adequate drainage.

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Part VII
Environmental Assessment Systems

Chapter 17
Built Environment Assessment Systems in Africa: Challenges to Assure Environmental Sustainability

Manuel Duarte Pinheiro

17.1 Introduction

Bioclimatic architecture is one essential dimension of built environmental performance, with strong implications for energy and comfort, materials and other aspects essential for the sustainable development of communities, cities and countries of Africa.

Environment assessment could be one essential base to identify the level of search sustainability of human interventions in a broad view considering the different environmental factors (clime, soil, water, ecosystem, landscape, socio-economic), its interrelations and evolution, potential balance solutions and measures.

Buildings are essential to ensure appropriate living conditions and be a key support to ensure environmental sustainability, and specific integrated sustainable assessment can be used as a tool for sustainability in African countries in places with different characteristics like Cape Verde, Sao Tome and Principe, Mozambique or Angola.

This is the key point of the chapter that (1) analyses environmental assessment tools for sustainability in built environments used in Africa, (2) presents a voluntary tool to assure a built sustainable assessment tool that is LiderA and how to apply it, (3) concludes with the identification of Africa major challenges that could assure environment sustainability and the potential of using sustainable assessment systems like LiderA.

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17.2 Sustainable Development and Environmental Assessment

The sustainable development are assumed in the Millennium Development Goals (MDGs): (1) Eradicate Extreme Poverty and Hunger; (2) Achieve Universal Primary Education; (3) Promote Gender Equality and Empower Women; (4) and (5) Reduce child mortality and Improve Maternal Health; (4) and (5) Reduce child mortality and Improve Maternal Health; (6) Combat HIV/AIDS, Malaria and other Diseases; (7) Ensure Environmental Sustainability and (8) Develop a Global Partnership for Development (ADB 2018).

The 2015 assessment of the MDG in Africa (ECA 2015) highlights that

- Poverty is decreasing, albeit slowly, with a real risk of reversals from shocks; Africa's productivity, as measured by output per person employed, is on the rise; Africa's growth has been relatively strong but not rapid or inclusive enough to create adequate decent employment opportunities;
- Disasters and persistent conflicts are obstructing the path to food security; Africa is close to the universal primary education enrolment target;
- Improving primary education completion rates remains a challenge; high primary enrolment rates are boosting youth literacy;
- Improvements in girls' enrolment and achieving gender parity; uneven gains in the share of women in wage employment in the non-agricultural sector; Africa is leading the way in women's representation in national parliaments;
- Impressive progress in reducing child mortality; Challenges abound in maternal health despite tremendous progress; downward trend in HIV/AIDS, malaria and tuberculosis;
- Africa's progress in environmental targets exceeds global performance; Access to safe drinking water and sanitation is improving slowly, *but progress remains skewed towards urban areas*; North Africa maintains the lowest slum prevalence among developing regions;
- Debt sustainability is a growing concern; notable progress in technology indicators.

Africa MDG assessment explain that "sustainability requires addressing the root causes, not the symptoms of underdevelopment", namely consider the specific conditions, assure effective communication, taken in consideration an integrated approach that reverse the loss of environmental resources (ECA 2015).

This challenge is essential to Africa due to its need for development and different environmental conditions (e.g. clime), and social and economic conditions; one key point is to ensure that policies, plans, programmes and projects consider a balance, namely assess environmental aspects and take this into consideration for environmental sustainability.

Most of Africa countries (94 %, 51 in 54 countries) have already established an assess of environmental impacts of some projects and include this analysis in the decision through a formal environmental impact assessment (EIA) process (NCEA 2018).

In some cases, in fewer countries (e.g. Cameroon and Mali), policies, plan and programs in Africa Countries also need to be assessed by a strategical environmental assessment (SEA) processed by the national law (NCEA 2018); also, even then in most international financial programs. For example, those funded by the Word Bank (2013), SEA or a similar process is used to understand what are the critical aspects and to support the decision.

Formal environmental assessment (EIA or SEA) is a formal procedure, ensuring the incorporation of environmental, and where required, social and economic information in sound and well-balanced decision making. This involves a holistic search approach to identify the effects and potential measures to select balanced alternatives or solutions or to minimize the negative effects and promote the positive effects.

These and other tools are being used to include environment, social and economic balance to help to search sustainable development. The problem is that in several cases they are being use and applied with a narrow view the not allow to achieve this ultimate goal.

Urban areas are growing fast and in most countries people are living more in urban areas than rural area, like Burundi (87%), Niger (81%), Angola (55%) or Mozambique (67%) (Indexmundi 2018) ensuring environmental sustainability in the built environment is a key point in the goals for development in Africa.

Urban areas and buildings are critical in Africa to assure sustainable development and as base to environment sustainability. In this context, there is been increasing the publications and the use sustainable rating systems to support the design and the assessment of buildings and urban areas also in Africa.

17.3 Built Environment Rating Systems

Besides EIA and SEA environmental assessment, environmental life cycle assessment (LCA) is a growing tool and also green building rating systems, like BREEAM, LEED, Green Stars, or LiderA. The search by sustainability in the built environment is follow by the increase in the number of international sustainability rating tools, even that in some cases is difficult to understand and compare the results and assure that are adjusted to the specific context and application (Reed et al. 2017).

During the past two decades, a large number of Green Building Rating Systems (GBRSs) have been developed by the countries around the world in order to rate and certify green buildings, where most important evaluation criterion considered was "energy", followed by "site", "indoor environment", "land and outdoor environment", "material", "water", and "innovation" (Shan and Hwang 2018).

Schweber (2013) refers "as long as market signals remain the ideologically preferred mechanism by which to implement sustainability, assessment methods will continue to affirm technical, mechanistic models of sustainability. While this does not discount the contribution of such methods to environmental sustainability, it does raise questions about ways in which the existing panoply of methods and tools is locking in certain understandings. It also suggests that, to be successful, 'paradigm' change necessarily depends on a more systemic change, not just in the construction sector, but in broader modes of governance".

Nevertheless, environmental and sustainable assessment and search has to be improved, as Frame and Cavanagh (2009) refer – "sustainability assessment is an awkward adolescence" (Frame and Cavanagh 2009). Other authors also refer (Xing et al. 2009) that there is no single, robust methodology that can simultaneously quantify and assess all three dimensions (economic, social and environmental) of urban development.

Schweber identify two opposed perspectives: a first "group of authors who support assessment methods as an integral part of any sustainability strategy"; and a "second group of scholars rejects current methods as inimical to genuine sustainability" (Schweber 2013).

This second group of authors "criticize the narrow environmental, technical and building focus of the tools which neglects the impact of buildings on their socio-ecological context and which precludes genuine stakeholder engagement and dialogue over value choices. "Most of these second authors groups emphasize the need for radical changes in the way in which people think. As Plessis and Cole (2011:448) say 'a shift in worldview is prerequisite to a paradigm shift'" (du Plessis and Cole 2011).

About the question of whether green buildings are more satisfactory, it must be recognised that the solution to the satisfaction of the occupant depends on the context; for example, in the occident, where the baseline is high the improvement of the green building is minimal. In a context where the baseline is not high (e.g. the orient) the improvement from green buildings would achieve significant satisfaction increases (Khoshbakht et al. 2018).

In this context where the baseline and rules are not very high there is a strong possibilities for the green building movement to upgrade the building design and maintenance standards and to have better living and working environments (Khoshbakht et al. 2018).

The green buildings rating system has different orientations and affects the green design, for example LEED in America is energy efficient oriented while Green Stars consider energy and indoor environmental quality (He et al. 2018).

17.4 Challenges of Africa

The population in Africa estimated in 2018 as 1287 millions of inhabitants, near 17% world population (UN – DESA 2018), with 42.5% live in urban areas. With different situations, for example Portuguese speaking countries: in Eastern Africa Mozambique 30.5 millions with 36% in urban areas; in Middle Africa Angola 30.7 millions with 65.5%, São Tome and Principe 0.2 million and 72.8%; in western Africa, Cabo Verde 0.5 million and 65.7%; Guinea-Bissau 1.9 and 43.4%.

The number of Africans living in informal settlements is important and the access to resources like food, supply services like water or energy, waste water and solid waste collection and treatment is a challenge.

So, there is a different situation in structured urban areas where the challenge is to ensure efficient buildings and in other situations where it is essential to ensure services and survival conditions. In both is important to reduce negative impacts, avoid environmental risks, and promote positive environmental, socio-economic dynamic integrating environmental, social cultural and economic conditions.

The rapid boom of population and construction increase the challenge for green buildings and built areas. Africa urbanization is a dynamic process and buildings are growing very fast. Green building is essential to green urban areas and to promote sustainable development.

Some countries already use international systems, develop and apply green building rating systems. South Africa uses Green Star or EDGE, in 2018, the proportion of green buildings will climb from 2017s 41% to 61% of all South African building project activity (GBCSA 2018). For example, Rwanda government introduce green building certification and guidelines as a base to search environmental sustainability (Tashobya 2017).

Environmental sustainability in Africa and its assessment is not only a question of focus in efficiency is also to assure a broad view, rational use of resources. But some of the systems (LEED or BREEAM) do not clear promote for example a bioclimatic approach that is a key point in energy and carbon rational use (Ferreira et al. 2014). LiderA is a Portuguese system that consider energy in three dimensions: bioclimatic approach, energy efficiency and low carbon intensity.

