THE ROLE OF EMERGENT AND DEVELOPING COUNTRIES
AMIDST THE ECOLOGICAL CRISIS

# HOUSING IN BENIN – PASSIVE DESIGN STRATEGIES

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# CONTENT

# THE ROLE OF EMERGENT AND DEVELOPING COUNTRIES AMIDST THE ECOLOGICAL CRISIS

## HOUSING IN BENIN – PASSIVE DESIGN STRATEGIES

**Note:** key terms in Italic in the glossary

Keywords:

Passive design, Bioclimatic architecture, Tropical climate, Local resources, Autonomous housing, Social housing

### *Abstract*

This paper has been written as a thematic research paper to be used as a basis for my architecture thesis project. It explores the ***passive design strategies*** appropriate for the Beninese climate and contextual conditions. This research has been led to create an autonomous neighbourhood.
The analysis is conducted in the growing urban context of Cotonou in Benin, West Africa. First, the analysis of the local climate and natural and contextual conditions allows an understanding of the country's strengths and weaknesses. The tropical climate brings challenges and advantages that make self-sufficient living a favourable option. Then the current housing situation in the cities is described to get a better understanding of the urban and architectural context.
With respect to programmatic needs and a chosen comfort model, a set of appropriate passive design strategies were determined at different scales to maximise the natural performance of the buildings and minimise the need for mechanical solutions. This contributes to supporting the global sustainability goals (United Nations, n.d.) and could provide a sustainable alternative for housing in Benin. For the residents, an increase in the quality of life is achieved. The costs for energy and water are reduced, and the security of supply is increased.
This set of design strategies was tailored to the specificities of the Beninese context and went beyond organisational strategies. To conclude this thematic research, a toolkit of strategies was determined to serve as the basis for my graduation design project.

# INTRODUCTION

*"We do not inherit the Earth from our parents, we borrow it from our children." Antoine de Saint-Exupéry*
*African proverb quoted in "Terre des Hommes."*
*(de Saint-Exupery, 1973)*

## Priorities for housing architecture and Urban development in Africa

Developing and emerging countries possess a unique role in housing in the 21st century. They should be the focus of discussion because they will experience the highest growth rates in the coming decades and are often at the beginning or in the process of massive urbanisation. Almost all developing and emerging countries are geographically located in tropical climates (Central America, Caribbean, Southeast Asia, Sub-Saharan Africa, the Indian sub-continent) (see figure 1).
In these countries alone, the population will double by 2030 (Institut de la Francophonie pour le Développement Durable, 2015). They should be high on the list of priorities for achieving global sustainability goals.
For Africa, UN-Habitat predicts that population and urbanisation rates will increase by more than 50% by 2040. This also means that the number of urban dwellings will triple from 400 million to 1.26 billion by 2050 (UN Habitat, 2014). In sub-Saharan Africa, 80% of those buildings are not yet built, compared to 30% in Europe. Therefore, greater attention should be paid to how construction is done there.

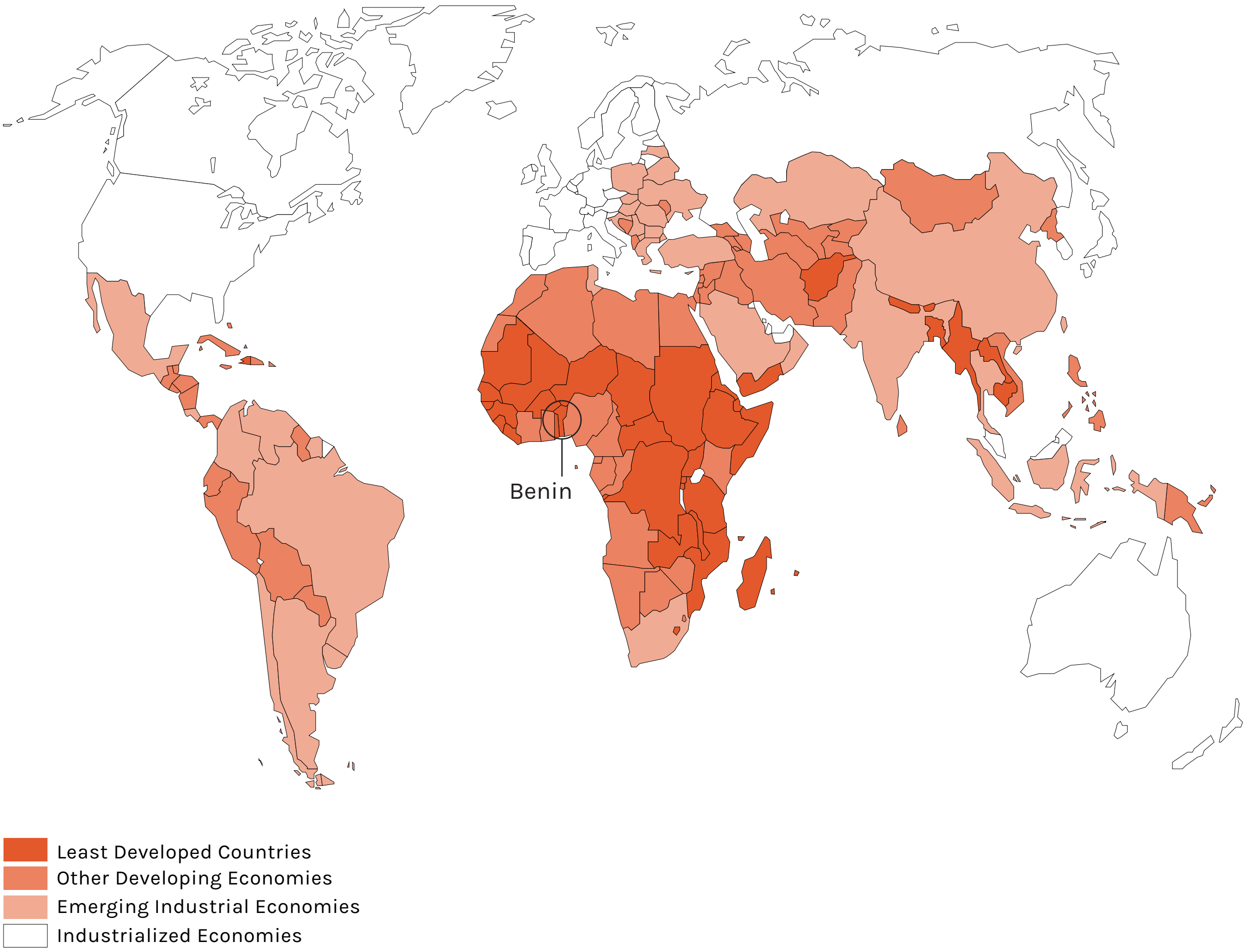



Figure 1. *Wold map of countries by stage of industrialization*

## Relevance - Why Passive Design?

In Benin, cities are becoming more and more the focal point of the population. From 1955 to 2020, the population in urban areas has risen from 7% to 48% (Worldometer,2021) (see figure 3,4). The increasing urbanisation directly follows the rising demand for land and real estate considerations that occurs due to the economic importance of Cotonou. Land (often privately owned) is parcelled out and then sold to developers. Often, complete urban development only takes place after the buildings have been erected. Land use plans and qualified development plans with overriding objectives do not exist. Against this backdrop and the increasing demand, the government of Benin has decided to build 20,000 new homes across the country in the next five years (Bénin Révélé, 2016). These new homes are planned to be located in the periphery of existing cities to allow their extension and favour the creation of new neighbourhoods and new cities.

Recent studies show that with the continuously rising temperatures due to climate change and already elevated outdoor temperatures, the current housing situation in Sub-Saharan regions is battling elevated indoor temperatures (Niang et al., n.d.). High temperatures in buildings located in hot and humid climates strongly affect the thermal comfort and, generally speaking, the well-being of people. With the rapid growth of West African cities and the shortage of currently available housing stock, builders and developers focus on quantity rather than quality (Choplin, 2020).
Many housing projects that are being built do not consider the specific climate conditions in Benin. Too often follow the occidental low-income housing model (Plattenbau, HLM) and battle temperature variations with mechanical cooling systems and standard universal amenities.
The needed urban infrastructure to supply these new dwellings with the necessary services is expansive and takes time to build. The existing networks are overloaded, and water and electricity supply interruptions are commonplace, even in the cities. Proper waste disposal and garbage collection are mainly non-existent, and landfills are the final waste destination.

As Professor Wolfgang Lauber says in his dissertation about "Climate-friendly architecture in the African tropics" (Lauber, 2003):

*"The architects of the tropics must develop construction methods against heat, intense solar radiation, high humidity and hurricane-like rainfall. Which offer the users comfortable rooms without the use of air-conditioning systems, which are absurd from an*

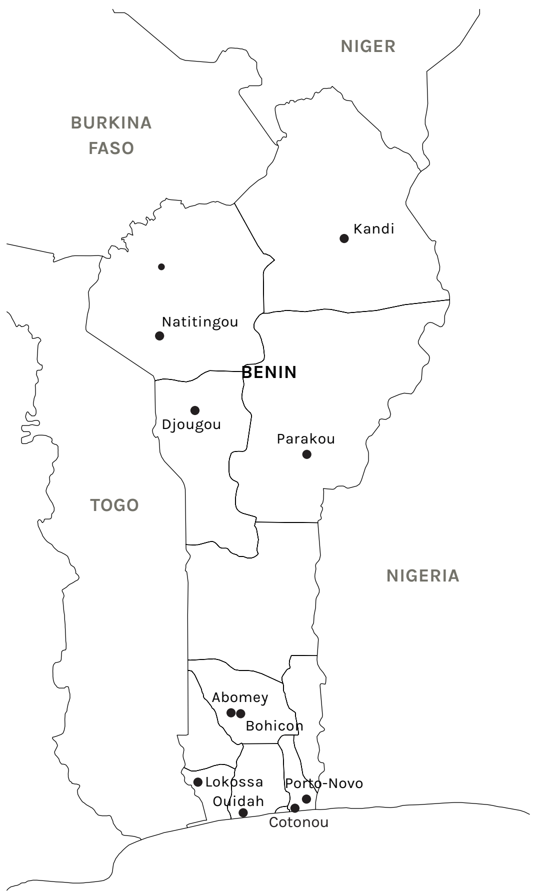



Figure 2. Map of Benin

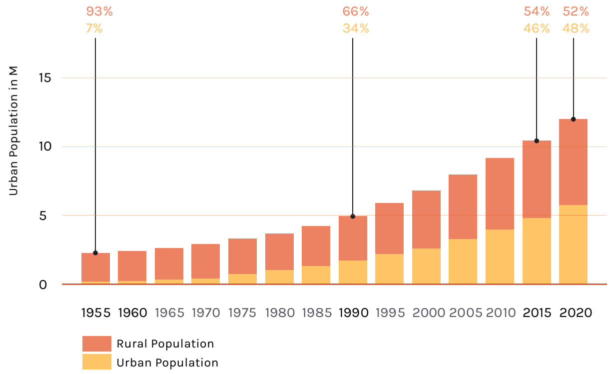



Figure 3. *Benin rural vs urban population*

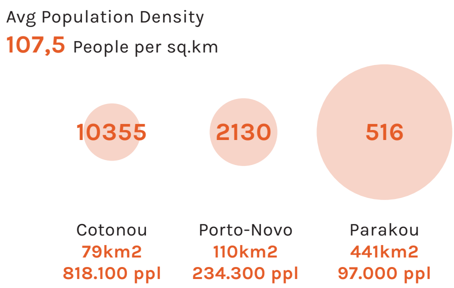



Figure 4. *Population density per city*

*ecological point of view because they consume four times the energy of heating a room, which today is still mostly produced with primary energies." (translated from german)*

Prof. Lauber ultimately fails to provide evidence for the claim that cooling consumes approximately four times more energy than heating a room in his dissertation.
Nevertheless, we can say that a large number of factors must be taken into account when assessing the energy balance and the demand. Some of these variables that need to be determined are: How is the energy for tempering the rooms obtained? Which cooling system with which efficiency is used? What are the building's physical properties? How large is the proportion of open areas? How are the buildings oriented? In which climatic region is the building located? The multitude of factors means that there is no generally applicable rule of thumb for the energy balance of a building cooling system. In any case, however, priority should be given to avoiding mechanical heating or cooling as far as possible. Today the aim of any planning must be to reduce the primary energy consumption of a building. In Central Europe, this is initially the heating of buildings and now increasingly also cooling. In the Cotonou area, with an annual average temperature of 27,5°C (Climate Consultant,2021), this is exclusively mechanical cooling. This should be avoided as far as possible in sustainable building design.

