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Bioclimatic architecture as a potential for developing countries

Christophe Nkuina, PhD

*Department of Architecture and Urban Planning, University of Douala, IBA at Nkongsamba, Cameroon
christophenkuina@yahoo.it*

Abstract. Energy savings inside buildings require a comprehensive design approach to balance bioclimatic strategies with the use of active systems. A climatic responsive building aims to mediate external agents both to reduce climate loads and to create a healthy and comfortable indoor environment. The sensitive approach to comfort gives nowadays more chances to implement passive strategies and especially the use of natural ventilation. The proper adjustment of the architecture to the climate is one of the basic characteristics of vernacular building. Nowadays this area received an important support through the application of cutting-edge technology. Still, despite the clearly visible change of attitudes towards nature, more detailed analysis often lead to the conclusion that the arising buildings are very rarely based on extensive studies of local bioclimatic conditions. The purpose of this paper is to discuss how the traditional ways of adapting dwellings to the climate are combined with advanced technology and applied in contemporary bioclimatic buildings but also to pay particular attention to the use of local materials and construction techniques. The northern and southern regions of Cameroon with the Mousgum huts and traditional chiefdoms respectively will allow us to highlight certain technical identities and constructive traditions that are answers to sustainability in local architecture in Cameroon. Five important case studies are briefly presented in order to demonstrate that the relevant distinguishing feature of bioclimatic architecture is to go beyond the scheme of low-energy buildings, constructed from renewable materials and meeting the conditions of sustainable development certification systems. It is much more vital for the true green design to implement the structures in the ecosystem in such a way that they become an integral part of it. Thus understood bioclimatic architecture is logical, well adapted to the climate and therefore also economical. It creates great opportunities and should be perceived as the solution for the developing countries (but also for the whole world).

Keywords: architecture; bioclimatic; ecosystem; materials; vernacular; energy; natural cooling.

Introduction

The idea of bioclimatic architecture is closely related to the proper adjustment of the dwelling to the climate. That is also one of the characteristics of vernacular building, based on the traditional ways of adapting architecture to the specific climatic conditions. Vernacular architecture is directly linked to the available resources that influence building techniques (Balbo, 2013, p.37). Furthermore, it is customized to the functional needs and cultural background of the inhabitants. The main difference between vernacular and bioclimatic building lies in the ability to select the technological solution most appropriate to the climate. In traditional architecture that kind of knowledge has been naturally transferred from one generation to another. In bioclimatic building the concept of architecture optimally adapted to the local conditions received an important support through the application of advanced technologies. Due to the combination of traditional climatic solutions and cutting-edge technology, bioclimatic dwelling is well suited to the needs of the contemporary user. The other difference involves proper understanding of complexity and sensitiveness of the natural environment. Bioclimatic architecture is based on holistic approach, including in-depth environmental analysis. Ultimately, the bioclimatic building should become an integral part of the ecosystem and ensure the symbiosis between the cultural and natural processes. However, despite clearly visible change of attitudes towards nature, the alarming datum is that more detailed analysis of projects often lead to the conclusion that although the idea of so-called sustainable design is manifested all over the world, in fact, the

arising edifices are. rarely based on extensive studies of bioclimatic conditions as the wider aspect of the problem is sometimes simplified (or even ignored) within the design process oriented towards the energy certification achievement (e.g. Telles, 2012).

Analysis of the various solutions, used in similar climatic conditions, combined with the application of contemporary knowledge allows to develop and to implement technologies that will help to customize the newly erected buildings to the requirements of the modern user. Two biggest challenges in this area are connected with the indoor climate and lighting (McIntyre, 1980; Mahdavi, 1996). Adequate lighting of the interiors with the use of daylight not only positively affects the user comfort, but also has a significant impact on reducing electricity consumption. Although this aspect is considered by the designers more often than the natural cooling, the proper use of daylighting should be further promoted.