17.5 The LiderA System

Since 2000, at the Department of Civil Engineering, Architecture and Georesources of Instituto Superior Técnico, the author has been developing studies for the technical support of sustainable construction. Amongst these studies, the development of a support and assessment system for sustainable construction at the national level, with particular emphasis on buildings and enterprises, known as LiderA – Portuguese acronym for Lead for the environment in search of sustainability in built environments, stands out (Pinheiro et al. 2002; Pinheiro and Correia 2005).

LiderA is a Sustainable Evaluation System that can be used to search for sustainability in plans or projects and be applied to urban environments or buildings, allowing them to be certified or recognised by the system's brand, according to different final purposes. LiderA is based on the concept of re-positioning the environment in urban environments, enterprises and buildings, according to a sustainable perspective, assuming itself as a leading system for an efficient search for sustainability.

LiderA Evolution

From Green to Sustainable Built Environment

The first LiderA version (Version 1.02), released in 2005 (Pinheiro 2005), was mainly intended to evaluate, certify or recognise projects within a building's scale and respective surroundings. However, given the number of applications studied, a new version (V2.00) has been developed, extending the possibility of application from a building's scale to build environments and urban districts, including the demand for sustainable outdoor spaces, blocks, neighbourhoods and/or communities (Pinheiro 2011).

The version published in 2010 (V2.00) is based not only on environmental areas, but also economic and social areas. The system is based on a set of six sustainable performance principles (local integration, resources, environmental loads, environmental comfort, socio-economic adaptability, and environmental management and innovation) that are then translated into a set of criteria, according to which the built environment (based on the buildings) is assessed in terms of its sustainable performance.

The demand for sustainability in the built environment is based on principles which cover the main aspects considered in 6 different categories and 22 areas, including

- Enhancing local dynamics and promoting proper integration (Site and integration), with regard to soil, natural ecosystems, and landscape and Heritage;
- Promoting the efficient use of resources (Resources) including energy, water, materials and food production and access;
- Reducing the impact of environmental loads, both in value and in toxicity (Environmental Loadings) involving wastewater, waste and other emissions and loads like: atmospheric emissions, noise emissions, and thermal and light pollution;
- Ensuring environmental quality and resilience is focused on environmental comfort (Environmental Comfort: including air quality, thermal comfort, lighting and acoustics) and resilience as adaptability capacity and climatic challenges;
- Promoting sustainable socio-economic (Socioeconomic aspects), which includes access and space for all, contribution to social vitality, culture and amenities, value and circular economy and connectivity.
- Ensuring the best use and management of built environments through environmental management and innovation (Support sustainable use), which includes Environmental Management and Innovation.

The Version V3

In 2018 a new version (V3.00) of the LiderA System was developed. This version maintains the principles of promoting good local integration, good use of resources, reducing environmental loads, but changes the logic of the environmental service, which is now centred environmental quality (e.g. comfort, security) assume the importance of de resilience in the service, integrating climatic challenges and flexibility, suggests some improvements in areas of socioeconomic dynamics (social vitality, culture, green and sustainable economy, value and costs, connectivity) and sustainable use (including awareness and marketing).

The LiderA structure (V3.00) details 6 principles in 20 areas, and 40 sustainable lines that is a broad view of the simple criteria logic since is a line where can develop several sustainable solutions. Each sustainable line has a detailed specification, a way of defining the scale of assessment and its respective weights. Each sustainable line (of the total 40 criteria) has a scale which allows the evaluation of the level of demand for sustainability, and guidance towards more challenging objectives. The principles, areas and sustainable lines are present in Fig. 17.1.

The sustainable lines (Fig. 17.1) and the guidelines presented intend to help select not necessarily the best existing solution, but the solution that significantly improves the current performance of buildings and other urban environments, and also the economic perspective.

The sustainable line specification depends on the phase of development. The criteria of sustainable lines are prescriptive in the initial phase, or performance based in later phases (detailed design, construction or operation) since the information available will be more quantitative.

In LiderA schemes, the sustainable lines (s) are focused not only on a specific scale of analysis but also include lower and upper scales. For example, if a building is being analysed, the scheme also considers a specific set of criteria (sustainable lines n° sX) that assesses other scales, including

- Materials and small scale solutions are interlinked and assessed by
  - Performance of the solution in terms of energy (s9 – Carbon management), water (s10 – water system) and other criteria;
  - Materials durability (s12) and materials from responsible sources (s13), control and security (s21) and life cycle costs (s33);
- Neighbourhoods and larger urban scales are interlinked and assessed by
  - Structural areas and criteria:
    - Site and integration, namely: territorial organization (s1), ecological valorisation (s4), ecosystem service (s4) and landscape valorisation (s5);
    - Resources, namely: energy passive management (s7, which includes the building and surrounding urban morphology), materials from responsible sources (s13), local food production and access (s14);
    - Closing the cycles in wastewater, namely potential local treatment and reuse as promoted by wastewater management (s15) or recycling solid waste (s16).
    - Socioeconomic dynamics, namely: transport system (s24) and active mobility (s25), safe and appealing common spaces (s27), social responsibility (s30), cultural identity (s32), local economic dynamics (s34) and connectivity and interactions (s36).

Site and integration	Soil		Natural ecosystems		Landscape and heritage	
	Territorial Organization	Land Functionality	Ecological Valorisation	Ecosystem services	Landscape valorisation	Built heritage valorisation
	1	2	3	4	5	6

Resources	Energy			Water		Materials		Food
	Energy passive management	Energy Systems	Carbon Management	Water systems	Local water management	Built structure durability	Material and products of responsible sources	Food production and access
	7	8	9	10	11	12	13	14

Environmental loads and management	Wastewater	Waste	Other emissions		
	Wastewater management	Waste management	Noise Management and other nuisances	Atmospheric emissions management	Other loads
	15	16	17	18	19

Environmental quality and resilience	Service quality		Resilience	
	Environmental quality service	Control and Security	Adaptability potential	Climatic challenges and other natural risks
	20	21	22	23

Socio economic dynamics	Accessibility		Space for all		Social vitality		
	Transport systems and low impact modes	Active Mobility	Inclusive spaces	Safe and appealing common spaces	Flexibility and different uses	Welfare	Social responsibility (and Social vitality)
	24	25	26	27	28	29	30
	Culture and amenities		**Value and circular economy**			**Connectivity**	
	Friendly Amenities	Cultural heritage and identity	Low life cycle costs	Local eco dynamic and economic attractiveness	Sustainable environment contribution (Jobs and structures)	Connectivity and Interactions (IT)	
	31	32	33	34	35	36	

Sustainable management	Sustainable management		Marketing and innovation	
	Information and awareness	Maintenance and Environmental Management	Governance and monitoring	Marketing and Innovation
	37	38	39	40

Fig. 17.1 LiderA ((V 3) categories), areas and sustainable lines at the Building level

Most of the criteria have a prerequisite that demands that all legal requirements are met and adopted as minimum base points in each area, including applicable building regulations. The improvement of these conditions is what is considered the search for sustainability).

Main Aspects

Performance Scale (Factorial Scale)

Each sustainable line (criterion) has a performance level (from 0 to 10 or higher) and a numerical assessment which is then communicated as a class from G to A++. LiderA performance in each criterion has a scale that is defined from the common practice (Class E) to an incremental performance scale, which includes an improvement of 12.5% (Class D), an improvement of 25% (Level C), an improvement of 37.5% (Class B), an improvement of 50% (Class A), an improvement of 75% or factor 4 improvement (Class A+) and finally an improvement of 90% or factor 10 improvement (Class A++) (Fig. 17.2).

Threshold for Each Type of Use

Built environments have various spatial scales and project types. Although it is important to reduce energy use in different land-uses, the level of energy consumption is not the same in a house, in a hotel or in a larger urban zone.

In this context, LiderA has developed different thresholds for each sustainable line according to different types of built environments, different uses (e.g. buildings: residential, touristic, commercial, offices) different scales, and different land-uses. For each sustainable line, LiderA defines the performance levels (or thresholds) that should be considered according to a scale from 0 to 10, which indicates the level of sustainability achieved by the solutions adopted. The parameters for each one follow either the improvement of the existing practices or the reference to the values of best practices, as it is usual in the similar international systems.

The thresholds defined by LiderA derive from three reference points:

- Technological performance, in which the existing constructive practice is considered the common level (Level E or Factor 1);
- Best performance, where it is considered that this results from the best viable constructive practice to date (Level C, B and even A (Factor 2));

Fig. 17.2 LiderA's certification levels

- And the definition of higher levels of sustainability, which focus on searches for neutral or regenerative cases (level A++ (Factor 10) and A+++ (positive balance)).

The performance levels are numeric, as mentioned earlier (from 0 to 10). However, for communication and reporting purposes, they are transformed into alphabetical classes (G to A+++).

Weighting

Weighting means giving importance to some aspects, which is a subjective process (Casasnovas and Riera 2012). In some specific cases, Chandratilake and Dias (2013) reveal that professionals can give similar importance to similar criteria (Chandratilake and Dias 2013).