Therefore, "Sustainability" in hot and humid climates is not only a way to have a positive impact on the environment, but instead, it is a fundamental mean that allows to lower energy use, lower long-term costs of use while improving the thermal comfort and quality of air (de Schiller and Evans, 1998). To be sustainable in Benin means to design the built environment with nature. Therefore the implementation of passive design strategies at various scales will also increase the spaces attractiveness, comfort levels and allow for more urban activities. Additionally, it forms the first milestone and fundamental base necessary to envision a future of neighbourhoods that live in self-sufficiency.

## Research Question

The following research aims at determining a set of passive design strategies for housing projects in Benin that will enable a more comfortable and sustainable indoor climate. Furthermore, the determined set will be used as a fundamental design guideline to develop autonomous housing in Benin. To be able to reach this goal, the main research question needs to be answered:

**Which passive design strategies are suitable for regulating the indoor climate in housing projects in Benin?**

To be able to arrive at an answer, several sub-questions needs to be addressed:

1. What are the climate characteristics in the coastal region of Benin?
2. What is the current housing situation?
3. Which passive design strategies can be used to cool neighborhoods and houses in Benin?

## Methodology

The methodology of this research is structured through the aforementioned sub-questions that each represents one chapter of the paper. Therefore, each chapter will directly answer a sub-question, and together they will help answer the main research question. For each sub-question, an appropriate research method was previously chosen. Generally speaking, the methodology is focused on the relationship between climate, person and building. The climate variables are defined through the help of meteorological data sets. Then the current situation in housing in our chosen context is documented through means of field research, photo documentation and interviews. The last section of the research is structured as a guide that determines appropriate design strategies at different scales for the specific Beninese climate, following the bundle method of M. DeKay and G.Z. Brown explained in their architectural design strategy guide (DeKay and Brown, 2014).

Figure 5. *Beach along the coast of Cotonou*

# RESULTS

## 1.1 Climate Classification

The climatic zones on Earth are determined by the intensity of solar radiation (illumination climatic zones). This decreases from the equator to the poles due to the changed angle of incidence of the sun and the associated increasing strength of the atmosphere to be penetrated. However, to evaluate the climate at a location, other factors (e.g. temperature, precipitation, humidity, vegetation) must be considered. This results in a more accurate subdivision of climatic zones based on actual climatic conditions (Diercke Weltatlas, 2015).

For the processing, the ***Köppen climate classification system*** was used as it considers these additional factors. According to this classification, Benin is located in the tropical climate zone, meaning that the monthly average temperature is above 18 degrees Celsius, and there is considerable rainfall throughout the year. Within the tropical climate, the Köppen climate classification distinguishes the seasonal precipitation patterns. It is differentiated according to three climate types: the tropical rainforest (Af), the tropical monsoon (Am), and the tropical savannah or tropical wet and dry climate (Aw). Benin belongs to the last subgroup (see figure 6). The most important characteristics are that the driest month has less than 60 mm of precipitation, and that a coefficient of < 100 - (total annual precipitation mm/25) is not exceeded, and a total of less than 2500 mm of precipitation occurs per year (John Arnfield, 2020).
In the case of Benin, the driest month of the year is in January. During this month, precipitation is only 2,5mm, referring to weather data from the World Bank. In comparison, the Netherlands (temperate climate), for example, receives an average of 38 mm of precipitation in the driest month (World Bank, 2020). Looking at the average annual precipitation of Benin (1245 mm) and comparing it with the Netherlands (847 mm), it can be stated that it rains considerably more in Benin (approx. 47%) than in the Netherlands. At the same time, Benin has considerably fewer rainy days per year (see Figure 12), and the rainfall is correspondingly more abundant.

If we look more closely at the African continent, we find that West Africa is further divided (in an east-west direction) into five bioclimatic "belts." These further characterise the climate and vegetation in these areas (CILSS, 2016). Benin is divided into two parts in the north-south direction according to this classification. The northern part of the country (starting about 650 km from the coast) lies in the zone known as the ***"Sudanese belt"***, while the southern part lies in the zone known as the ***"Guinean belt"*** (see Figure 7, 17-18). Indeed, if we look at the climatic conditions and flora in the north and south of the country, we can see remarkable differences as described in *Landscape of West Africa* - A Window on a Changing World by CILSS (CILSS,2016). For this thematic research work, the software ***Climate Consultant*** was used and, more specifically, the meteorological data of the weather station in Cotonou (the largest city of Benin) (Climatewebsite, 2020). It is located in the Guinea belt and is the weather station closest to my chosen project site at a distance of about 20 km.

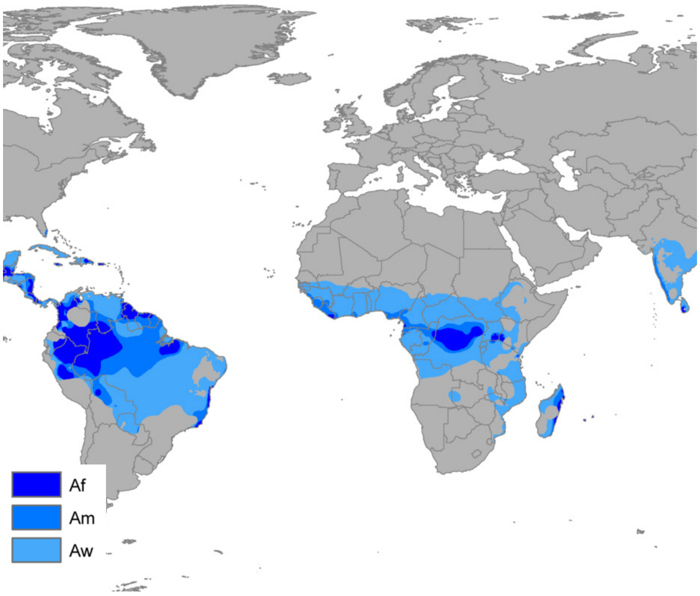



Figure 6. *Köppen-Geiger climate classification group A*

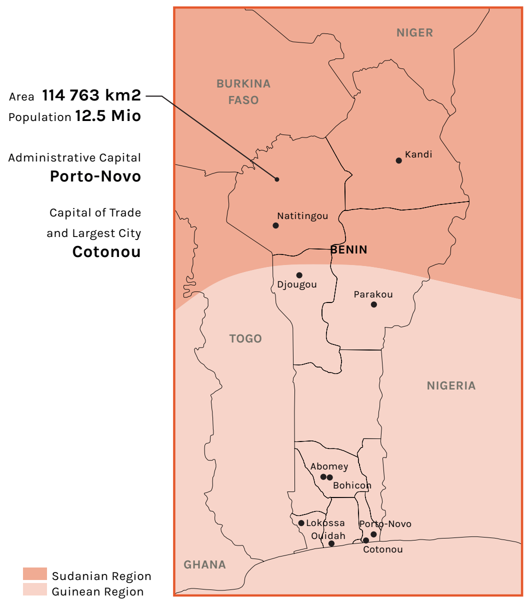



Figure 7. *Map of Benin with climate regions*

## 1.2 Climate Conditions Cotonou

### Geography

Cotonou is located in a flat, sandy coastal region, and the city is bounded by lagoons and stretches between the coast of the Gulf of Guinea and Lake Nokoué. With over 800,000 inhabitants, Cotonou is the largest city and the economic centre of Benin.

### Seasons

In Cotonou, the year can be divided into two types of seasons (dry and rainy). There are two dry seasons and two rainy seasons. In Benin they can vary in length throughout the country and are directly influenced by the ***Intertropical Convergence Zone*** (see figure 15). Therefore, seasonal rainfall can vary significantly from year to year (World Bank, 2020). However, it can be roughly said that the primary rainy season lasts from March to July and the shorter one from September to November. Between December and February is the main dry season (see figure 8).

### Temperature

The average temperature is high (27.5 degrees Celsius). It should be noted that the temperature fluctuations here are small and largely more stable than in the centre or north of the country. The maximum temperatures vary between 28 and 32 degrees and the minimum temperatures between 23 and 26 degrees. At night, temperatures hardly change from daytime. Ground and water temperatures are also comparatively high (see Figure 9, 10).

### Solar radiation

On average, Cotonou has 8 hours of sunshine a day, and during the dry season, this average goes up to 9. During the rainy season, the lowest average can be seen during the months of July and August, where there are only 6 hours of sunshine a day (Climate-data.org, 2019), probably due to very high cloud coverage. This hypothesis can be confirmed by the data set from Climate Consultant that shows that the cloud coverage median is above 70% during the rainiest month. In contrast, in the driest month of the year (January) the percentage is only 35%.
The average daily global horizontal radiation is 5,5 Kwh/sq.m, referring to the CC data set. In comparison, in Amsterdam, it is only 2,7 Kwh/sq.m. Therefore, the average daily global

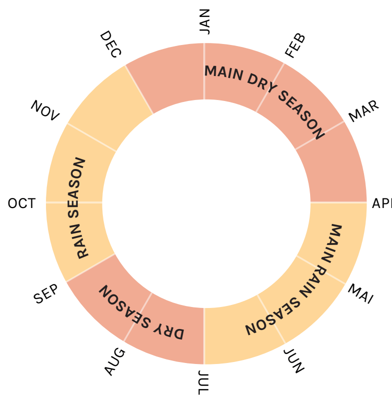



Figure 8. *Seasons in Cotonou*

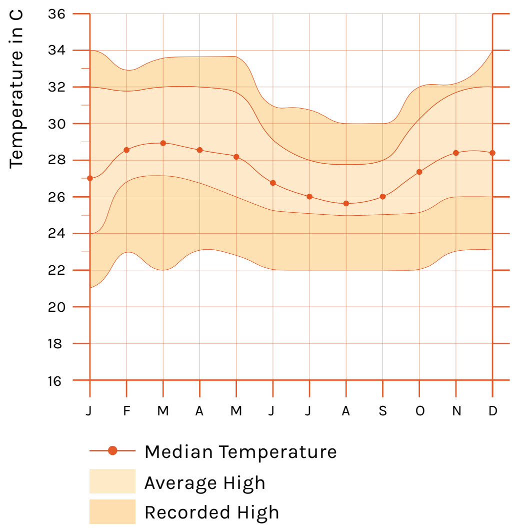



Figure 9. *Average temperature Cotonou*

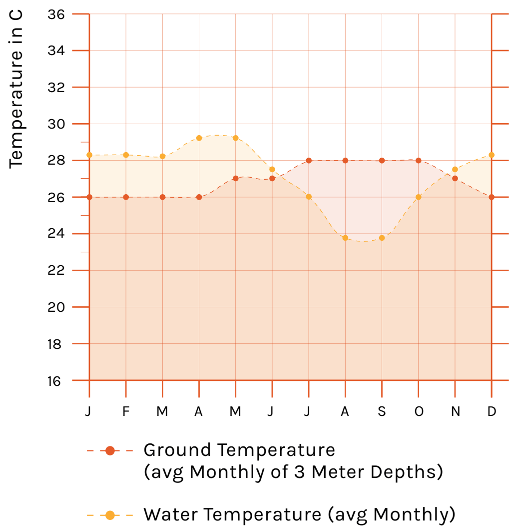



Figure 10. *Average ground and water temperature Cotonou*

horizontal radiation in Cotonou is twice as high as in Amsterdam.

Let us now look at the photovoltaic power potential map published by the World Bank Group, referring to the data from the global solar atlas (Solargis, 2019). Cotonou's solar intensity allows for an average of 3.9-4.1 kWh/kWp daily and 1400-1500 kWh/kWp per year. The more northern within the country we go, the higher this number gets and can surpass the 1600 kWh/kWp per year (see figure 11).

## Humidity

Due to its high average temperature and geographical location between coast and lake, Cotonou has a high average annual humidity. The monthly average is 84% and does not drop below 75% (see figure 14). These averages can even be exceeded in some coastal regions, especially wetlands. The average annual precipitation is 1245 mm. The month with the most precipitation is June, with over 350mm (see figure 12). The months of January and December, on the other hand, have an average of only three days with precipitation together.

## Wind direction

The wind in Cotonou comes from two opposite directions. The main wind comes from the ocean, from the southwest all year round. During the dry season, especially in December and January, the wind comes from the Sahara (northeast). This wind is called Harmattan and carries large amounts of reddish dust covering the land like a veil. In addition to these primary wind sources, we can see a much smaller proportion of winds that come from other directions and are relatively evenly distributed (see Figure 13).