The necessary factors of the comfortable indoor microclimate are: thermal comfort, proper air humidity, adequate air exchange rate, the correct oxygen content (this parameter can be improved for example by the introduction of green plants inside the building) etc. In most of developing countries the challenges of thermal comfort derive from the necessity of cooling the indoor air. Despite many criticism, the plant air conditioning systems are so widespread that they are most frequently applied in purpose to provide low temperature and low humidity in the buildings (Mahdavi, 1996). That kind of cooling is commonly used, especially in the offices, retail spaces or public buildings, regardless the high costs, electricity consumption, environmental impact and without considering the application of natural systems, based on local bioclimatic conditions. In many cases the only difference between conventional and so-called sustainable building is limited to the fact a part of electric energy for air conditioning systems comes from photovoltaic panels or other renewable sources.

NATURAL VENTILATION SYSTEMS IN HOT CLIMATE

Cooling systems in vernacular architecture in hot climate zones are based on natural ventilation. Among various schedules observed in traditional dwellings there are three basic models distinguished by Sørensen, that may be applied in contemporary bioclimatic architecture (Sørensen, 2008). These are:

1. Cross ventilation based on the pressure difference across the building shown in **Figure 1a**.
2. Chimney ventilation based on the stack effect i.e. underpressure caused by the rising hot air shown in **Figure 1b**.
3. The wind catchers and wind towers based on overpressure and underpressure presented in **Figure 1c**.

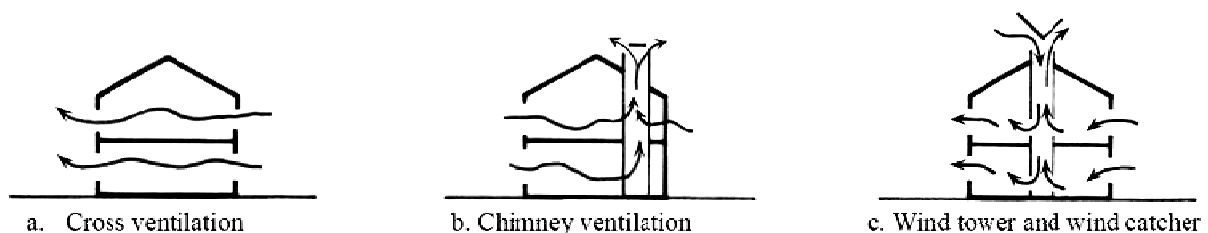


Figure 1 Basic models of natural ventilation. Based on Sørensen (Sørensen, 2008).

In many regions some modifications improve these basic systems. In hot and humid regions, e.g. in Thailand, many traditional houses are openwork and built on high stilts, so that the cross ventilation is combined with the elevated floor as described by Tantasavasdi and presented in **Figure 2** (Tantasavasdi et al., 2001; Tantasavasdi et al., 2007). In Japan, where the temperatures are lower, the floor is slightly raised above the ground. In both cases the air flows under the building to cool it in summer and – in case of the Japanese house – to separate it from the ground in winter. Also in both dwelling types the roof drainage systems (made of natural materials) allow for collecting rainwater.

Different solutions may be observed in hot and dry climatic conditions of Arab countries where the wind towers and wind catchers are quite common. They may be additionally combined with simple but effective evaporative cooling systems described by Hassan Fathy (Fathy 1986) as shown in **Figure 3**. On the basis of these solutions some holistic concepts for bioclimatic architecture were created. The leading architectural workshops in this area are Mario Cucinella Architects (MCA) and TR Hamzah & Yeang.

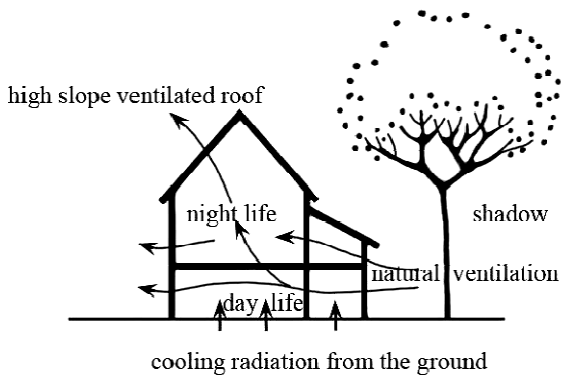


Figure 2 Natural cooling in Thailand. Based on Tantasavasdi (Tantasavasdi 2001).