Although LiderA is multi-criteria based, it also enables the aggregation of results using a weighting process. In the case of LiderA, the weighting process is done through an inquiry process in which four sets of stakeholders are asked to rank the most important areas in a two by two comparison. A categorical based evaluation technique calculates the final weightings using an approach designated MACBETH that stands for Measuring Attractiveness by a Categorical Based Evaluation Technique (Bana e Costa and Vansnick 1994).[1]

The weights for each area were obtained through this method, through inquiry and consensus. The area considered as most important was the Energy (17%) area, followed by the Water (8%) and Soil (7%) areas. When taking into account the weights of the different areas within the six comprehensive sections of the system. Resources are positioned as the most relevant area, constituting 29% of the final evaluation, followed by socio-economic aspects (28%), environmental quality and resilience (13%), site Integration (10%), Environmental Loads (10%), and sustainable use (10%).

The global aggregated value is obtained by weighting each level of performance of the 20 areas. The new version involves an actualisation and adjustment of the weights of the areas of the system. The system assumes the possibility depending the local and country situation to adjust the weights.

Typologies

LiderA has five specific schemes (Fig. 17.3) that can be used to assess buildings (residential, offices, commerce and tourism), urban zones, sustainable destinations, sustainable infrastructures and sustainable communities.

[1] As assessments are entered into the software, it automatically verifies their consistency. A numerical scale is generated that is entirely consistent with all the decision makers' judgements. Through a similar process weights are generated for criteria (see http://www.m-macbeth.com/en/m-home.html).

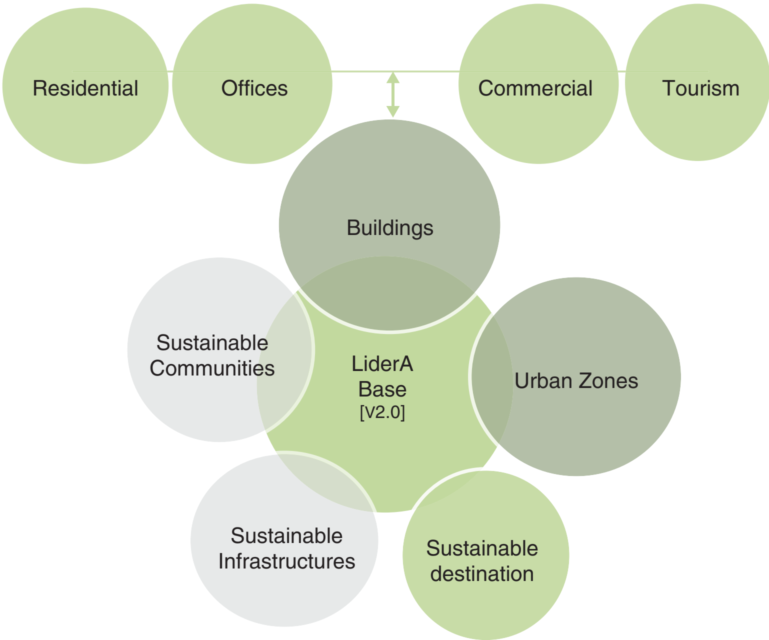

Fig. 17.3 LiderA versions

Application in the Life Cycle

Is essential to consider the life cycle since give an effective view of the impacts and the opportunities of intervention. LiderA can be applied at various life cycle stages, and in fact, is particularly relevant in the design phase, as it can obtain a performance value that can be improved for the construction phase (Fig. 17.4).

From the early stages (Fig. 17.4), each promoter must adopt an environmental or sustainable policy (or demonstrate its implementation), which should be suitable for its development and environmental characteristics when considering the sustainable principles, referred before.

Initial Phase

In the initial phase of each project, the Developer, being responsible for commissioning operations and awarding a contract to the winning plan or design bid, defines the characteristics, conditions and solutions that should be implemented. There must be an environmental policy that is able to provide that all the involved stakeholders conduct the undertaken work with good environmental practices. The developer needs to establish general rules for planning, organising and coordinating the project during all phases.

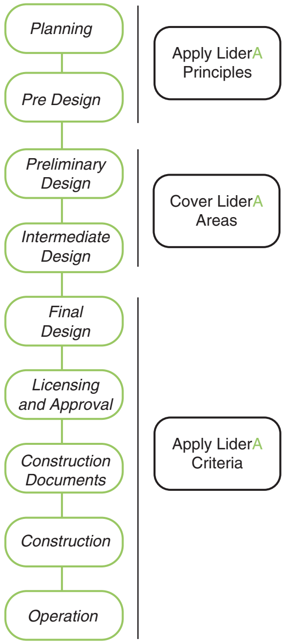

Fig. 17.4 Schematic application at the building level, from preliminary phase to operation

The Developer needs to be aware of the planning conditions necessary to execute the proposed work and thus anticipate all the risks inherent to each type of work. In subsequent interventions or necessary adjustments, he must ensure that the technical compilation is updated, and that the adopted solutions are flexible and modular, in order to provide the building with a new use in the future, if needed.

This approach consists of the following principles: to promote proper location and environmental integration, to attain efficiency in consumption and management, to reduce the impact of environmental stressors, to achieve adequate comfort, to pursue socio-economic adaptability, and to foment a consistent environmental management and a proactive search of innovation.

These principles, established at the policy level, should be applied at an early design stage and define performance as the commitment which needs to be met in order to achieve them. This commitment should be formalised as an on-going strategy towards the sustainability of the built environment, in which a set of sustainable principles must be assumed.

This approach should define the principles that will regulate the planning, urban and building development throughout all stages of approval. The potential principles to be considered (with minor or major efforts) are the following:

- Principle 1 – To improve local dynamics and promote appropriate integration;
- Principle 2 – To promote the efficient use of resources;
- Principle 3 – To reduce the impact of environmental loads (both in value and in toxicity);

- Principle 4 – To ensure building services and urban development process (search for sustainability, planning and implementation process and structural adaptability);
- Principle 5 – To promote sustainable socioeconomic dynamics;
- Principle 6 – To ensure the sustainable use of the built environment, through environmental management and innovation.

LiderA can be used according to a triple dynamic: (1) assess the actual situation of the building and urban zone from a sustainable point of view; (2) identify what proposals will improve the search for sustainability; and (3) assess and recognise the search for sustainability of the proposal.

For example, to improve local dynamics and site integration analyse the local and identity if it is possible and how to

- Assure use of soil adjust that preserve sensible areas and soil and promote compact development?
- Preserve and develop natural ecosystems and services?
- Preserve and develop local landscape and heritage?

Category		Area	Weight (%)	Objective
Site integration	1	Soil	3.00	Preserve good agricultural soil and promote urban compact development to reduce the physical impact in the soil
	2	Natural ecosystems	3.00	Preserve and develop natural ecosystems and services
	3	Landscape and heritage	4.00	Preserve and develop local landscape and heritage

For example, to promote the efficient use of resources (principle 2) in the case of energy (that is one of the resources) is important to promote bioclimatic solutions, reduce the need of energy and low carbon energy systems, and identify how is possible:

- Build based bioclimatic principles?
- Decrease of the nominal energy needs – optimize the energy cycle?
- Encourage the use of renewable systems (solar thermal, photovoltaic, wind, geothermal, biomass, etc.) adapted to the local conditions?

Planning and Design Phase

In the planning phase, the approach principles must be defined according to an environmental or sustainability policy. Agenda 21 and the LiderA Sustainability Guidelines could be taken into account as orientation at this level to assure can implement the parameters defined.

For example, to improve local dynamics and site integration, develop the plan and project taken in consideration if could integrate sustainable line to improve: Territorial Organization (s1), Land Functionality (s2), Ecological Valorisation (s3), Ecosystem services (s4), Landscape valorisation (s5), Built heritage valorisation (s6).

Category	Area	N°	N°	Sustainable line	Weighting (%)
Site integration	Soil	1	1	Territorial organization	1.0
			2	Land functionality	2.0
	Natural ecosystems	2	3	Ecological valorisation	2.0
			4	Ecosystem services	1.0
	Landscape and heritage	3	5	Landscape valorisation	2.0
			6	Built heritage valorisation	2.0

In energy, first promote *bioclimatic energy management (s7)*, built based on bioclimatic principles as a way of decrease the nominal energy needs – optimize the energy cycle. After must be consider *energy system (s8)* namely promote efficient energy systems, reduce energy consumption, monitoring energy consumption and verifying energy certification levels. The energy that could be needed if possible assure a *good carbon management (s9)* encourage the use of renewable energy sources systems (solar thermal, photovoltaic, wind, geothermal, biomass) adapted to the local conditions.

Area	N°	N°	Sustainable line	Weighting (%)
Energy	4	7	Energy passive management	6.0
		8	Energy systems	4.0
		9	Carbon management	4.0

These solutions should be adapted to the local situation and existing buildings.

Implementation Phase

In the implementation phase, during the different project developments, the system could be used in the dynamic triple process – to determine the actual sustainable performance of the building (or propose a solution) or urban zone, to support the search for sustainability and detailed proposals, and to assess and certify if the level of performance is proven to be consistent with Level C or higher.