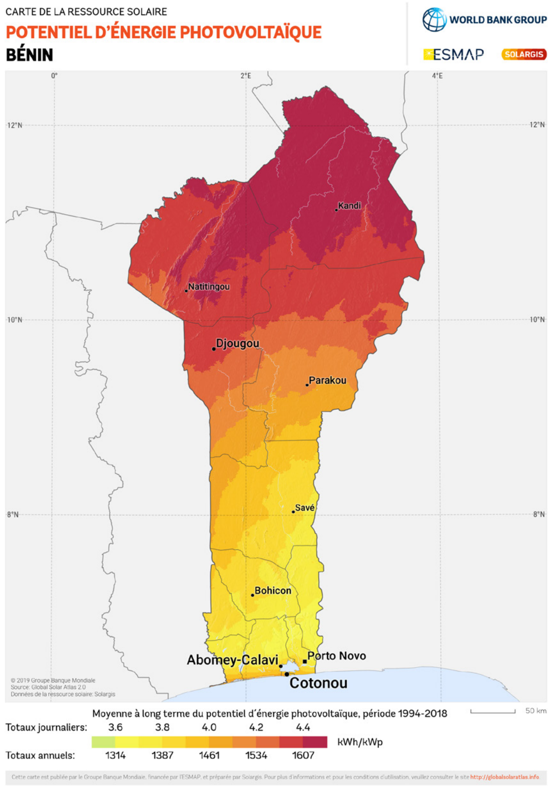



Figure 11. *Photovoltaic energy potential*

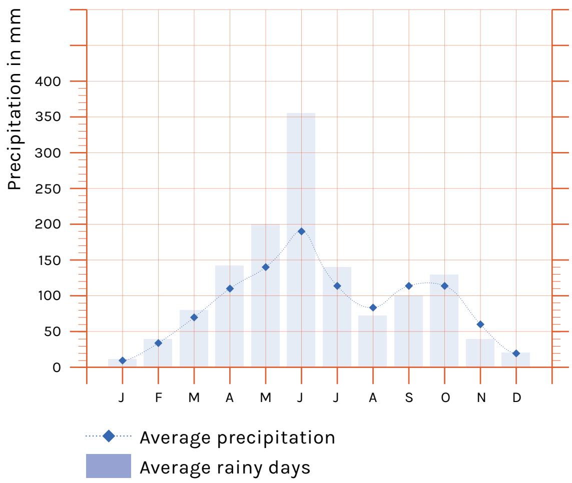



Figure 12. *Precipitation Cotonou*

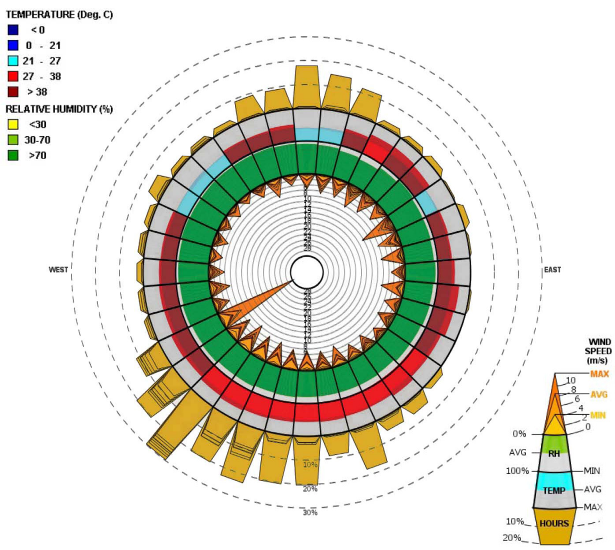



Figure 13. *Wind rose Cotonou*

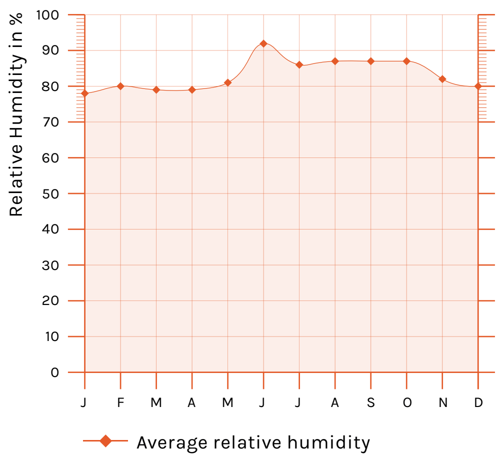



Figure 14. *Humidity Cotonou*

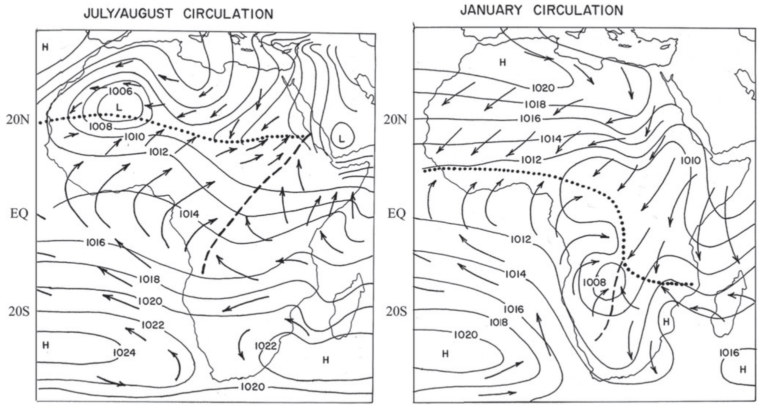



Figure 15. *International convergence zone*

## 1.3 Thermal Comfort

The aim of all architectural planning should be to create the most possible comfort for the user. Therefore over the years, many comfort models have been developed for a general western population. The ASHRAE model is one of the most known and used models currently, but it is not adapted to the climate conditions in tropical climates.
The ASHRAE Standard 55 Adaptive Comfort Model is an exception here. This model explicitly describes the thermal comfort requirements for naturally ventilated rooms and buildings. The differentiation makes sense because users of naturally ventilated rooms have different expectations of the indoor climate than users of air-conditioned rooms. The standard is limited to users with an activity level of 1.0 to 1.3 met (relaxed sitting, sedentary activity, light activity). The models' variables were determined through 21,000 measurement series that were evaluated worldwide in order to have an accurate representation of comfort in naturally ventilated environments (Dente and Dietrich, n.d.). It is therefore suitable for describing activities in the domestic environment.

For this graduation project and research, I am opting to design a residential neighbourhood by minimising the need for mechanical infrastructure. The starting point is the elimination of HVAC systems. The biggest challenges in the Beninese climatic conditions are the constant heat during day and night, and the high percentage of humidity, air motion will be of crucial importance when designing residential neighbourhoods there. Instead of an energy-intensive and user cost-intensive air-conditioning technology, we will be proposing a set of passive design strategies that will maximise the building performance by minimising its heat gain.

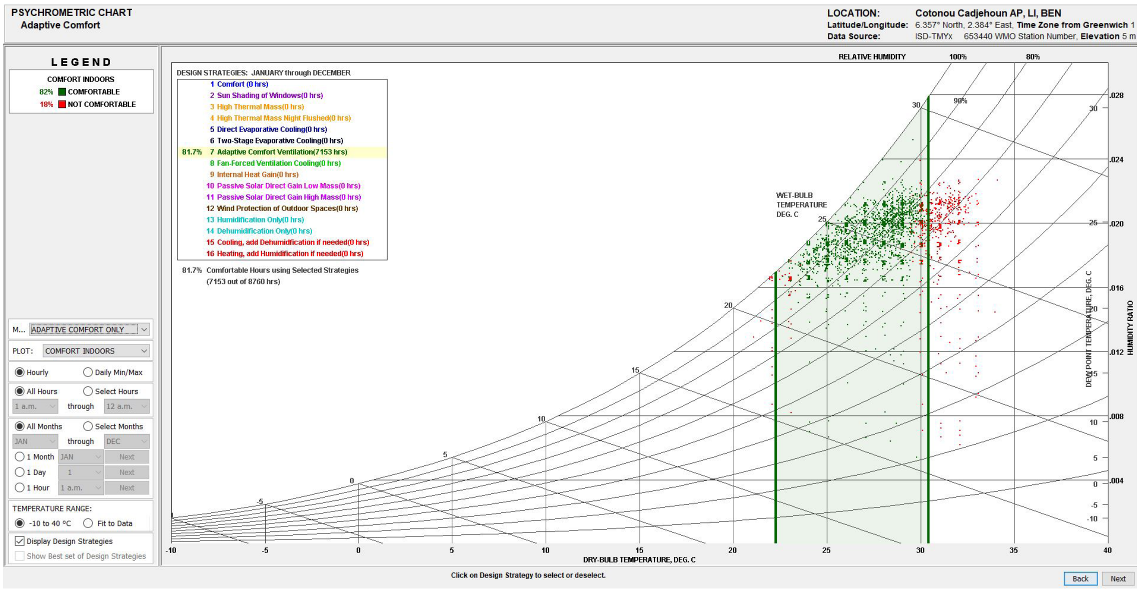



Figure 16. *Psychrometric chart following the Adaptive Comfort Model*

Figure 17a. *Northern Benin*

Figure 18a. *Southern Benin*

Figure 17b. *Northern Benin*

Figure 18b. *Southern Benin*

Figure 17c. *Northern Benin*

Figure 18c. *Southern Benin*

Figure 17d. *Northern Benin*

Figure 18d. *Southern Benin*

Figure 19. *Porto Novo, Ouémé forest*

## 2.1 The Beninese city is a concrete jungle

During an on-site interview (see Appendix Interview I, pp 38-41) the architect Jean-Paul Houndeffo founder of Atelier Houndeffo, said:

*" Au Benin, aujourdh'ui quand on parle de construction on parle de batiment en béton et c'est une réalité à laquelle il faut faire face. "*

*"In Benin, today, when we talk about construction, we talk about concrete buildings and this, is a reality that we have to face. " (see figure 21)*

Figure 20. *Concrete in Cotonou*

But why is this heat-storing material, Which is responsible for 8% of the global CO2 emissions during its production (Nature 597,2021), the number one construction material in a country with local materials with better thermal qualities? During the research and interviews, several aspects explaining why concrete has become the "new way of building" in Benin and why very little is done with local materials could be identified.

There is a significant stigma under the population and most professionals in the field. There is a common belief that building with concrete is more secure and more durable than the local alternatives. This is because the Beninese tend to think that everything that comes from the outside, meaning, for example, Europe is better in quality even though sometimes this is not the case. For geographer Armelle Choplin, who has studied the relationship between Africa and concrete, this material is no longer that of the colonists; it has become a local source of pride and a symbol of modernity (Choplin, 2020). On the other hand as Caroline Grellier says it in her dissertation about Endogenous design : L'habitat en materiaux locaux subit une stigmatization, celle de l'habitat du pauvre. ("The habitat in local materials undergoes a stigmatisation, that of "the habitat of the poor".) (Grellier, 2020)

In addition to the sentimental evaluation of concrete as a building material, there is also a technical view. The structural and qualitative standards of traditional building materials, bricks, concrete etc. are not regulated across the board. The required quality control that guarantees reliable building materials is lagging, especially in the private sector, mostly inexistent. The properties of building materials delivered to the construction site (e.g. masonry bricks) can vary significantly from delivery to delivery (Arowolo et al., 2019). This is even more extreme when looking at private construction sites. Not only is the technical know-how of the construction workers limited, but they mostly use low-tech equipment for the fabrication of earth bricks, for example. The quality of the resultant bricks varies in reference to the quality of the soil used and the strength of the person making it.
The client and project manager (Carre Hinoudo)

Sedjro Mensah, explained: "Since we did not only use professionals for the brick manufacturing process but integrated the community the bricks structural integrity could differ from brick to brick." (Virtual round table discussion, 2021).

Architects and civil engineers know this. Therefore, most buildings structures are over-dimensioned and constructed as reinforced concrete skeleton structures or entirely out of concrete (see figure 21). All building elements are made of concrete from the foundation to the roof, even though we often only talk about single to two-story construction (see figure 22).