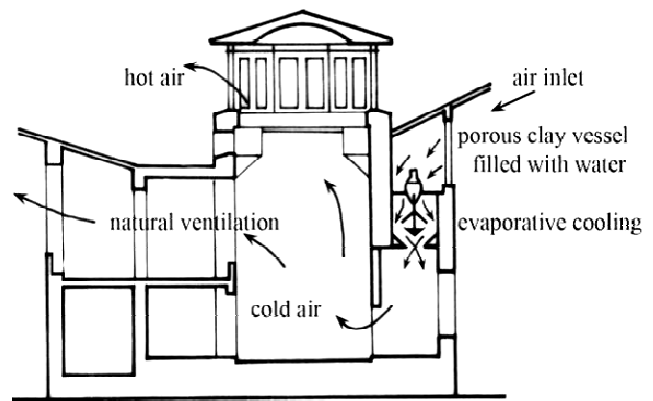


Figure 3 Evaporative air cooling system in Egypt. Based on Fathy (Fathy 1986).

BIOCLIMATIC ARCHITECTURE AND ECOSYSTEMS

It should be noted that while sustainable development program in architecture strongly accentuates local aspects, under the label of sustainable architecture there is often an attempt to create a global golden rule of architecture. The evaluation methods are inherently characterized by some averaging, but the creation of the built environment truly adapted to the bioclimatic conditions requires an individual approach. Conducting environmental analysis is necessary each time for the specific location. Moreover, due to dynamic nature of ecosystems, analyses should be repeated and changes monitored (Yeang, 1996). Increased attention is given to the relationship between the architecture and the ecosystem (Hart, 2011). Ken Yeang, one of the most important creators and promoters of bioclimatic architecture, notes the necessity of integration of the following Eco Infrastructures:

1. Green - connected with natural habitats and the environmental biodiversity.
2. Gray - related to engineering that include sustainable energy and technologies oriented towards low environmental impact as well as zero CO₂ emissions.
3. Blue - concerning water management, rainwater harvesting and gray water recycling.
4. Red - referring to human culture i.e. law regulations, social norms and habits, user comfort, standard expectancy, materials as well as the human impact on the environment.

Each part of infrastructures described above is analyzed and developed in close relation to the existing ecosystem, with the intention to restore, preserve and enrich its equilibrium and biodiversity. Proper implementation of that strategy into the bioclimatic design leads to the authentic adaptation of architecture to the local context. Thus created holistic approach is an important distinguishing feature of bioclimatic architecture.

CAMEROON BETWEEN CULTURAL IDENTITY AND SUSTAINABLE CONSTRUCTIVE TECHNIQUES

Before the effective implantation of the Europeans in 1884, Cameroon like many African countries had their own type of architecture. Evidenced in her ancestral traditional societies, she serves as a determining tributary for ecological zones within which multiple techniques have been experimented. The research focuses on the traditional architecture that is synonymous with the precariousness and ingenuity of the man who has been able to exploit the elements that nature has given him to suggest that sub-Saharan Africa has no architecture. It was difficult to accept that traditional Cameroonian architecture carried technical identities because of its vulnerability and fragility.

The architectural richness of Cameroon is due to the multiplicity of its architectural forms. There are, however, some sixty of them in the north without even going down to the level of variations between the same ethnic groups. Factors that determine traditional architecture can be categorized as determining factors and disruptive factors. These factors are twofold: on the one hand objective: climate, available materials, know-how, lifestyle and on the other hand subjective: aesthetic taste, respect for traditions, magico-religious environment. These different elements deserve to be analyzed point by point.

- The climate. The fundamental parameter is an absolute constraint imposed on man. It includes temperatures; precipitation; relative humidity of air; winds; sunshine.

It should be noted that, in the same climate, different responses may be envisaged depending on the nuisances and the protections that are favored.

- The materials available. There is often a wide range of options: -dug shelters; stone; -terracotta; raw earth; wood and bamboo; vegetable fibers (straw); hides; wool. These materials can be combined, which further increases the number of variants.

- Know-how. It is the set of techniques available, it depends on: - the degree of development of the group; the tools available; the chance of inventions; the ingenuity of men; external influences. Here again, a large choice of techniques is often indispensable.