In the implementation of proposals, refurbishment and new construction of public and private ventures, for each type of intervention (building, infrastructure, or other) it is recommended to apply the LiderA scheme to buildings or infrastructures from the design phase, through construction and operation phases, and at the end-of-life phase. During implementation, sustainable assessment and monitoring will allow us to understand the evolution and the need for improvement. The application of the sustainable communities scheme could also be considered a very useful tool.

Interconnections and Links: Potential and Limitations

LiderA has a defined set of sustainable lines (criteria) that can be applied to all types of buildings. The performance scale and thresholds differ with each type of building. For example, it is important to reduce water consumption. However, the quantity that defines usual practice and best practices will be different in an office, residential or other type of building. This logic allows adjusting and tailoring each sustainable line – criteria to the specific sustainable assessment of each type of building. Since the criteria are similar and the scale is relative (0–10), it allows the comparison of the performance of different types of buildings and in a specific zone (or in another locale).

This performance scale together with a life cycle cost sustainable line could be used to assess what is the best scale to apply to a given solution (one building, several buildings or an urban zone). For example, in terms of energy level, a good balance between performance and pay-back costs could be solar heating collectors at the individual building level, and wind energy at the urban scale. Some solutions could be, at the urban scale, public transportation, or storage of rainwater in a small dam; both of which are not as performance cost effective at the individual level. Thus, this approach promotes an integrated framework interlinking different types of buildings and the urban scale.

On the other hand, interconnected schemes, such as the ones generally foreseen by LiderA, will allow system users to have a glimpse at narrower or wider horizons without having to recur to the scheme that assesses the scales that are immediately above or below. In other words, this strategy will allow users to understand a building's integration in local surroundings, without having to use the neighbourhood's development scheme, for example. Using interconnected schemes also means that system users are able to use sustainable line criteria that are specifically adapted to the assessed scale, as narrower assessment horizons will imply more objective goals, and wider assessment horizons will imply more comprehensive goals.

Furthermore, the usage of interconnected schemes could mean that it will be easier to assess or establish successive goals that contribute to the common goal of meeting bottom-up with top-down sustainable development policies. This will enable transforming the search for sustainability into a process that ensures the accomplishment of environmental performance goals whether the policies are implemented top-down or bottom up. One of the main benefits of such contribution would be underpinned by the fact that the implementation of sustainable development strategies could more easily be interconnected and become complementary so that bottom-up and top-down policies could actually be implemented at the same time, guaranteeing that they actually meet somewhere along the way.

The complementarity of schemes of the same system should not be underestimated. Complementary schemes of the same system allow its users to assess sustainability at different scales, considering also the environmental performance of different or mixed uses. It also means that, nowadays, it is possible to establish a complete set of environmental performance sustainable line criteria to address the search for sustainability of a certain built environment.

However, complementary schemes, such as the ones offered by BREEAM or LEED, also imply that it is not possible to understand the complete picture of sustainable development without using more than one scheme. Consequently, users will have to recur to the usage of the Building and Neighbourhood development schemes if they intend to foresee, for example, how the building is locally integrated.

On the other hand, using interconnected schemes for different scales would definitely imply a better adjustment of each scales' goals, thereby contributing to the better management of the sustainable development process.

Many decisions that affect long-term economic, environmental and social functions at larger scales are made at a lower level (the community). Conversely, broader-level sustainability depends on the combined effects of both comprehensive policies and a larger number of smaller-scale decisions or policies. These decisions are interrelated since its effects could spill over socio-economic and environmental boundaries and also affect different scales. Although, most of the schemes that have been proposed have not yet been developed in order to promote full interconnection between scales.

This theory and the approach at stake will probably be easier to understand if they focus on three themes that are dear to most sustainable development frameworks, namely energy, wastewater and low impact mobility.

For example, for a building, it can be argued that one way to promote low impact mobility would be to install parking spaces for bicycles inside residential buildings, or outdoor parking within the building's allotment. Furthermore, buildings could also have dedicated parking spaces for electric cars and promote comfortable sidewalks within the allotment. Office buildings, on the other hand, could promote the same measures and include locker rooms and showers for the employees that adopt the bicycle as their mean of transport.

When considering a broader horizon, for example at the Neighbourhood scale, one could probably implement measures, such as bicycle paths, comfortable and appealing sidewalks, quick access to public transport, comfortable waiting stops, and quick electric charge points (which are still expensive, and would probably imply a significant investment at the Building scale) that would complement the electric car parking spaces. If the city scale is considered, these measures could probably be complemented by an efficient system of public transport (such as electric bus or trams), comprehensive nodal transport facilities, low impact transports (carpooling lanes and car sharing frameworks and facilities). As a result, the combination of all these measures, at different scales, would promote walking, cycling, the use of public transport, the use of low impact mechanical means of transport, with all the respective environmental, social and economic benefits that would be visible in a given built environment.

As for wastewater treatment, one could probably promote local grey water treatment at the building scale. This would mean that building infrastructures would be prepared to treat grey water, and eventually reuse the treated water for secondary water consumptions such as toilet flushing. This would imply local grey water treatment and thereby reduce the pressure on the neighbourhood's wastewater infrastructure. If this is complemented at the Neighbourhood scale by black water treatment, city infrastructure could be downsized, as the pressure on municipal infrastructure would decrease.

Once again, interconnected schemes at different scales would bring a reduction of expenses and a better use of resources. Wastewater would not have to travel tens of kilometres in order to be treated, and wastewater facilities would probably be larger in number, but smaller in size, and would be adapted to local treatment needs. Consequently, environmental impacts and costs related to wastewater treatment would be reduced and local authorities would be one step closer to completing local water cycles.

When considering the energy aspects within an urban environment, one must also consider the physical implications of applying measures such as energy production from renewable sources could allow local solutions and the same in the water cycle (including wastewater treatment and reuse).

If the prescriptive option of the legislation specified a performance level instead of solar collectors, for example the percentage of renewable energies, this would allow the selection of other alternative solutions like biomass or geothermal. These options would improve performance and cost effectiveness. For this reason, LiderA promotes a performance scale in the detailed design and subsequent phases.

At the building scale, planners and builders that apply LiderA guarantee that more passive design measures are taken into consideration and that buildings comply with current energy Legislation. Buildings will play an important role in reducing energy demands. If on the other hand, at the Neighbourhood scale, other energy production strategies are applied such as photovoltaic systems, wind turbines or any other form of energy production from renewable sources, communities will have the ability to converge to near zero energy policies, which are being implemented in the European Union.

Furthermore, by creating an energy framework that complements itself at different scales, costs could be reduced as more expensive systems with larger pay-back times would be applied at larger scales, serving a wider population and therefore reducing the direct costs that a single inhabitant would have to support. Creating energy strategies that are not only complementary but also take into consideration pay-back times of the implemented systems to define which scale is more appropriate to each system can definitely improve local energy policies, contributing to a better management of energy related resources.

Interconnecting schemes of the same system, optimising the foreseen sustainable measures, and adjusting them to the respective scale of application will allow users to better understand and explore the search for sustainability. This will also allow all involved stakeholders to consider measures that are more appropriate to a given scale, without compromising the narrower or wider horizons of other scales. As a result, development fees and costs, as well as other socio-economic interests, may be correctly weighted and adjusted to local needs.

Consequently, it is important to discuss the true potential of exploring interconnected schemes of different scales. Therefore, one should recommend that future studies in this area of approach to sustainable development should be conducted in order to better understand the problem and likewise optimise and adjust system schemes to local needs and different scales of approach.

These studies would help practitioners to fully understand the benefits of interconnecting sustainable development bottom-up and top-down policies. In order to properly envision the future of sustainable communities, practitioners will have to understand the environmental, social and economic consequences of measures applied through a set of interconnected sustainable lines criteria that can be applied throughout the set of scales that constitute present and future urban environments.

Assessing the link between global structures and individual buildings is not the only fundamental interlink. Other links are the relationship between structures, and their use in common situations, the global performance dependent upon its way of use. Also, the deviation of usual performance under natural risk and other questions must be researched at different scales. Other areas of research are the process of weighting, ratings and certifications, and how spatial upper and lower scales could be integrated, namely with an increased use of the LCA approach.

17.6 Conclusion

During the past decade, sustainability has emerged as a dominant topic of interest among building designers and urban scholars but academics and urban planners have yet to make substantial inroads into the marketplace, which has almost fully accepted the superiority of these forms of development (Krause and Bitter 2012).

Since the early 1990s, modern societies have witnessed the widespread use of environmental performance assessment systems across the globe, at the local and national levels. The use of building, neighbourhood and urban sustainability assessment tools have become widespread since the turn of the twenty-first century and many communities, mainly in the developed world, are utilising these tools to measure their success in achieving sustainable development goals (Sharifi and Murayama 2013).

One of these systems is the LiderA system – Portuguese acronym for Lead for the environment in search of sustainability in built environments. LiderA is a sustainable evaluation system that can be used to search for sustainability in plans or projects and be applied to urban environments or buildings, allowing them to be certified or recognised by the system's brand, according to different final purposes.

LiderA is based on the concept of re-positioning the environment in urban environments, enterprises and buildings, according to a sustainable perspective, and is assumed to be a leading system in the search for sustainability. LiderA has had three different versions: the first was published in 2005, the second in 2010 and the third has been made available since 2018.