One of Benin's current large scale construction sites with concrete is the so-called cite Ouedo (see Annex pp 44-45). A large-scale project which aim is to create 10000 new social houses, approximately 4000 buildings (primarily apartments and 3500 villas) (EIES, 2018). These buildings are currently in construction and are being built entirely out of prefabricated concrete panels (like the German Plattenbauten typical from East Germany, also called) or cast in place (in-situ) concrete in the case of the villas.

Figure 21. *Reinforced concrete skeleton*

Figure 22. *Reinforced full concrete*


Figure 23a. *Concrete housing in Cotonou*

Figure 23b. *Concrete housing in Cotonou*

Figure 23c. *Concrete housing in Cotonou*

Figure 23d. *Concrete housing in Cotonou*


Figure 23e. *Concrete housing in Cotonou*

Figure 24a. *Concrete under construction in Cotonou*

Figure 24b. *Concrete under construction in Cotonou*

Figure 24c. *Concrete under construction in Cotonou*

Figure 24d. *Concrete under construction in Cotonou*

Figure 24e. *Concrete under construction in Cotonou*

## 2.2 Informal Settlements

Informal settlements are commonplace in Benin in the cities as well as in rural areas. They are of residential function but also places of commerce.

Referring to a study led by UN-Habitat, over 200 million people in sub-Saharan Africa live in informal settlements. The developing countries are characterised by recent urbanisation and began to see the development of informal settlements in the 1950s and 1960s. Two factors explain the phenomenon: on the one hand, the impoverishment of the countryside following state programmes focused more on a desire for industrialisation. This priority given to the cities to the detriment of the countryside caused a significant migration of the rural poor to the cities. Once they arrived in the city, these people built shacks near the employment centres and thus developed spontaneous and unhealthy housing where cheap labour lived.

In Cotonou especially, there is a massive shortage in housing and, of course, even less affordable housing, which is why there are entire city districts like, for example, the district of Akpakpa Dodomey Enagnon that mainly consist of informal residential settlements.

The architect and founder of the ONG atelier des griots during an interview described the experience he made with his team while doing field research in the city:

*"Our team of architects concluded from our field research, that the people who lived in sometimes the poorest neighbourhoods from Cotonou did a better job at making constant use, or multifunctional use of their spaces and were more creative then we the professionals who design new neighbourhoods where streets and boardwalks ended up to only be used for one specific function and left dead during the remainder of the day. We ripped the streets of their potential and special quality."*

During my research, I came across many buildings and open spaces that the residents created. They are very often self-built structures and conceived without a professional. The building materials are decided by the owners' personal ambition, budget, and what is available nearby. Mixed building forms are created in heavy and light construction (mostly roofs in wooden constructions with corrugated sheet metal) (see figure 25-26). They are designed entirely according to the needs of the


Figure 25a. *Informal settlements in Savalou*

Figure 25b. *Informal settlements in Savalou*


Figure 25c. *Informal settlements in Savalou*

Figure 25d. *Informal settlements in Savalou*

Figure 25e. *Informal settlements in Bohicon*


Figure 25f. *Informal settlements in Bohicon*

occupants and often have surprising functional or aesthetic details on closer inspection. They are often located in strategically interesting places.: along the streets, in proximity to more significant junction points for commerce, generally speaking, places with lots of people coming through to sell goods to. This usually starts with people setting up a small shop the size of a lemonade stand, for example, and after some time, if business is good, they grow and become real shops.
The presence of informal settlements often is a good indicator of where to position functional facilities in a neighbourhood and, therefore, often form the starting points for a later qualification and development of the area.

## 2.3 Lagoon villages

A little different type of informal settlements are the stilts houses in the lagoon villages (see figure 27). The most famous village on the lake Nokoue called is "Ganvie", meaning "We have survived". This village was created during the Portuguese invasion (15th century). Today Ganvie counts more than 30000 habitants. It is the biggest city on stilts in the world and is humorously called "the Venice of Africa". The constructions are ephemeral, and the lifespan of the used materials do not exceed fifteen years. The houses are built by builders who live on the water and possess the endogenous know-how. The main building materials being used for the construction are wood, palm tree leaves, stems and branches, corrugated sheet metal.
Here again, it is an excellent example of how creative people became out of necessity. Besides the on stilt construction, the people who live in Ganvie created their own entire system and live in self-sufficiency, independent from the mainland. They circulate with canoe's that are often carved out of tree trunks. They live from fishing, agriculture on small islands in the water and nowadays a little from tourism. Closer to the mainland during the dry season, the underside of the buildings is used as a shelter for animals, and the fishers become breeders (Chaperon and Mensah, 2021).

Figure 26g. *Informal Settlements in Akpakpa Dodomey Enagnon Cotonou*

Figure 27a. *The Stilt Houses of Ganvie*

Figure 27b. *The stilt houses of Ganvie*

Figure 27c. *The stilt houses of Ganvie*

Figure 27d. *The Stilt houses of Ganvie*

Figure 27e. *The stilt houses of Ganvie*

## 2.4 Compressed Earth Bricks Construction

Next to the overwhelming concrete construction industry, there is also a minor construction movement with Compressed Earth Bricks.
Compressed earth bricks are the modern version of adobe construction. It is a brick that is made of a mix of wet Earth, which sometimes is stabilised by lime binder. The mixture is compressed in moulds and then removed from the mould. The bricks are then left to dry naturally under a cover (tarpaulin) or directly exposed to the sun. The resultant bricks use traditional techniques in combination with more modern production methods.

The CEB is attractive due to its excellent thermal, and acoustic qualities. The Earth used for it is extracted locally under the topsoil, and delivery routes are reduced to a minimum since appropriate soil can be found in nearly all the regions of Benin.
The majority of the clients who ask for houses using CEB currently are small in numbers and mostly come from the African diaspora.
In an interview with creative Caroline Grellier in 2018, Habib Meme said that less than 10% of the clients that his firm deals with want to make use of local materials in the projects (Grellier, 2018).

Figure 28a. *CEB construcion company Art Deco*

Figure 28b. *CEB construction company Art Deco*

Figure 29a. *Cite Bethel, CEB construction*

Figure 29b. *Cite Bethel, CEB construction*

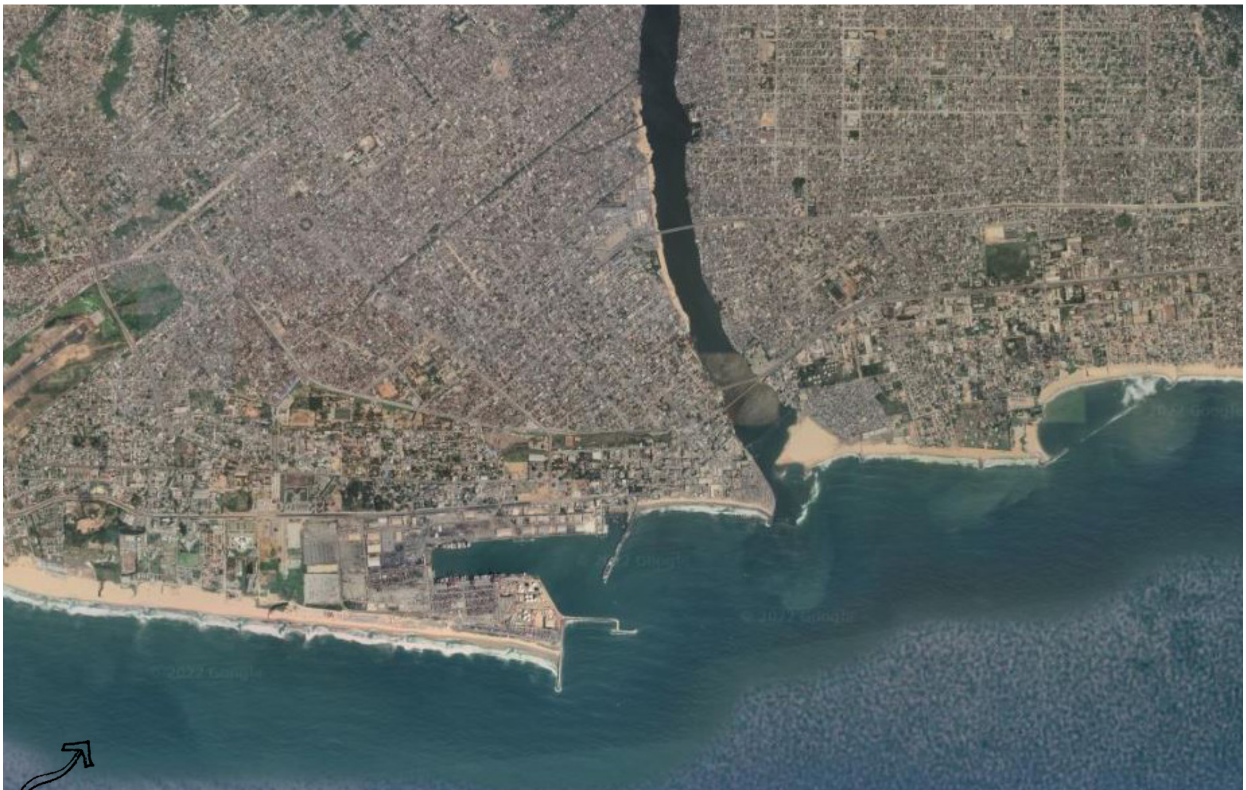
Figure 30. *Earth wall in Savalou*

## 3.1 The role and importance of designing with the environment

Historically buildings were always conceived with nature. The building structures were designed to integrate into their environment, and the given climatic conditions were analysed. Housing solutions were developed using natural resources that were present. This seems like a logical process when analysing the features of certain species in a specific climate condition. It is not nature that adapts but the physiology of the living organism, animals that adapt to the environment.

Therefore typically, vernacular architecture is intrinsically considered bioclimatic: an architecture based on the local climate, which uses environmental resources to ensure thermal comfort and a healthy living environment. Today a bioclimatic building needs to fulfil the previously mentioned characteristics while avoiding the use of polluting building materials and making efficient use of energy.
Beyond the bioclimatic strategies, passive design strategies have become more and more popular, and the so-called Passive House emerged. A German construction standard system that covers the bioclimatic criteria's but also has strict goals in reducing internal energy consumption. Worldwide, there are currently approximately 25, 000 mainly in countries with a temperate climate (Germany, Austria, Switzerland and Scandinavia) (Corporativa, n.d).
Therefore the following determined set of design criteria's fit under the umbrella of the general term passive design strategy.

To better understand what specific design strategies can do to improve comfort in housing in Benin, I chose to analyse only those dealing with the cooling of the city, the neighbourhood, and the buildings. Insufficient cooling leads to the increasing use of air-conditioning technology. Air-conditioning units are by far the most significant energy consumers in tropical buildings, and their energy demand is extraordinarily high. Therefore focusing on passive design strategies that help cool is of central importance on the way to making buildings as energy-autonomous as possible, sustainable and affordable, while keeping a certain thermal comfort within the built environment.



Prevailing wind

Figure 31. *Cotonou aerial view*

## 3.2 Urban Scale – Cooling the city and generating microclimates in the neighbourhood

On the urban scale, one of the main strategies that should be applied in a hot and humid climate, as in Benin, is that of trying to cool down the city. In the following section, the different strategies that can be made use of will be analysed and merged to give us a first idea of the urban grid that would be adequate for the Beninese climate.

### Loose Urban Grid

The hot and humid environment in the southern part of the country requires adequate space between the buildings to allow cool breezes to flow through the streets at pedestrian level. Here a looser grid than in hot arid climates is required in order to allow enough cross ventilation through the districts to cool the exterior building facades. If we apply the urban model of M.Dekay to the Beninese specific wind directions needs to be laid out as seen in figure 32.
In Benin, if we look at the climate, we can consider that in the southern part of the country, the urban grid, due to the high level of humidity, needs to be looser. The more northern in the country we get, the tighter the grid can become as we can make use of the cooling effect at night, especially during the dry season where the wind from the Sahara

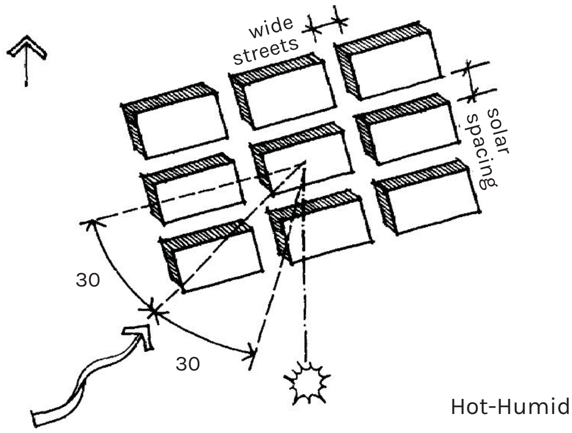



Figure 32. *Urban grid configuration in reference to prevailing wind in hot and humid climate*

cools down the temperatures at night. There can be a temperature drop of 16 degrees between day and night. During my visit, this was the case on several occasions, and in the morning, a strong wind prevailed.