- Type of life. It determines the type of habitat enormously by imposing constraints: the nomad will have to transport his shelter; the semi-nomad will have to dismantle and move his habitat; the sedentary will ensure the sustainability of his housing; the relations of neighborhood and insecurity impose particular types of construction or exceptional sites of settlement.

- Aesthetic taste. However difficult to identify, it is linked to the unconscious of the group; to the structures of the mind; to the analogies with nature; to external influences.

- Respect for traditions. A fundamental element in ancient societies, it stems from a need for balance for the group. It is obtained through group-level sanctions, such as in the Bamiléké; magical-religious sanctions.

- The magical-religious environment. It influences the organization of the habitat which must be in accordance with the precepts of lifestyle; be protected against malevolent supernatural spirits.

In the Southern region of Cameroon in general, a zone of dense forest the Fang, Beti, Bulu, Sawa, Maka, Bamiléké and the Pigmies, were able to exploit materials offered to them by nature which permitted them to put in place an assembly designs and structures. Indeed, they dealt with knitting, careful fitting and sculpture to build square house using barks of trees, bamboo as well as other kinds of sticks and leaves most used by the pigmies.

The earth mud most used today arrived this region lately. In the Sudano-Sahel region a different kind of assembly bond of sticks alongside bigger stones and an accessories of earth bricks are variedly used. In this area, the pisee is most cherished to build houses among the Mousgum (*The Mousgum inhabit the lowlands of Logone, which borders Chad and Cameroon.*)

Referring to human culture i.e. law regulations, social norms and habits, user comfort, standard expectancy, materials as well as the human impact on the environment, Cameroon results as one of the countries in the world where the diversity of architectural models and construction methods are of particular uniqueness.

THE CIVILIZATION OF BAKED CLAY AND RAW EARTH IN NORTHERN CAMEROON

Traveling around Mousgum country, the cob they call “the main material” is a mixture of suksukiy herbs, goat excrement and clay soil. Goat manure acts as a binder. These round dwellings of 3 to 5 meters have only one opening: the entrance and exit door. When it comes to building the dwellings, each builder plans his construction work preferably in the dry season. In the morning, he prepares the amount of cob he will use during the day. Once the location is defined with the hoe, the technician manually cuts the cob into clumps. The material is spread over the outline of the plane and forms the base layer 15 cm high. The cob is deposited in successive layers from bottom to top. The operation is repeated up to the desired height of the wall, which usually does not exceed 3 meters. When the wall elevation, which lasts an average of seven days, is completed, the conical roof begins to be made. The roof frame is made up of poles assembled by ligature and consolidated by rings. The roof is covered with thatch and forms a bouquet at the top.

The initial choice of location for a shell box concession depended on the metaphysical nature of the land. The site was tested at midnight: the ground had to give off a freshness (symbol of peace with nature). If the terrain was heating up (a symbol of disturbance), it was advisable to find another location. The construction of the shell hut, as we have seen, is a global phenomenon: the manifestation of a constructive intelligence that comes to life in the confrontation between the physical constraints of a territory, the potentialities of the available natural materials, and the customary beliefs structuring the life of the Mousgoum. The construction of a shell house does not require a foundation.