The built environment assessment system of LiderA is organized in six key principles that are subdivided into areas. Each area comprise criteria for the assessment of sustainable lines that allow the support of the search for sustainable buildings and urban zones.

The key principles suggested for this search for sustainability are as follows:

1. Enhancement of the local land dynamics and promotion of a proper integration;
2. Promotion of the efficient use of resources;
3. Reduction of the impacts of environmental loads (both in amount and toxicity);
4. Focussing on the services provided by the built environment and its sustainability search including resilience;
5. Promotion of sustainable socioeconomic aspects;
6. Ensuring the best use of sustainable built environments, through environmental management and innovation.

In the LiderA (as in the other schemes) the 6 main principles are subdivided into 20 areas and 40 sustainable line criteria that are used in the process of search for sustainability and to assure the assessment and certification.

The use of LiderA by municipalities, regions has allowed the creation of a common vision between different municipal departments and stakeholders, contributing to create a dynamic search for sustainability.

Major challenges identified using the assessment of LiderA system orientation for Africa to achieve an environment sustainability in built environment are as follows:

- To assure that sustainability approaches are applied not only at the building level but also in the urban zone, in order to assure promotion of bioclimatic solutions and common renewable energy systems;
- To assure a good water cycle, from supply to local treatment and reuse linking building and urban zones;
- To promote the use of local materials (without achieve a critical level of the stocks) and solutions that interpret local techniques that could be low tech or not, but have a good balance in life cycle costs;
- Make a contribution to the socio-economic dynamics;
- Ensure that different locals and regions must adjust solutions to climatic and local conditions.

The applications presented show that this system could be a base for supporting the search for sustainability, since it creates an integrated view of that search and allows the identification of different kinds of solutions to be applied in the short term and in the long term.

The benefits of these applications range from creating a vision that potentially contributes to involving stakeholders to creating value. Nevertheless, this approach has to be improved and deeper research is needed, since a full set of challenges namely the generation of a larger consensus and involvement have been identified, as a changing paradigm.

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Appendix 1: Climatic Contexts

Fig. A.1 Africa global site and position map

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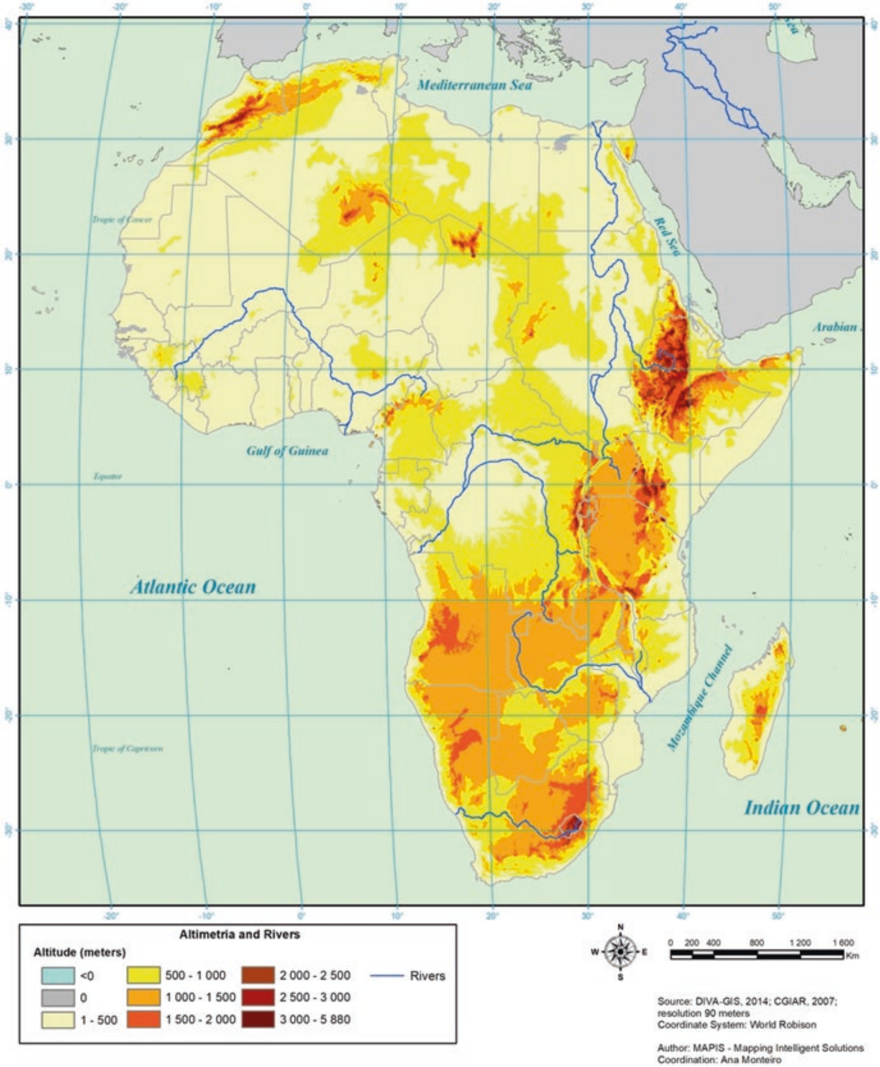