### Converging Ventilation Corridors

With climate change and the rise in temperatures, many countries are thinking about how to bring fresh air into their cities. The city of Dresden (Germany) is one of those cities that is thinking


Figure 33. *Cotonou aerial map urban grid*

about emphasising the areas where the air is currently coming into the city by integrating convergent air corridors into the urban planning. Referring to recent studies, the benefits of open spaces, green spaces on the adjacent buildings clearly support to design cold air corridors into the urban grid. On hot summer days, temperature differences between the densely built-up inner part of the city and the less dense part of the city can be up to 5 degrees Celsius (Dresden, 2015). Every vacant lot, every open square or strip of greenery provides an opportunity for ventilation and cooling.
In the case of Benin, the main wind source coming from the sea, coastal areas need to be designed in regards to the inland. They can be the starting point of wind corridors that will lead fresh air into the city of Cotonou. In the case of my chosen project site that is located 20km away from the coast, the outer edges of the "new city" play the role of the coast and by positioning areas of alternating building heights and open spaces to the north and south of denser part of the cities, recovery pockets can be generated to allow cool breezes to circulate (de Schiller and Evans, 1998).

### Green Lungs and Green Edges

In the case of Amsterdam, fresh air is brought into the city through numerous canals and a multitude of parks. In the "Amsterdam Agenda", the city determined a green vision in order to increase biodiversity, air quality and lower temperatures within the city until 2050. The current green spaces of Amsterdam should be connected to create a "green network". This network is then accentuated by the so-called "green fingers" of the city, which constitute large bodies of forest, park, and green space that allow fresh air to come into the city (Groenvisie 2020-2050, n.d.).
If we apply these principles to Benin, the neighbourhoods need to be connected by larger green bodies of vegetation that cover the ground in order to reduce the amount of heat absorbent surfaces on the ground, in combination with tall trees that provide shade without blocking cool breezes at the pedestrian level. The tall tree species already present in the natural environment of southern Benin are ideal for this purpose as they mainly consist of trees with long stems and an "umbrella like" tree crowns.

Palm tree: Cocos nucifera, Ptychosperma macarthuril, Pritchardia Pacifica, Elaeis guineensis
Other trees: Milicia excels, albizia niopoides, polyalthia longifolia, casuarina equisefolia, Delonix regia, kigelia Africana

Something to pay attention to is to use primarily tree species with little or no fruits in the trees as they cause lots of waste when fruits fall and require much more intensive maintenance.

### Passive and Overhead Shade

At the same time, there is a need for urban microclimates so that pedestrians can circulate in a more comfortable way through the neighbourhood and follow their daily activities. Open spaces, outdoor spaces and circulatory spaces need to be configured so that they also receive a certain amount of shade.
If we look at vegetation and microclimates at the housing block scale, the example of the city of Savannah, Georgia, in the United States is remarquable. With a hot and humid climate in the summer, this city is built in a grid system with 24 green squares amongst it (see figure 34). Referring to Dekay and Brown the temperature in the squares can be 6-8 degrees lower than in the built-up areas (Dekay and Brown, 2014)

## 3.3 Building Scale – Regulating the interior climate

Referring to Climate Consultant in combination with the Adaptive Comfort Model in ASHRAE Standard 55-2010, occupants will be comfortable 68% of the year already using only strategies that allow adaptive comfort ventilation (only passive ventilation). Therefore, I will zoom into passive ventilation strategies and material choices to prevent heat gain in the following paragraph.

### Cross Ventilation

One of the significant challenges at the building scale is to minimise the heat gain of the building mass. Therefore a climate-appropriate building orientation is critical. The west-facing glazing needs to be kept as minimal as possible or completely eliminated to reduce heat gain. At the same time, the rooms should be oriented facing the wind to allow proper cross ventilation. This means inlets windward and outlets leeward. In the case of Benin, the primary wind direction is

southwest which causes a conflict when looking at the fact that we need to minimise west-facing glazing.
Therefore we need to consider alternatives when positioning and designing openings on this facade (refer to section 3.4) if located perpendicular to the prevailing wind. If designed and used correctly, cross ventilation can maintain the indoor temperature approximatively 1,5 degrees lower than outside (de Schiller, 1998). As we are located in a hot and humid environment cross ventilation, it is recommendable to make use of stacked cross-ventilation by maximising the height difference between air inlet and outlet (see figure 35, 36). This was implemented into the design of the villas in the "cite Ouedo" project. Air outlets were integrated as ridge vents (see Apendix page 45). An open plan floorplan is undoubtedly beneficial to support this goal.

### Ventilate above and under

In the southern part of the country, we are often located in wetland areas. The humidity is above 75 per cent all year long. In addition to damp soils, this hot and humid climate demands attention when designing the way the building touches the ground. We need to think of ways to maximise natural ventilation underneath the building. Classically this is being done by raising the building off the ground, but this is typically connected to a lightweight construction method. In the southern part of the United State we are mostly looking at lightweight wood frame construction, raised above the ground with openable walls, large overhangs and porches. Due to our Beninese context, where wood construction is not practised, we need design solutions that allow ventilating the building from underneath with more heavy Earth-like construction while keeping animals out.

### Material Choices to prevent heat gain

The biggest surfaces exposed directly to the outdoor environment are the exterior walls, and therefore it is essential to prevent those from overheating by making appropriate material choices. Currently, the main material that is being used for walls and partitions in Benin is concrete. This is the case even though it is not the most appropriate material in terms of thermal performance, availability, and being environmentally friendly.
On the other hand, soil is present across the country in high quality. It is often possible that entire buildings are made using the earth already present below the topsoil on the construction site in question. A resource present, at no cost and with excellent thermal qualities.
Referring to a study lead in Burkina Faso, comparing the thermal qualities of hollow concrete bricks to stabilised CEB, the earth bricks have clear advantages. They are less dense than the concrete bricks and create a structural advantage when compared to mechanical loads. Additionally, the warm indoor discomfort in a space constructed with stabilised CEB bricks was 400 hours less than when made with hollow cement blocks. Generally speaking, the indoor climate using earth walls is cooler than when using concrete walls. The framework of the study was keeping the indoor temperature below 28 degrees year-round. It was found that by using CEB as a building material, the energy consumption cost for cooling in the studied building would be 310,000 CFA francs (535 USD) lower than with the cement blocks (Moussa et al., 2019).

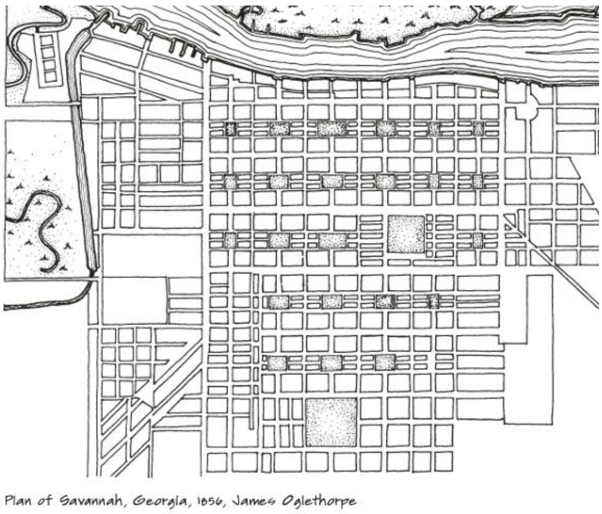



Figure 34. *Savannah city grid*

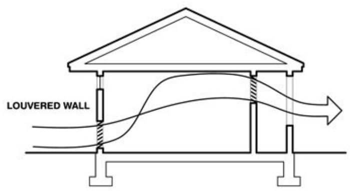



Figure 35. *Cross ventilation diagram*

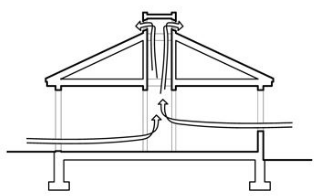


Figure 36. *Stacked ventilation diagram*

## 3.4 Component Scale – Ventilation apertures

### Facade Openings

What type of openings are adequate in the Beninese climate is very interesting and challenging. Openings need to allow for constant ventilation while protecting the interior from direct sunlight and mosquitoes coming in. On the other hand, openings need to be designed so that they can be kept open during intense rainfall. Another aspect to think about is security. The openings need to be conceived so that the house's occupants feel safe keeping their windows open during the day without necessarily being at home.

During cross ventilation, the wind speed increases with the outlet opening smaller than the inlet and vis-versa. The wind speed going across the room is the fastest close to the smaller opening. In most cases, the windward opening is larger than outlets. Thereafter many researchers have analysed what effect various window widths have in relation to the overall wall width. Referring to Givoni (1965), an appropriate window to wall width ratio can increase the indoor air velocity by 5-20% (Maghrabi, 2000). An analysis led by Sobin (1981) on indoor wind velocity in relation to opening shape and wind direction has shown that horizontally elongated windows positioned with a 45 or 135-degree angle to the primary wind direction are the most efficient (see figure 37). This should be considered in the architectural design process as it can significantly improve indoor climatic conditions.
As ventilation is critical in Benin, window design should be optimised to enhance natural ventilation, but well-designed walls and doors can also significantly impact the indoor climate. Here are some of the appropriate opening types for a hot and humid climate.

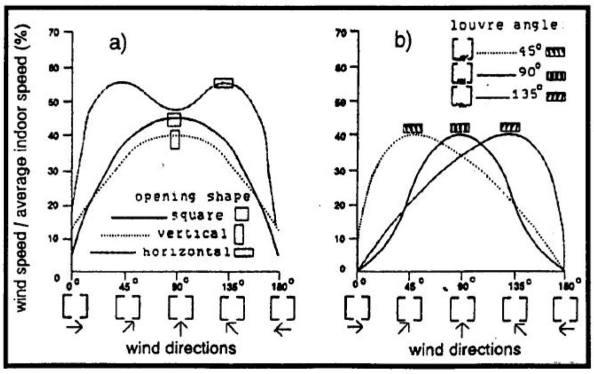



Figure 37. *Wind indoor speed analysis*

### Louvred Windows (naco)

Louvred windows are used across the world in many forms and sizes in areas that deal with hot and humid climate (see figure 38-41). They have many advantages in the Beninese climate in the southern and northern parts of the country. They allow air in while keeping the interior protected from the sun and rain. The glass louvres, when open, reflect the sun away from the building. The same goes for rain when angled under 90 degrees. Unlike regular windows, the louvre windows facilitate consistent and constant airflow as they can be kept open even when not at home. Due to their fixed smaller panel sizes, the windows are not affected by wind direction and speed compared to casement and awning windows. In the southern part of the country, louvre windows will probably be kept open the entire day and night due to the constant high temperatures. However, in the northern part of the country, the wind from the Sahara can be powerful, especially during the night and the louvres might be opened less or wholly closed on the wind facing side.

The Burkina Institue of Technology designed by Kere Architecture is a great example where window louvres are reinterpreted and transformed. In this project the louvre windows become entire louvre window walls, where wooden panels replace the glass panels. These take the function of wall, window and shutters all at once, and they allow a significantly larger portion of the wall to be used to ventilate a space while providing security at night.

### Perforated walls

Next to the louvred wall, there are also other types of walls appropriate to the Beninese climate. Perforated walls are often used as an outer layer before the actual wall. They act as a second skin often connected to buffer zones (outdoor living spaces). They are made of a variety of materials that let through the air. One frequently used example of perforated walls in tropical climates is the air brick wall used as a second skin and as a primary facade in some cases (see figure 42-45). An exemplary project using the air brick wall technique is a residential project in Vietnam designed by the architecture office Tropical Space (Rojas, 2016) (figure 44a&b). With only one actual window, the life in this project is more directed towards the inside while constantly staying connected to the outdoor climate and environment through the brick size openings across the building. If implemented in Benin, this strategy needs to be either used as a buffer wall so not as the main building facade or needs to be designed in combination with a screen to keep the mosquitoes out, that is not only a source of discomfort at night but also the carrier of diseases like malaria.