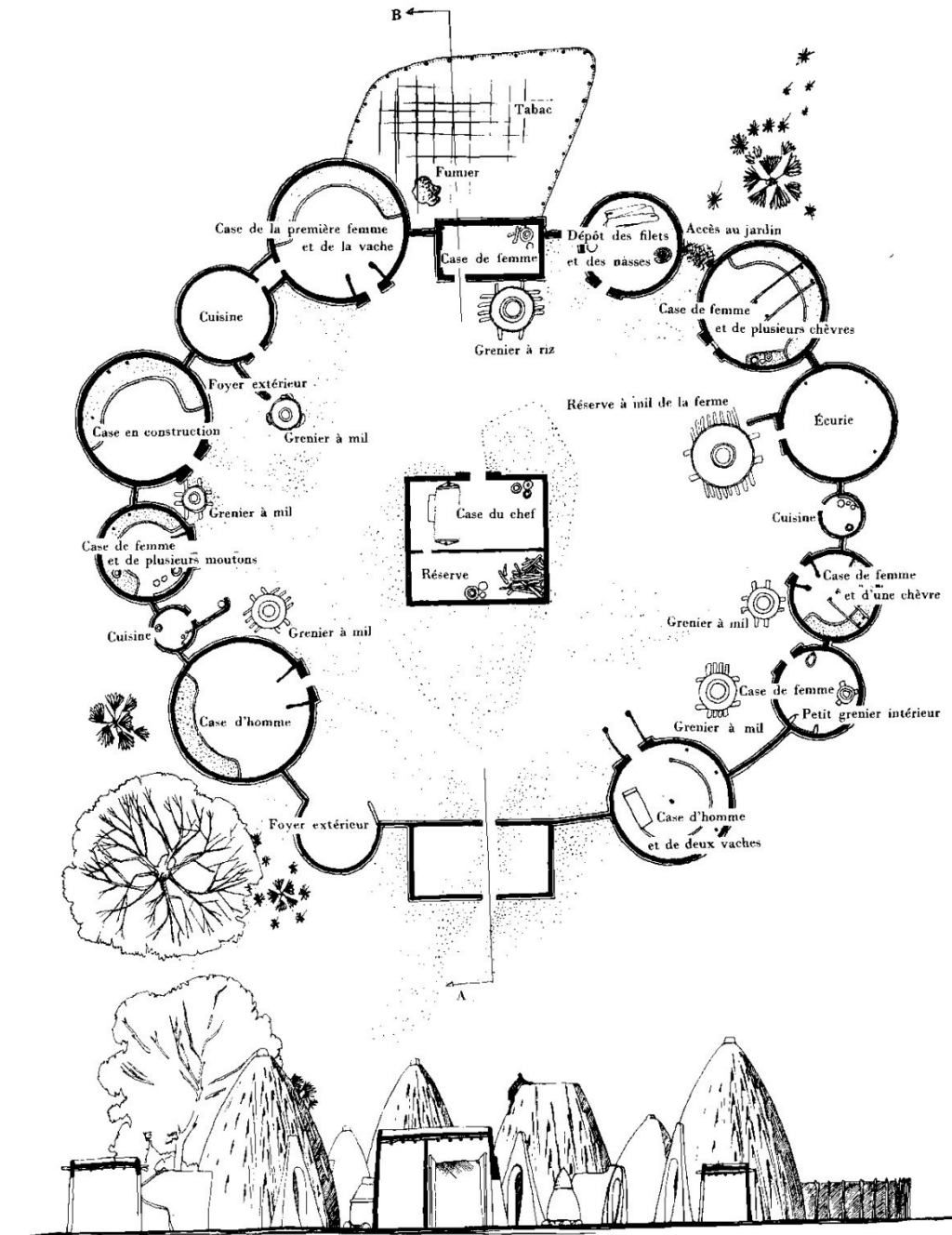


Figure 4

Mousgoum Farm.© GAIA.

Analyzing the architecture of the Mousgoum, a people of the lowlands of Logone bordering Chad and the far north of Cameroon, we notice that their dispersion over a vast geographical area reflects a turbulent history. The type of construction Mousgoum is adapted to the Sahelian climate prevailing there. This type of concession can have about fifteen huts housing an entire family (from grandparents to grandchildren) organized around the hut of the head of the family. In the central courtyard, is installed an attic that receives the millet reserve. The rest of the courtyard contains a meeting place for adults, an initiation area and play areas for children. A concession before it is occupied is always blessed with a ritual of sacrifice to drive out unclean spirits. The shells have always been very slender, with a diameter of up to 5 meters and a height of 8 meters. Clay is the only material available in sufficient quantity in the area. Mastering pottery well, the Mousgoum built their boxes using the same shaping technique that imposed a progressive closure, therefore very high. However, despite its apparent simplicity, this box model made it possible to respond judiciously and economically to many needs and to deal with serious problems. The Mousgoum would have had the concern to protect themselves against bushfires (common in dry seasons) as well as raids of warrior tribes (the huts could be mistaken for termite mounds and not attract attention).



Figure 5 Mousgoum shell hut in Mourla. Source: Encyclopédies du Cameroun

The cob in the northern part of the country is helping to shape one of the most beautiful traditional architectures in the world, the Mousgoum shell hut and the kotoko palaces. These productions have enriched the world's real estate heritage. This diversity of architectural techniques constitutes, in fact, particularity of the local architecture. We will focus here on the the Mousgoum shell hut.