Fig. A.2 Africa morphology and hydrography

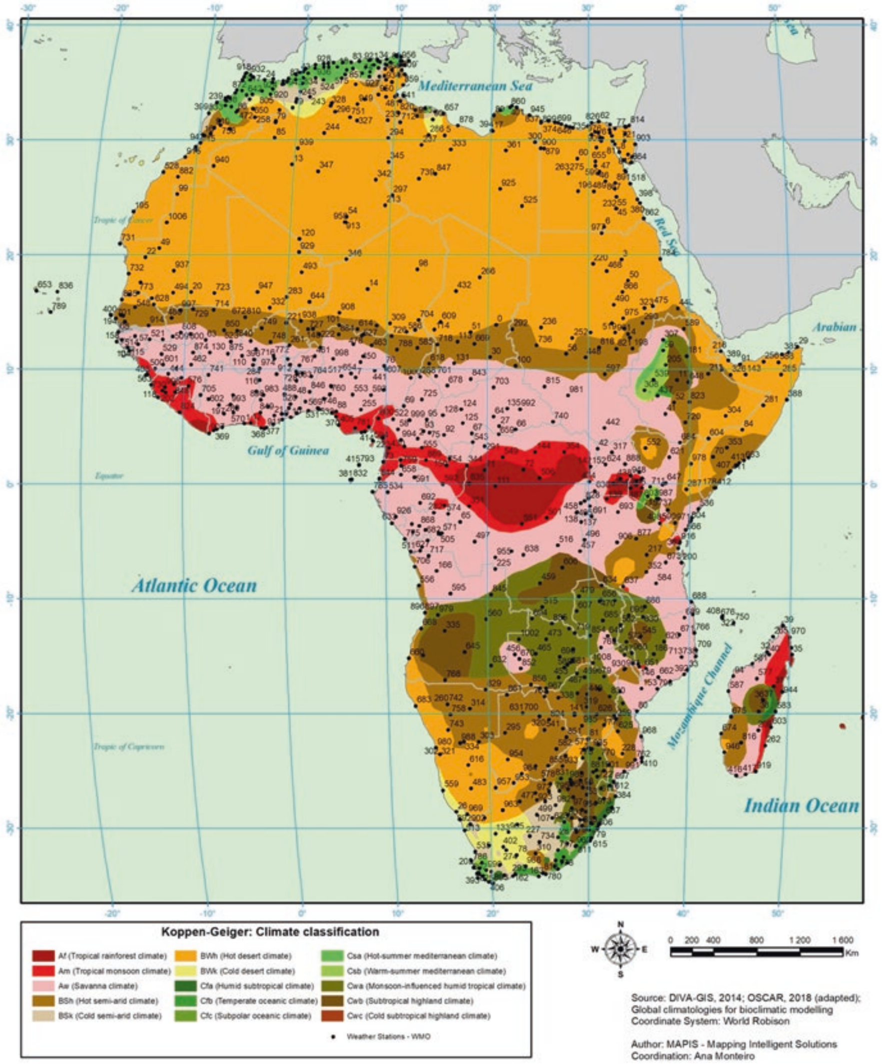

Fig. A.3 Africa World Meteorological Office (WMO) climatological stations

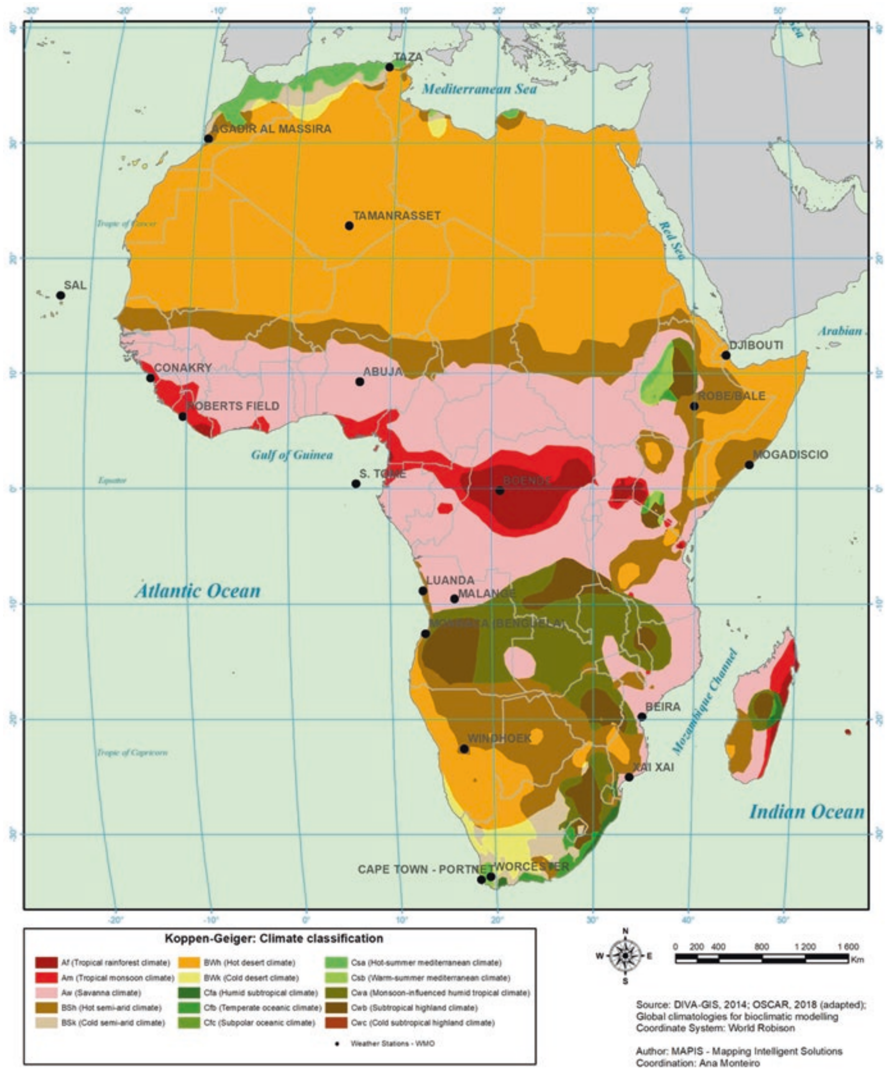

Fig. A.4 Examples of WMO climatological stations in the main climate subtypes

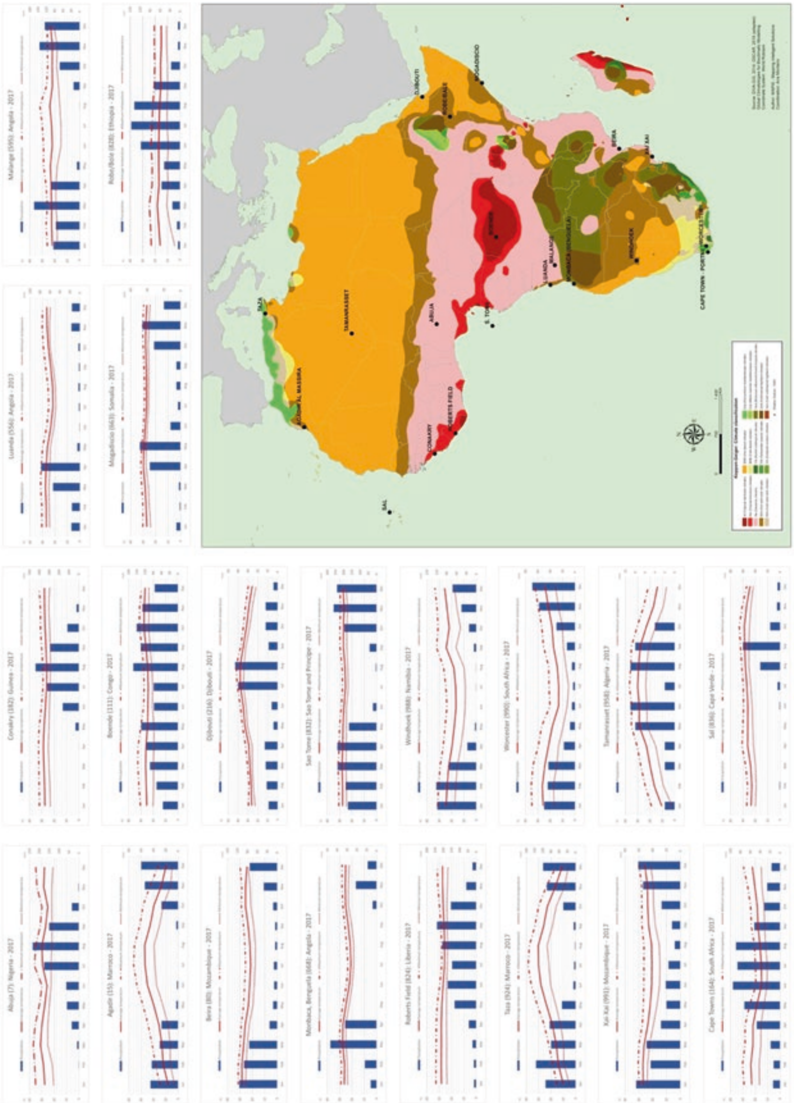

Fig. A.5 Temperature and rainfall diagrams of some WMO climatological stations with some of the main African climate subtypes

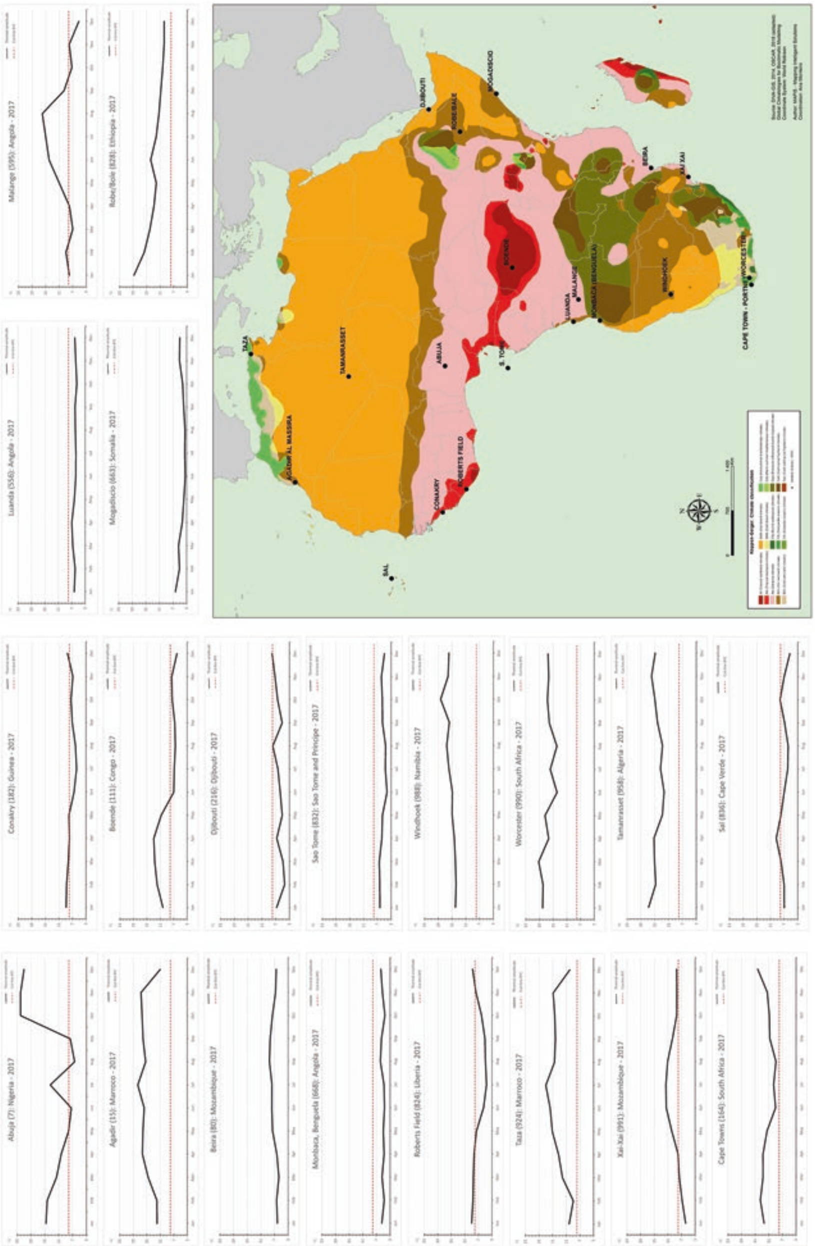

Fig. A.6 Average daily temperature amplitude of some WMO climatological stations with some of the main African climate subtypes