### Door vents

As many bedrooms generally speaking only have one window or facade directly connected to the outside (except in corner rooms), it is crucial to think of the door as an air outlet and inlet.
In the monastery Sainte-Marie de La Tourette (Lyon, France), Le Corbusier added an operable shutter or mini louvre into the door of each sleeping room (see figure 46a&b). Therefore air could circulate into the room at night without opening the door and keeping enough privacy. The operable single-pane vertical louvre concept goes through the entire building and is integrated into doors, interior walls, and walls directly connected to the outside. By doing so, Le Corbusier could cross ventilate the entire building without using operable glass windows. At the same time, the floor to ceiling vertical shutters allow for a cool breeze at all heights.

Figure 38. *Utsav House in Alibag*

Figure 39. *Kéré's primary school building in Gando*

Figure 40. *Schorge secondary school in Gando*

Figure 41. *Burkina institue of technology*

Figure 42. *Gando teacher's housing in Burkina Faso*

Figure 43. *National Park Mali*


Figure 44a. *LT house Vietnam*


Figure 44b. *LT house Vietnam*


Figure 45a. *Projet Diapalante*


Figure 45b. *Projet Diapalante*


Figure 46a. *Bedroom in Monastery La Tourette*


Figure 46b. *Bedroom in Monastery La Tourette*

# CONCLUSIONS

## Climate

The climate in Cotonou is characterised by constant high temperatures and high humidity with a low amplitude between day and night. Temperatures are also high at night. A heating system in the building is not necessary. The sun shines for an average of 8 hours per day. Precipitations are abundant but concentrated in certain months of the year. They fall suddenly, are of short duration and often have a very high intensity. Therefore, the risk of flooding is exceptionally high during the rainy season. The precipitations cause only insignificant cooling. There are two main wind directions. The primary wind direction comes from the southwest (Atlantic Ocean) throughout the year. The secondary, seasonal wind direction comes from the Sahara from the northeast during the dry season (December/January). The latter is much more noticeable in the northern part of the country. Planning in Cotonou and the surrounding area must pay special attention to making the best use of the existing wind directions to direct air through cities and houses, thus increasing people's comfort in neighbourhoods and individual buildings. This is one of the reasons why the separation between "outdoor space" and "indoor space" is less important in building design than in particularly hot or cold climates. The boundaries between outside and inside can be blurred. Due to the intensity of solar radiation, the shading of buildings and open spaces is of particular importance.

## Current Housing

Architecture in Benin is creative and in motion. It is strongly influenced by the ambitions, needs, aesthetical preferences and intellectual experiences of the clients and users. Architects are in the midst of a process of forming opinions in defining adequate technical solutions and a coherent architectural language for the cultural and social needs of society. A look at the informal building sector is worthwhile, as special societal, functional and spatial needs can often be read in detail here. The choice of suitable building materials is limited. In the formal construction sector, building with a high proportion of concrete is predominant for technical reasons and reasons of the status associated with it. This does not make sense climatically regarding its Carbone dioxide emissions. Alternative building techniques and the revival of traditional building methods are only being promoted selectively and primarily by individual committed architects and the diaspora as their only client.

## Passive design strategies

In Benin's hot and humid southern climate, the avoidance of mechanical cooling systems plays a central role in saving energy. This is comparatively easy due to the prevailing climate, measured against the technical (e.g. mechanical ventilation) and material (e.g. insulation thicknesses of over 20 cm) effort required for a Passive House in Europe.
In order to achieve acceptance among users, the indoor quality of buildings must be ensured even without the use of mechanical cooling. Passive measures are of central importance for building design. In the urban context, they can positively influence the quality of stay in open spaces through a consistent application because the ambient temperature is lowered.

## Important points and limitations of the method

Relevant to this research is that we gained a clear understanding of the current climatic and architectural context of the urban southern part of Benin. That knowledge informed the last section of results that provided us with a set of selected passive design strategies that are critical to fulfilling the adaptive comfort model criteria. A limitation of this research is that we cannot determine a complete set of design strategies in full depth as this would require a much large body of work. Therefore the analysed strategies were selected according to their relevance and high feasibility in the Beninese context. Furthermore, the selected passive design strategies form a fundamental base that complemented by active strategies such as:

- The generation of electrical energy through renewable energy
- The reduction of energy consumption through the use of optimised technology, e.g. for lighting

- The retention and storage of rainwater in cisterns,

brings us closer to the goal of developing an autonomous neighbourhood.

The strategies described contribute to improving the energy balance and the careful use of resources. Through the climate analysis lead in the research, Benin's high potential in substantially using these strategies becomes apparent. In addition to a more ecological use of resources, the measures also increase the residents' independence while securing a continuous supply of electricity and tap water.

### Proposals for further studies

Additionally, to being a base for new building projects, the established set of design strategies can also be implemented in existing buildings in renovation measures. It would certainly make sense to conduct a further study on the possibilities of rehabilitating existing buildings using the example of the city of Cotonou. The result could be formulated as procedural recommendations for house owners planning to renovate or convert their buildings. The approach seems feasible because large parts of the city (especially in the western part) are aligned on a grid running from southwest to northeast. Therefore they are already following the orientation recommendation to enable effective urban cooling strategies.

# APPENDIX

**ASHRAE**
American Society of Heating, Refrigerating and Air-conditioning Engineers

**Autonomous housing**
A building that is able to be operated independently from the infrastructural support service. A building that functions off-grid while using the contextual climatic conditions to its advantage to harvest energy, capture and store water etc. Currently it is mostly used in single family homes.

**Bundle**
A set of related design strategies that work together to resolve commonly occurring problems

**Comfort Zone**
On the bioclimatic chart, the comfort zone is the area of combined temperatures and humidities that 80% of people find comfortable. People are assumed to be in the shade, fully protected from wind, engaged in light activity and wearing moderate levels of clothing that increase slightly in winter. In the context of Benin these traditional comfort levels like ASHRAE standards needs to be reassessed and contextual appropriately redefined.

**Global sustainability goals**
An Agenda for Sustainable Development, created by the United Nations in 2015. It comes with 17 goals which referring to the UN need urgent or immediate action. The goals have for objective to end poverty, improve health and education, reduce inequality etc. One of the goals is also to tackle climate change within which the building industry plays an essential role.

**Government Action Plan (PAG) "Benin Révélé"**
A large-scale investment programme based on 45 flagship projects in 9 key sectors, which aims to give the country's economy a sustainable boost. In concrete terms, the aim is to create a more favourable framework for investment and to improve the daily lives of the Beninese.

**Integrated Design**
The synthesis of climate, use of loads and systems to achieve a more comfortable environment for the occupants, and a building that is more energy efficient than current best practices.

**Local materials, Appropriate materials**
In the scientific literature on materials research, the term 'local materials' is no longer used because it does not represent all the particularities associated with them. Indeed, a local material is by definition a material that is available locally; This includes materials imported into Africa such as cement or sheet metal. This is why the term chosen by scientists is appropriate materials, meaning alternative materials to conventional to conventional construction proper, which, because of their characteristics, fit favourably into a given setting and a perspective of local and sustainable and a perspective of local and sustainable development.

**Passive Design**
A building design that takes full advantage of resources of the context; meaning nature, site, climate in order to improve the environmental performance of the building. Passive design does not use mechanical means to satisfy heating, lighting or cooling loads.

**Passive System**
A system that uses non-mechanical, non-electrical means to satisfy heating, lighting or cooling loads. Purely passive systems use radiation, conduction, and natural convection to distribute heat and daylight for lighting.

**Photovoltaic (PV)**
A means of generating electricity from sunlight using semiconductors that exhibit the photovoltaic effect.

**Renewable Energy (RE)**
Energy produced from renewable sources (not from burned fossil fuels), such as sun, biomass and wind. RE may be produced on site or purchased from a power utility.

**Relative Humidity**
The percentage of water vapour in the atmosphere relative to the maximum amount of water vapour that can be held by the air at a given temperature.

**Solar energy**
Solar energy is any type of energy generated by the sun. Solar energy can be harnessed directly or indirectly for human use.

**Strategy**
A generalized solution to a recurring design problem that connects architectural form to performance in ways that allow for design flexibility.

**Sustainability**
Sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs. The processes and actions through which humankind avoids the depletion of natural resources, in order to keep an ecological balance that doesn't allow the quality of life of modern societies to decrease.

**Thermal comfort model**
Thermal comfort in the condition where the majority of people express a feeling of satisfaction with the thermal environment. This subjective evaluation is then used to establish thermal comfort model as base for design strategies. Some of the most used thermal comfort models are ASHRAE, California Energy code comfort model In the case of the Beninese climate none of the typical thermal comfort models are appropriate.

**Tropical Climate**
A climate with an average temperature above 18 degrees Celsius and considerable precipitation during at least part of the year. These areas are non-arid and are generally consistent with equatorial climate conditions around the world.

**Interview Series - about Building in Tropical Climate**
Interview Partner: Jean-Paul Houndeffo
Location: Atelier Houndeffo, Cotonou, Benin

Dear Mr Houndeffo, thank you very much for meeting with me and discussing the problem of building in a Tropical climate within the frame of the project Carre Hinnoudo and your professional practices experiences over the years.

The pleasure is all mine. I am always delighted to share my experiences, the good and more challenging ones over the years, with the next generation of architects.

1. You were the local contact architect for the project called Carre Hinnoudo. Can you tell us a little about this project and how far it has evolved since its start in construction in 2015?

A project that only uses local materials and in its conception already pushes the boundaries of what living in Benin could be and look like.
The project was thought of as a built and learn project. Therefore we organised a series of technical workshops to allow the involved workers and people from the community to acquire the necessary knowledge to be involved in the building process.
Therefore the project was laid out in a very low-tech way. We used mainly manual machines on-site except for the excavations in order to create a basement.
The project's vision was to be a closed-looped (circular) ecosystem and therefore has a certain amount of independence from its construction to its maintenance after completion.

2. How far has the project evolved since its start in construction in 2015?

I am always a little conflicted because it was quite an ambitious project at the beginning of my career. We were quickly faced with the reality of things and the difficulties that experimental building brings.
I can say that for us young architects, the challenge at this stage of our career was too big to run smoothly and without mistakes. From the start, construction has been lagging. The house to date is still not habitable. For me, this is due to several factors. Our team of architects, workers and all involved people were young and inexperienced in this type of construction. The ambitious, innovative design of my colleague Romain Boboe, brought many challenges. Challenges that the group of craftsmen we were working with had difficulties fulfilling. Therefore, we had to go through several trial and error phases to figure out the proper way. These were connected to substantial costs and our client already, of course, had a budget.

The client's wish was to build a house without any structural concrete, but with the spans within the building, this was not manageable, and again here, we could have saved a lot of time and effort if we had made a compromise right from the beginning.

On another note, I have to say that due to many pauses in the project, I am not part of it anymore, and I cannot precisely say how far we are in the actual construction today in 2021.

3. What would you change if you had to redo the project or pick it up again?

Having gained practical experience, I am confident that we would approach the project differently. We would not need to go through trial and error phases because we would know what is possible and how to manage the difficulties.
If the project were picked up again by the client with the intent to finish it, I would be honored to take it under my wing as I feel responsible for the completion of this project that has helped me launch my career and that even though its current construction status has reached certain media attention. As an architect, failure or dissatisfaction is where I believe the most significant learning curve happens. Therefore, I am convinced this project still has a bright future ahead of it.

4. Do you consider the client's initial wish to build without structural concrete feasible today?

Personally no. In my practice, we want to make sure that the projects we built last long. Therefore our philosophy follows to use concrete where it is structurally needed and use local finishes to give the concrete a more context-appropriate appearance. This method seems the most appropriate for us, especially if the brickwork or rammed earth walls are produced manually and sometimes not by construction workers but by people from the community. In these cases, structural integrity cannot be guaranteed by the lone use of brickwork, as the quality of each brick can vary.

5. Where did the building materials for the construction of the project come from?

When conceiving a project in Benin, it is essential to first look at the geological properties. Often some of the desired building materials are already present on site.
In this case, our project site is located in Porto-Novo. In Porto-Novo, the ground is made of red Earth, which has the necessary qualifications for construction with bricks or with the rammed earth technique.
The architect who designed the project thought of this and planned a basement to gain in square meters and retrieve enough Earth to build the entire ground floor and all the other earth walls in the project. The excess of excavated soil (Earth not fit for construction) was then used to level the ground on a different construction site.
Additionally, we used other soil types during construction; for example, a kind of Earth rich in basalt was collected in the region (within a 1-hour radius maximum). The granite that we used as aggregate in the rammed earth walls only exists in the northern part of the country.

6. Humidity is one of the most problematic factors in the West African climate. Do you have any ideas about the most appropriate materials to use in this hot and humid climate? How to combat humidity?

When trying to be sustainable and think about our environment, we are a bit stuck when tackling the problem of the high humidity in the air. We have to make compromises.
For example, ceiling fans that help circulate the air in our spaces do not deal with the actual humidity within the room. The only response to getting rid of moisture is air-conditioning and air dehumidifiers. Today, for me, this is the most appropriate way to get rid of humidity in the built environment. It is not the most ecological device, but if used at selected hours of the day and not to excess can make a big difference. A reality outside and inside in the South of Benin is that you always have a layer of water over your skin that makes you feel like you are constantly sweating. This can be avoided with air-conditioning, and as you can see in our office here, we only have air-conditioning in the actual working space. All the service spaces, break rooms, or meeting rooms do not have air conditioning. As soon as you enter the working space, you feel the difference, and you can imagine how much more efficient our computers run and our small team can perform better.

Of course, some building materials absorb the humidity better than others, but this humidity also needs to get out and therefore, a strategic layout that allows good ventilation is essential. It has to be able to get rid of the gathered humidity from the rain season during the dry season. A crucial point in Benin is to design a building that lives with the seasons. We do not have four seasons with extreme shifts from hot to cold, but our seasons also bring significant changes with them. Precipitation here is the biggest factor.

I often see the building as a "living organism" that, if not well designed, suffers from the repercussions caused by extreme rainfall. These repercussions sometimes are not visible right away put as everyone knows humidity nested in walls for an extended period can cause health issues for us, the inhabitants.

7. In this interview, we have been talking about the design approaches and materials in relation to your professional expertise. In research, actual costs are often a secondary concern, but I believe that it is of great importance today. Therefore I would be interested in knowing more about the costs of using local materials compared to concrete construction?

"Currently in Benin, building with concrete is the traditional building method, and this is a reality that needs to be addressed."
With the project Carre Hinnoudo we were quickly confronted with this reality. The knowledge in construction with local materials on a high standard is underdeveloped and often inexistent. This is also why we hosted these training workshops with rammed Earth and brick specialists. These workshops take time and need

to be factored into the construction costs.
Another factor that needs to be taken into account when building with local resources as bamboo is that the amount of bamboo needed often is just a fraction of what is actually cut and brought to the construction site. As an architect, we have an eye on quality, and therefore the quality of the materials used is important. The selection process of each bamboo needs to be done carefully. If you do not go into the forest and make the selection, your order usually needs to be three to four times what you actually need to ensure that you will have enough usable once. I actually did go and did the selection myself on site for my own house, but this is an effort that cannot be expected of the architect on top of his work for every project and material.

So if you ask me if construction with local building materials in an urban context is cheaper than with concrete, my answer today is no. First, there is a need to develop an entire building industry as well as craft, and then the cost of building with local materials might become cheaper or equal to building with concrete.

8. I want to shift the conversation to the current project that is being built at the Cite Ouedo. Currently, they are building ten thousand social houses. These houses are categorised into different types, but the main element that connects all these is the use of prefabricated concrete slabs, facade panels and partitions. What do you think of this project?

First of all, I would like to say that in Benin, because there is an extensive need for housing, the fact that a project at this scale is being done brings already some good.
I know the architects who have worked on the project, and I have seen how much time and effort they have spent to bring it to life. In fact, I also know that initially, the project looked very different. The project was envisioned more down to Earth with a low-tech approach, and this vision had to shift in the development project for guarantee purposes. At this scale of a project, having the State as a client required a guarantee from the architects to complete the project with a certain quality, in a given timeframe. At the same time, there was a challenge in the budget that needed to be met and find a way to build things efficient and fast. I am explaining these difficulties to say that the project with these requirements had to be adapted and modified to be in construction today.
I personally am excited to see the outcome of this large scale project. I think there is a need to make sure that the buildings are oriented correctly and that other materials than concrete are used on the facades most exposed to the sun because of the thermal qualities of, for example, bricks made of Earth compared to Earth the concrete are undeniable. Also, the layout of the apartments and houses and the actual way of the usage of the places will show if this project will be a success. I am very optimistic that it will be a positive outcome even though it most definitely will not be perfect. I believe it is an excellent start to the near future of massive urbanisation in Benin.

There is no future in the current model that one plot houses one family, and the need to build higher and allow shared ground will be needed sooner or later. This project will show if and how the Beninese population, the future inhabitants, will redefine their way of life and reappropriate this new model.

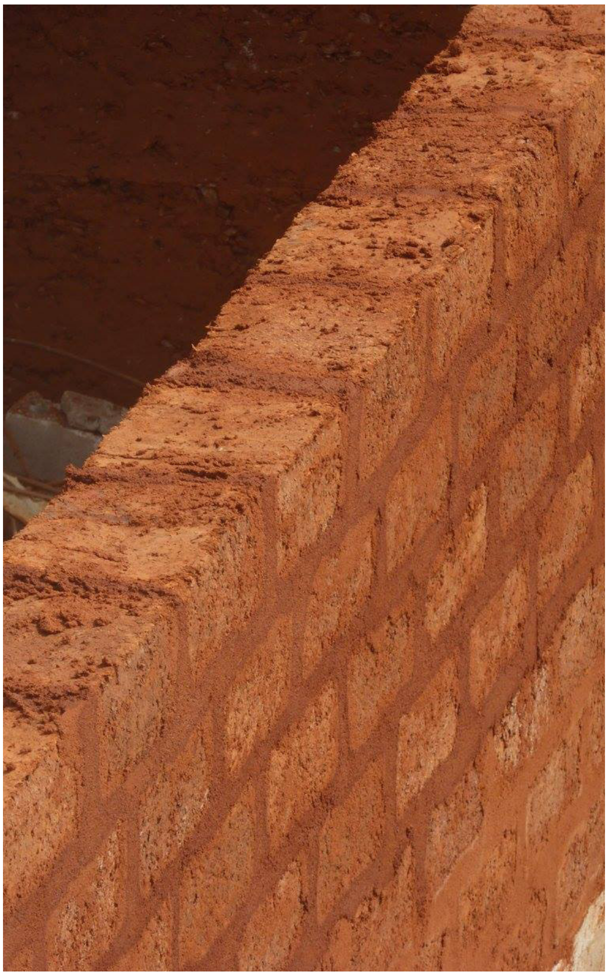


Figure 47. *Carre Hinnoudo construction site*

Figure 48. *Carre Hinnoudo project design*

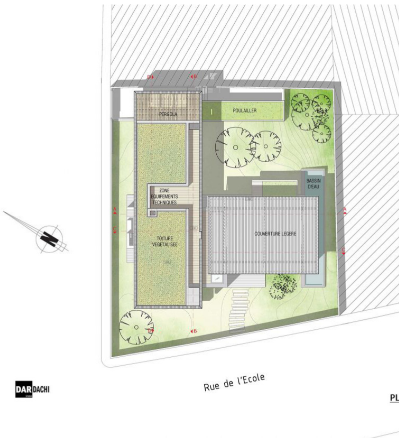



Figure 49. *Master plan*

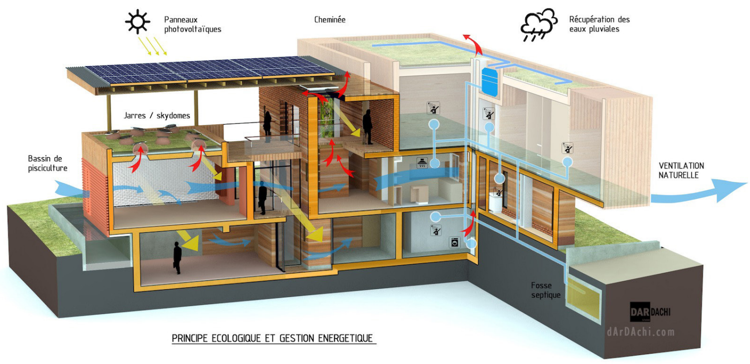



Figure 50. *Ecological principle and energy management*

Figure 51. *Carre Hinnoudo construction site*

Figure 52. *Carre Hinnoudo construction site*

**Interview Series - about Building in Tropical Climate**
Interview Partner: Habib Meme from Cabinet du Soleil and Atelier des Griots
Interview Location: Cabinet du Soleil, Cotonou, Benin

Dear Mr Meme, thank you very much for meeting with me and discussing the problem of building in a Tropical climate and the role of the architect in Benin, within the frame of your practice Cabinet du Soleil and within the frame of the ONG brought to life Atelier des Griots.

Welcome in our studio here in Cotonou. It is a pleasure to have you here physically and not only remotely.

1. You are the director and head architect of the Cabinet du Soleil and one of the founders of the ONG Atelier des Griots. What was your motivation to start such an organisation next to your architectural practice?

This is indeed a good question and I will give my answer to this question by starting through a different angle.
To me the role of the architect is not the same as it once was before. We are too often enclosed in our cubicals, often not even in the same country as our projects, thinking that we are changing the world and there are many good things that come out of these projects. The main challenge or problem I see with this way of working is that we often lose the contact to the people for who we built, the people that are actually going to use the spaces we design.

I myself specialised during my master in sustainable design and as a young graduate from the university of Politecnico di Milano came back to Benin to try to implement what I believed architecture here should be like, within the frame of our already established architectural practice.
An architecture that did not follow the concrete construction lobby, but an architecture that would make use of local materials: materials that are available in abundance and are more appropriate for the hot and humid climate. I was quickly confronted to the reality of things. Our clients were not ready to shift away from concrete construction, which is currently the most used contruction material in Benin.

I was confronted to a situation where either I would go with the masses and follow the concrete movement or not have clients at all, that's how well received concrete was and is and how stigmatised local materials were. Of course this was not an option for us as we are a practice that needs to be able to sustain itself.

Thereafter the Atelier des Griots is born not from a moment of luxury but more from a deep urge and necessity. The necessity to redefine the way we work in the architectural field but also the necessity to reinitiate the dialogue between professional and citizens, the dialogue between young and elderly people, between academics, professionals and neighbours in order to facilitate an exchange of knowledge, and help lift this stigma that is omnipresent when it comes to the use local building materials.

2. Can you please tell us a little bit about how you started the organisation and what role do you plain within it?

We started this endeavor by walking through the different neighborhoods of Cotonou just looking, actively opening our eyes and analysing what we saw. We started by doing field research, doing interviews with the people from the city without any preassumption that we might have had before due to our previous knowledge or articles from the net.

To our surprise, it was in the most vulnerable neighborhoods were informal settlements were the norm that we saw lots of opportunities and potential to learn from and to built from. In these type of neighborhoods the streets are very vibrant and every part of the neighborhood is being used. The streets are being occupied by the kids of the neighborhood who play there, meet there. After service the churches become places to gather, places for communal activities. On the contrary in the more wealthy neighborhoods as Fidgerosse, houses and properties are so closed off by high property walls and the roads so predetermined that there is no activity outside the vincinety of your private home. The streets are deserted. For our team this is a clear urban design issue. The streets of a city are like the veigns and arteries in our bodies. They need to be constantly used, there needs to be constant activity so that they function properly. In Benin where commerce often happens on the street this sentence has even more meaning and needs to be addressed with care when desiging new districts, new cities.

Our team of architects concluded from our field research, that the people who lived in sometimes the poorest neighborhoods from Cotonou did a better job at making constant use, or multifunctional use of their spaces and were more creative then we the professionals who design new neighborhoods where streets and boardwalks ended up to only be used for one specific function and left dead during the remain of the day. We ripped the streets of their potential and special quality.

During our research we also saw that the people created their own little communinities and created spaces for the kids to play, for people to gather. When things were missing they also took initiave to address those issues. As an example we found that in the most vulnerable neighborhoods the citizens created their own well to have an easier access to water. Local materials or trash were recycled and upcycled and used as building materials. Maybe some of these solutions are not great but the will to create and to live in better conditions was there and therefore we saw the opportunity to learn from each other and work together to create spaces for the people by the people under the guidance of Atelier des Griots. Therefore within the organisation we architects and urbanist do not play the role of the architect, we are more the facilitators, and or people of guidance that help to accomplish the visions of the population.

3. In your blogue I read a little about the youth centre, can you tell you a little bit about this project and what is currently happening there?