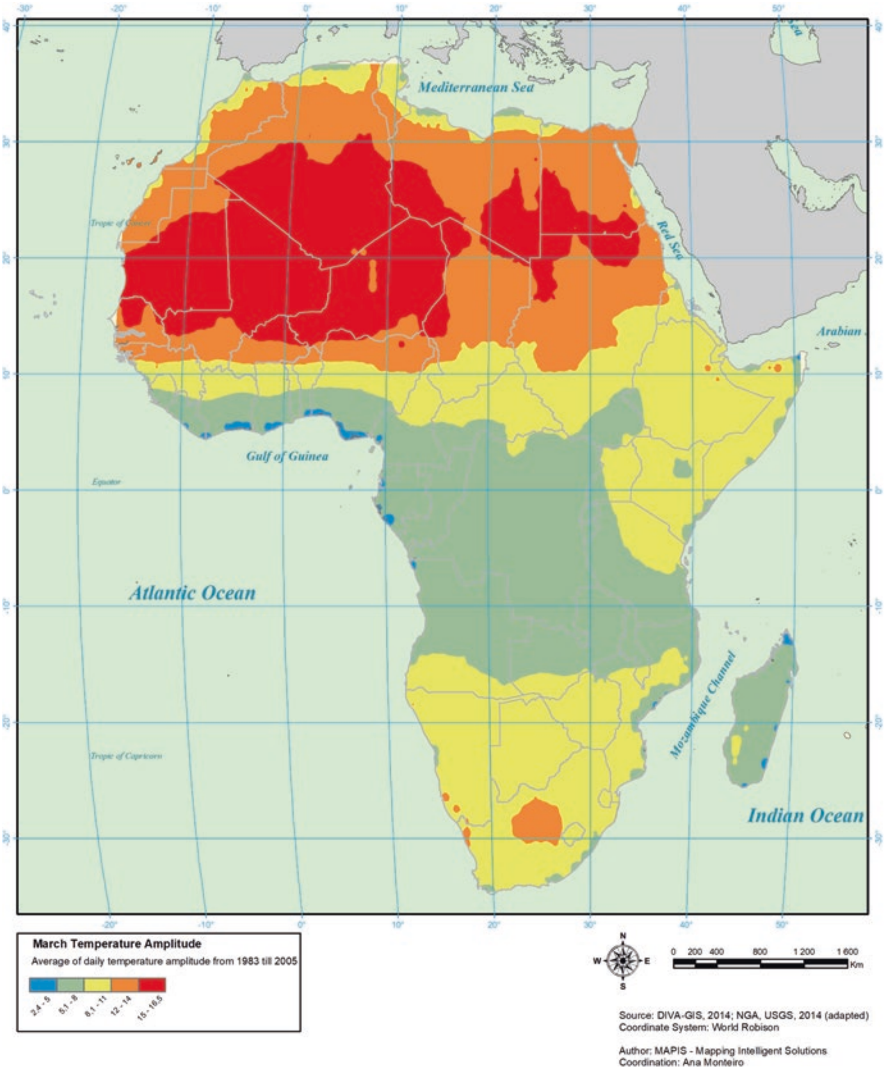

Fig. A.7 Africa March average daily temperature amplitudes (1983–2005)

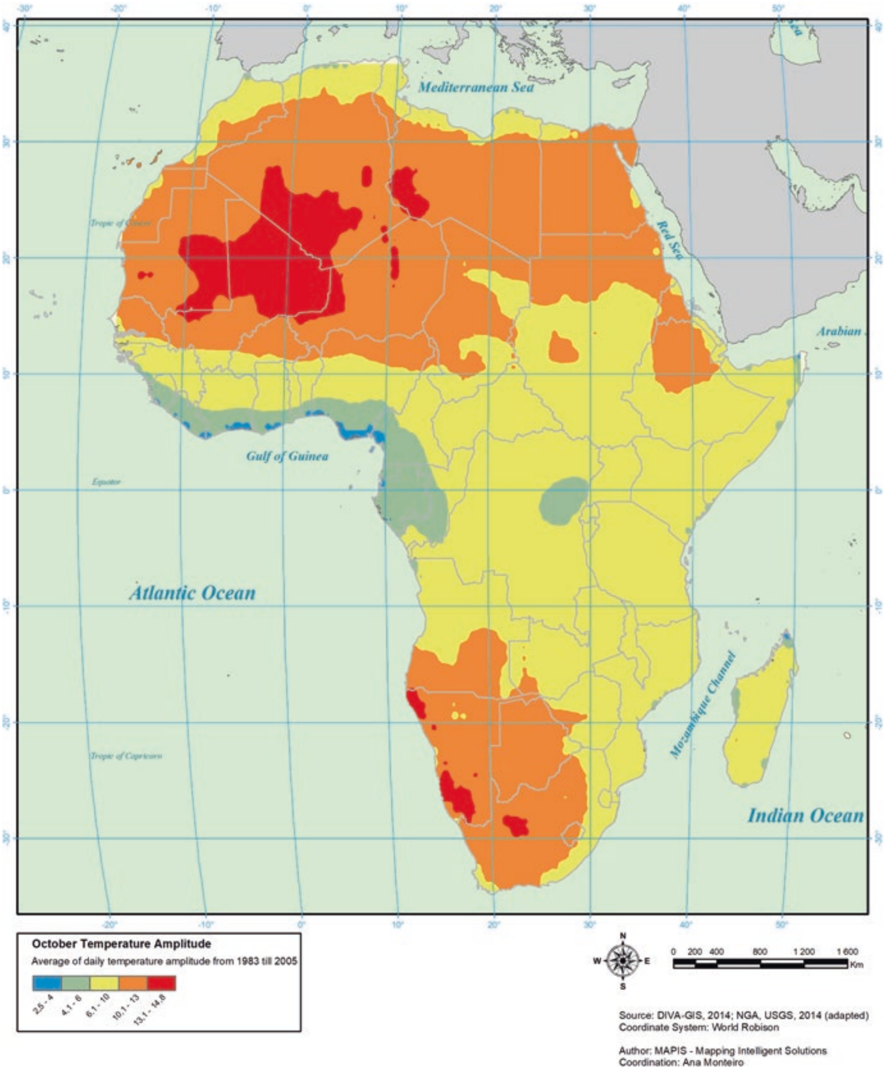

Fig. A.8 Africa October average daily temperature amplitudes (1983–2005)

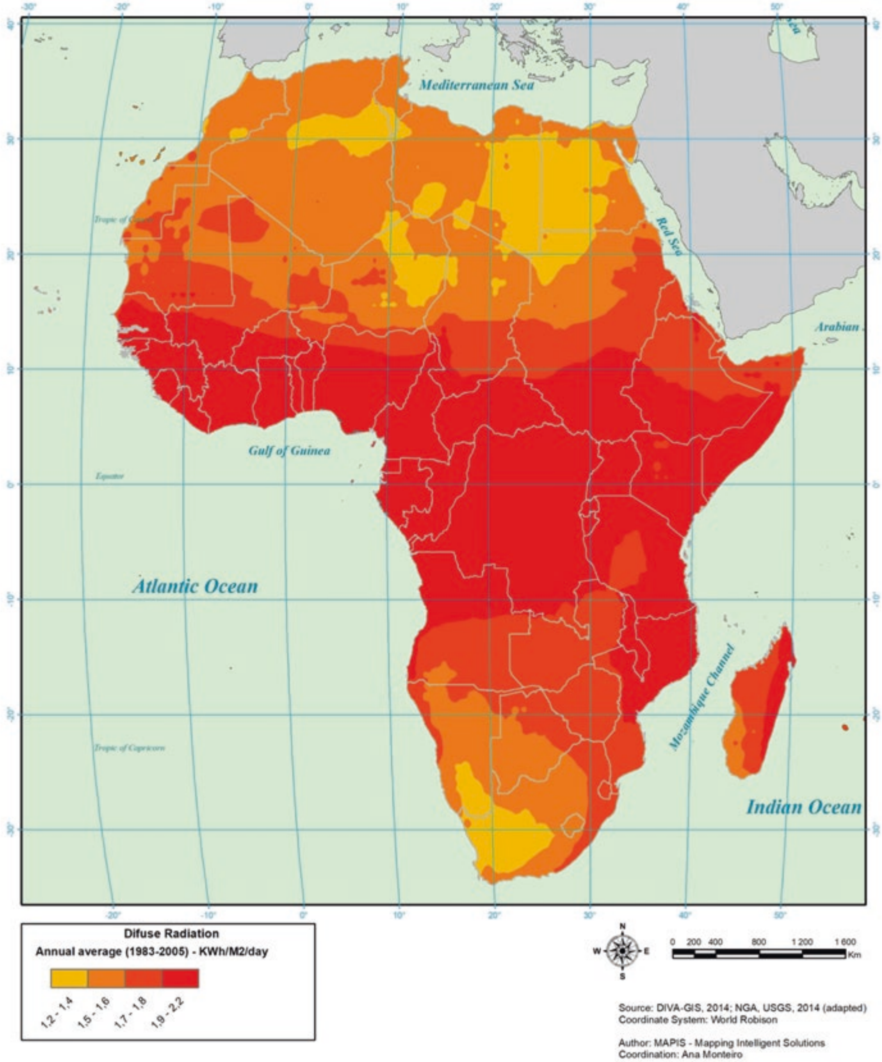

Fig. A.9 Africa annual average diffuse radiation (1983–2005)

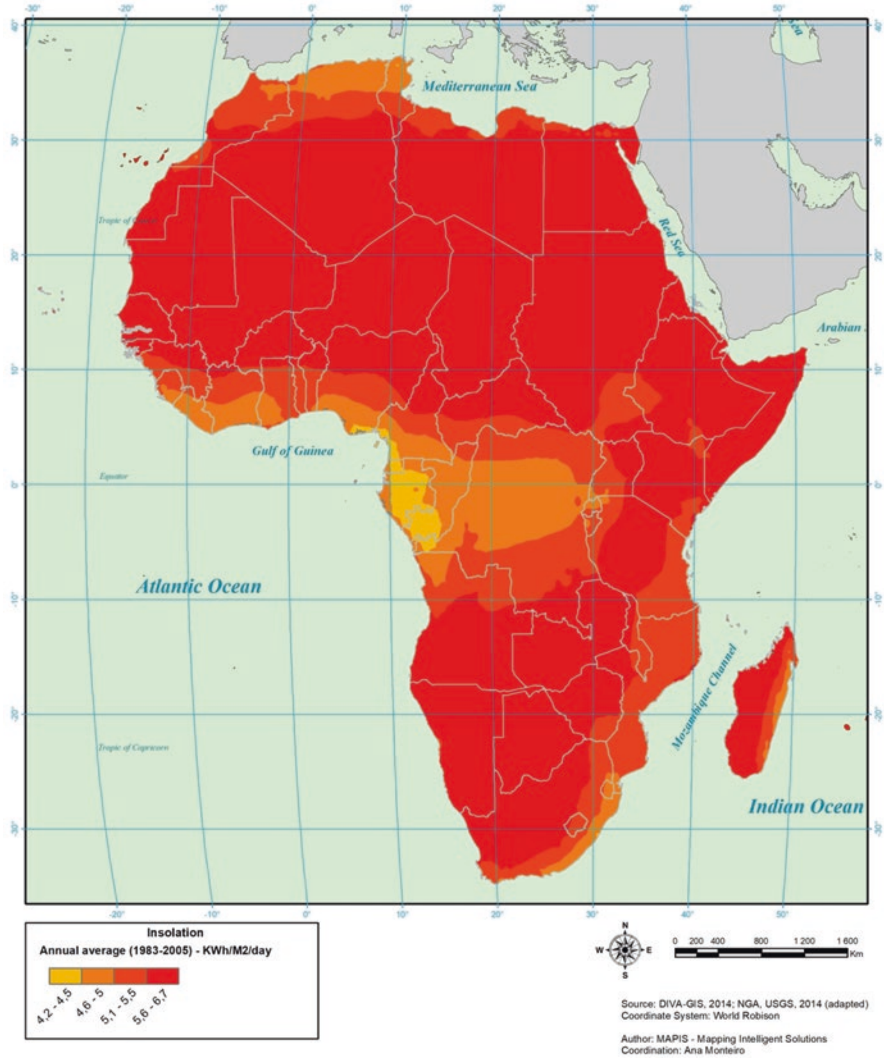

Fig. A.10 Africa annual average insolation (1983–2005)

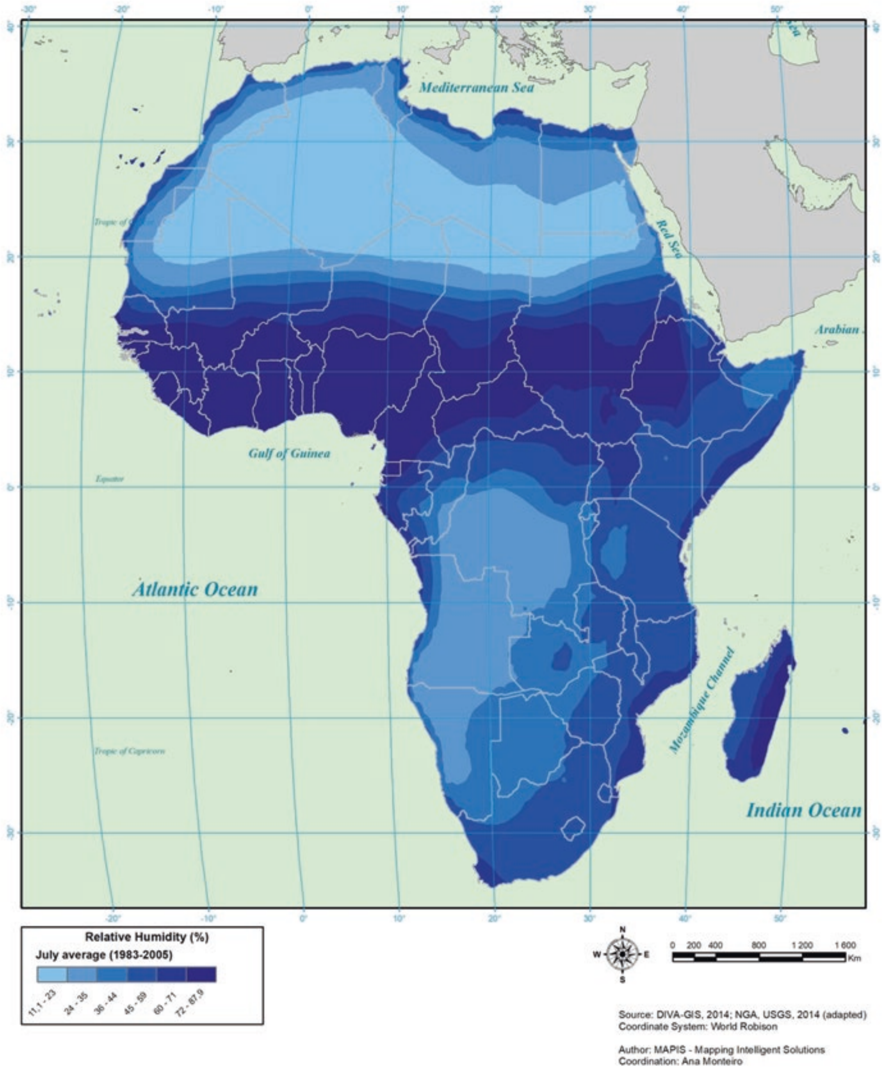

Fig. A.11 Africa July average relative humidity (1983–2005)

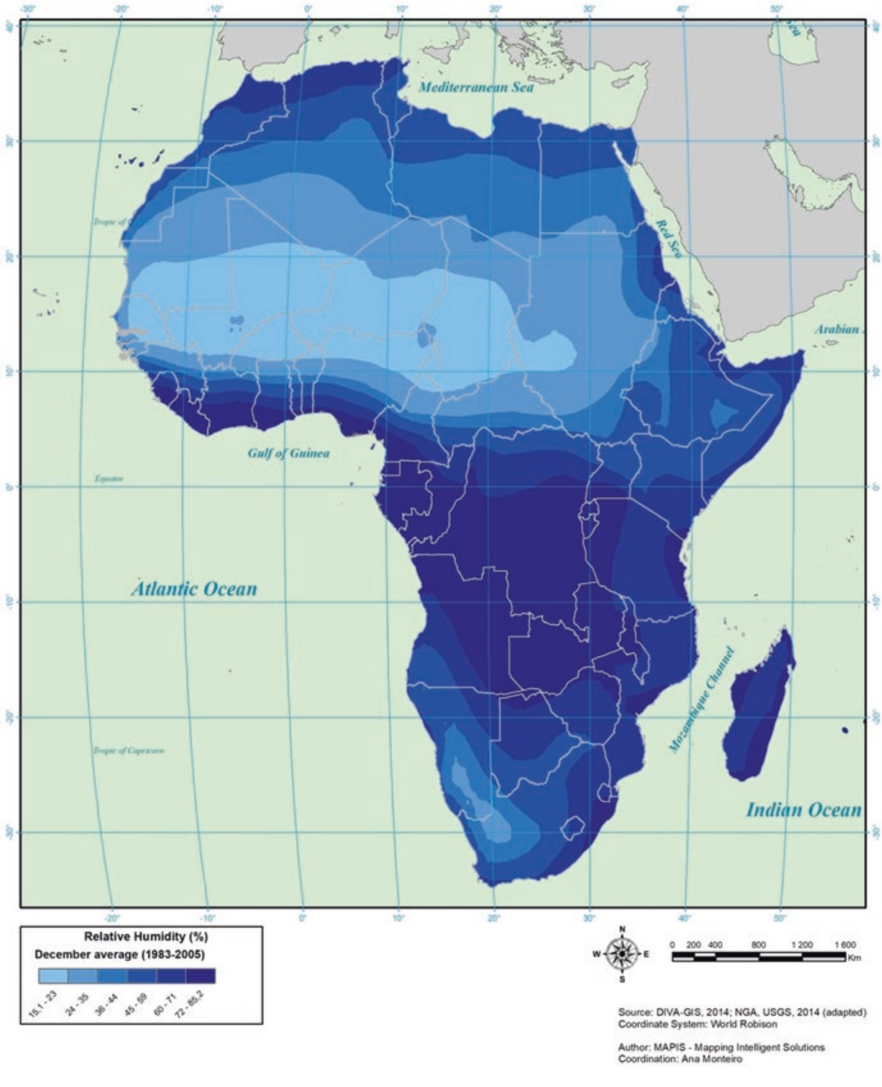

Fig. A.12 Africa December average relative humidity (1983–2005)

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