Indeed one of our bigger projects was the regeneration of the youth centre in the district of Akpakpa Dodomey Enagnon, in Cotonou. This public space was already defined but the inhabitants of yhe neighborhood as a space for gathering, to organise events, a space for all ages. Unfortunately the space was not being used by the inhabitants because it was too run down.
We wanted to bring this space back to life in order to allow the community to benefit from it properly. Therefore we started by organising meetings with the neighborhood leaders, as well as the young generation and just people from the neighborhood who wanted to be involved. We started to build a vision together, but all the ideas came from the people. The ideas were already there, we just needed to start the conversation and organised workshops where we taught the participants how to make measurements, plans etc. We brought in professionals from the outside who gave their feedback to keep a constant conversation, and also show what possibilities are out there. Next to these workshops, and sessions to learn and create we did not only want to have the position of teacher, or mediator but we also wanted to be part of the community so we spend time with the people.
Human moments, as simple as watching a movie together that was projected on the fa ade of the adjacent building to our project site.
Now this is what the project currently looks like and this is the vision that the community has developed with us over the past.

The vision is to add a library to the current space. A library made out of local materials, a library that can sustain itself meaning that the necessary energy to keep the building running needs to be produced on site and in the end needs to be for free. Therefore we envisioned to capture solar energy to power the building with electricity in the spaces that need access to light. We also envisioned to capture the rain water and store it so we can offer the basic sanitary services. In the end the idea was to create the first fully self sufficient building. This idea did not come to life due to the ecological vision of young aspiring architects but due to the fact that the community knows how to build with local materials and can handle many elements of the building process themselves. Indeed the idea was that the community builts the entire project themselves. During our many collaborations with this community we realised that when the people were involved personally in the construction process they also would take care of the result in a much more active way. On the other hand they do not have the financial means to maintain the building properly if they have to worry about paying electricity bills and water bills of their homes and of this communal space. Therefore it was essential to design this project in a self sustaining way.

Currently we are still trying to find funding for this project but I am confident that one day it will come to life.

Figure 53a. *Cite Ouedo apartments*

Figure 53b. *Cite Ouedo apartments*

Figure 53c. *Cite Ouedo apartments*

Figure 53d. *Cite Ouedo apartments*

Figure 54a. *Cite Ouedo single family houses*

Figure 54b. *Cite Ouedo single family houses*

Figure 54c. *Cite Ouedo single family houses*

1. Adaji, M. U. et al. (2019) Indoor comfort and adaptation in low-income and middle-income residential buildings in a Nigerian city during a dry season, Building and environment, 162(106276), p. 106276. doi: 10.1016/j.buildenv.2019.106276.

2. Arowolo, T. A. et al. (2019) Factors affecting quality control in building construction, International journal of advances in scientific research and engineering, 05(11), pp. 172–177. doi: 10.31695/ijasre.2019.33548.

3. Benin Energy Situation - energypedia (no date) Energypedia.info. Available at: https://energypedia.info/wiki/Benin_Energy_Situation (Accessed: October 25, 2021).

4. Bénin Révélé (no date) Beninrevele.bj. Available at: https://beninrevele.bj/ (Accessed: October 11, 2021).

5. Bioclimatic regions map (no date) Usgs.gov. Available at: https://eros.usgs.gov/westafrica/node/147 (Accessed: January 5, 2022).

6. Blogspot (2014) kwekudee-tripdownmemorylaneq, Blogspot.com. Available at: http://kwekudee-tripdownmemorylaneyou.blogspot.com/2014/03/ganvie-lake-village-venice-of-africa.html (Accessed: January 12, 2022).

7. BTC - Histoire de la BTC - Briques de Terre Compressée (no date) Briquestechnicconcept.fr. Available at: https://www.briquestechnicconcept.fr/histoire-de-la-btc.html (Accessed: January 9, 2022).

8. Chaperon, A. and Mensah, S. (2021) La construction traditionnelle sur le lac Nokoué, au Bénin. Reconsidérant l'abri , La Pierre d'Angle. Available at: https://anabf.org/pierredangle/dossiers/le-climat-change-quid-de-l-architecture/la-construction-traditionnelle-sur-le-lac-nokoue-au-bnin-reconsid-rant-l-abri (Accessed: January 9, 2022).

9. Choplin, A. (2020) Cementing Africa: Cement flows and city-making along the West African corridor (Accra, Lomé, Cotonou, Lagos), Urban studies (Edinburgh, Scotland), 57(9), pp. 1977–1993. doi: 10.1177/0042098019851949.

10. CILSS (2016a) Landscapes of West Africa – A Window on a Changing World, 252nd St, Garretson, SD 57030, UNITED STATES, 47914.

11. Climatewebsite (2020) Onebuilding.org. Available at: https://climate.onebuilding.org/WMO_Region_1_Africa/BEN_Benin/index.html (Accessed: January 10, 2021).

12. Corporativa, I. (no date) Bioclimatic architecture, buildings that respect the environment, Iberdrola. Available at: https://www.iberdrola.com/innovation/bioclimatic-architecture-passivhaus (Accessed: January 10, 2022).

13. Cotonou Population 2021 (no date) Worldpopulationreview.com. Available at: https://worldpopulationreview.com/world-cities/cotonou-population (Accessed: October 11, 2021).

14. DeKay, M. and Brown, G. Z. (2014) Sun, wind, and light: Architectural design strategies: Architectural design strategies. 3rd ed. Chichester, England: John Wiley & Sons.

15. Dellicour, O. et al. (1978) Vers une meilleures Utilisation des ressources locales en construction. Unesco.

16. Djongyang, N., Tchinda, R. and Njomo, D. (2012) Estimation of some comfort parameters for sleeping environments in dry-tropical sub-Saharan Africa region, Energy conversion and management, 58, pp. 110–119. doi: 10.1016/j.enconman.2012.01.012.

17. Dresden (2015) Dresden schwitzt, das Umweltamt misst und plant die Kaltluftschneisen der Zukunft, www.dresden.de. Available at: https://www.dresden.de/de/rathaus/aktuelles/pressemitteilungen/archiv/2015/07/pm_049.php (Accessed: January 10, 2022).

18. EIES (2018) Rapport final de l'EIES des 8 900 logements sociaux et économiques, Boad.org. Available at: https://www.boad.org/wp-content/uploads/2019/08/EIES-8900-version-finale-030418.pdf (Accessed: January 9, 2022).

19. Grellier, C. (2020) Design endogène : processus de création de matériaux locaux appropriés au Bénin. Dumas. Available at: https://dumas.ccsd.cnrs.fr/dumas-03065620.

20. Grellier, C. (no date) Atelier Des griots. Available at: https://www.infinitecreativityfiniteworld.com/en/works/atelier-des-griots/ (Accessed: January 12, 2022).

21. GTAI (2021) Wirtschaftsdaten kompakt - Benin, Gtai.de. GTAI. Available at: https://www.gtai.de/gtai-de/trade/wirtschaftsumfeld/wirtschaftsdaten-kompakt/benin/wirtschaftsdaten-kompakt-benin-179902 (Accessed: October 11, 2021).

22. Guide du bâtiment durable en régions tropicales - Tome 1 - IFDD (2019) Francophonie.org. Available at: https://www.ifdd.francophonie.org/publication/guide-du-batiment-durable-en-regions-tropicales-tome-1/ (Accessed: October 11, 2021).

23. Institut de la Francophonie pour le Développement Durable (2015) Guide-du-batiment-durable-en-regions-tropicales-tome-1. Available at: https://www.ifdd.franco-phonie.

org/publication/guide-du-batiment-durable-en-regions-tropicales-tome-1/ (Accessed: January 9, 2022).

24. John Arnfield, A. (2020) Köppen climate classification, Encyclopedia Britannica.

25. Kiki, G. et al. (2020) Evaluation of thermal comfort in an office building in the humid tropical climate of Benin, Building and environment, 185(107277), p. 107277.

26. Lauber, W. (2003) Klimagerechte Architektur in den afrikanischen Tropen. Universitat Kaiserslautern. Available at: https://opus.htwg-konstanz.de/frontdoor/deliver/index/docId/28/file/Klimagerechte.pdf.

27. Leo Samuel, D. G. et al. (2017) Thermal comfort in traditional buildings composed of local and modern construction materials, International journal of sustainable built environment, 6(2), pp. 463–475. doi: 10.1016/j.ijsbe.2017.08.001.

28. Ligner, S. (2013) La Villa Ajavon, Fondation Zinsou. Available at: https://www.fondation-zinsou.org/musee-de-ouidah (Accessed: January 9, 2022).

29. Lippsmeier, G. (1980) Tropenbau: Building in the Tropics. Engl./Dt. 2nd ed. Munich, Germany: Callwey.

30. Maghrabi, A. A. (2000) Airflow characteristics of modulated louvered windows with reference to the rowshan of Jeddah, Saudi Arabia Thesis submitted in accordance with the requirements of the University of Sheffield for the degree of Doctor of Philosophy by, Whiterose.ac.uk. Available at: https://etheses.whiterose.ac.uk/14623/1/327624.pdf (Accessed: January 13, 2022).

31. Moussa, H. S. et al. (2019) Comparative Study of Thermal Comfort Induced from Masonry Made of Stabilized Compressed Earth Block vs Conventional Cementitious Material. Available at: https://www.researchgate.net/publication/336691329_Comparative_Study_of_Thermal_Comfort_Induced_from_Masonry_Made_of_Stabilized_Compressed_Earth_Block_vs_Conventional_Cementitious_Material.

32. Netherlands (no date) Worldbank.org. Available at: https://climateknowledgeportal.worldbank.org/country/netherlands (Accessed: January 5, 2022).

33. Nicholson, S. E. (2018) The ITCZ and the seasonal cycle over equatorial Africa, Bulletin of the American Meteorological Society, 99(2), pp. 337–348. doi: 10.1175/bams-d-16-0287.1.

34. ONU Habitat (2014) L'Etat des Villes Africaines. Available at: https://www.academia.edu/9384448/Letat_des_Villes_Africaines_2014_Reinventer_la_transition_urbaine?pop_sutd=false.

35. Peel, M. C. and Finlayson, M. C. (2011) Köppen-Geiger climate classification group A, Wikimedia.org. Available at: https://upload.wikimedia.org/wikipedia/commons/f/fa/Koppen_World_Map_A.png (Accessed: September 11, 2021).

36. de Saint-Exupery, A. (1973) Terre des hommes. Paris, France: Gallimard.

37. Sarr, F. (2020) Afrotopia. 1st ed. Translated by D. S. Burk and S. Jones-Boardman. Minneapolis, MN: University of Minnesota Press.

38. de Schiller, S. and Evans, J. M. (1998) Sustainable urban development: design guidelines for warm humid cities, Urban design international, 3(4), pp. 165–184. doi: 10.1080/135753198350299.

39. Schreckenbach, H., Kojo Abankwa, J. G. and Institute of Advanced Architectural Studies (1982) Construction technology for a tropical developing country. Gtz.

40. Simau (no date) SImAU SA, Simaubenin.com. Available at: https://simaubenin.com/ (Accessed: October 25, 2021).

41. Sivak, M. (2013) Air conditioning versus heating: climate control is more energy demanding in Minneapolis than in Miami, Environmental research letters, 8(1), p. 014050. doi: 10.1088/1748-9326/8/1/014050.

42. Solargis (2019) Global Solar Atlas, Globalsolaratlas.info. Available at: https://globalsolaratlas.info/download/benin (Accessed: January 9, 2022).

43. UNIDO (2013) Country grouping in UNIDO statistics, Researchgate.net. Available at: https://www.researchgate.net/publication/275019711_Country_grouping_in_UNIDO_statistics (Accessed: October 11, 2021).

44. United Nations (no date) The 17 goals, Sdgs.un.org. Available at: https://sdgs.un.org/goals (Accessed: January 10, 2022).

45. Wade, A. (2019) Ganvie, Benin - the Venice of Africa, Happy Days Travel Blog. Available at: https://www.happydaystravelblog.com/ganvie-benin-venice-of-africa/ (Accessed: January 12, 2022).

46. World Bank (2020) Benin, Worldbank.org. Available at: https://climateknowledgeportal.worldbank.org/country/benin (Accessed: January 5, 2022).

47. Worldometer (2021) Benin Demographics, Worldometers.info. Available at: https://www.worldometers.info/demographics/benin-demographics/ (Accessed: October 25, 2021).

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