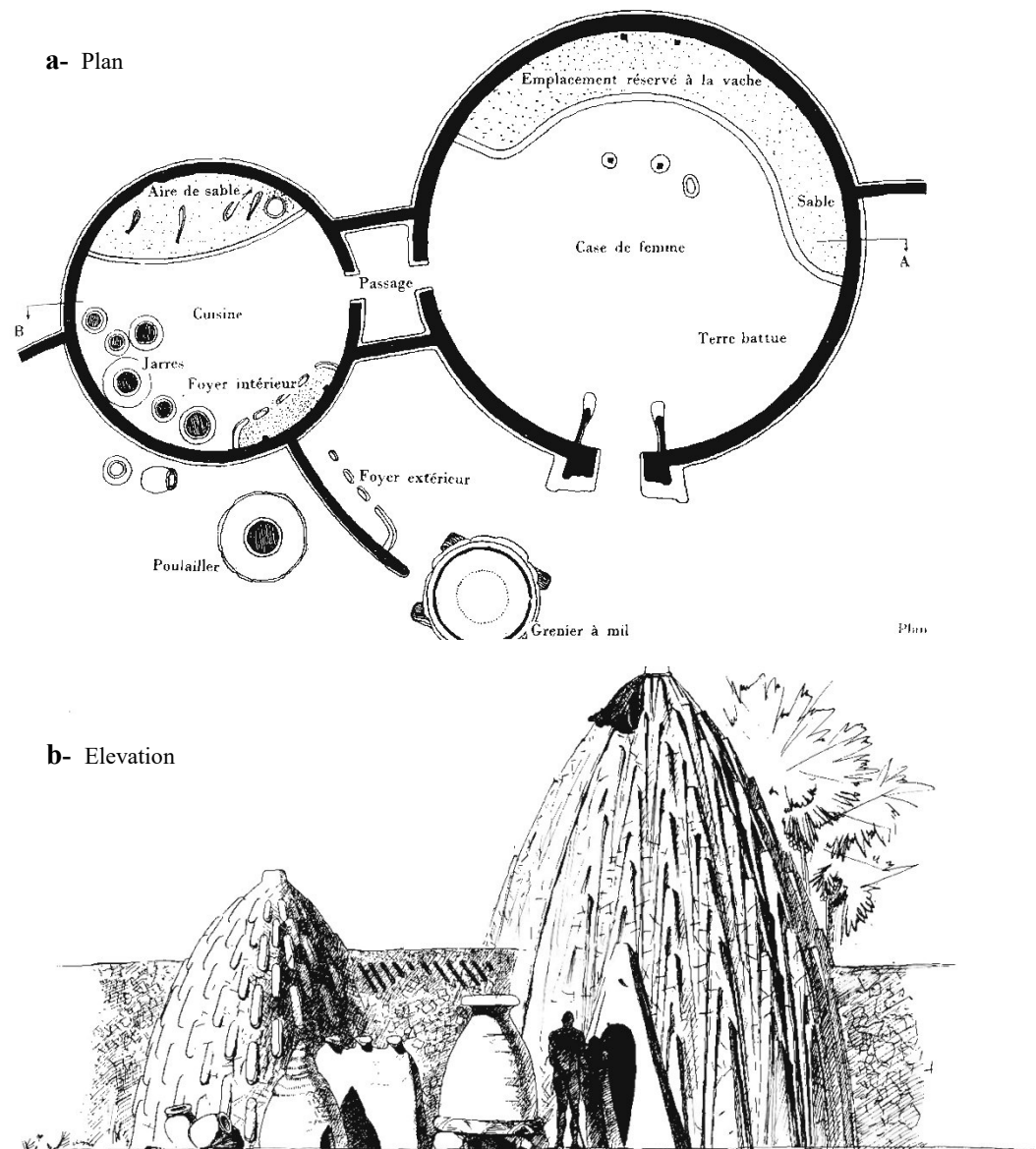


Figure 5 a-b Plan and elevation of a woman's hut

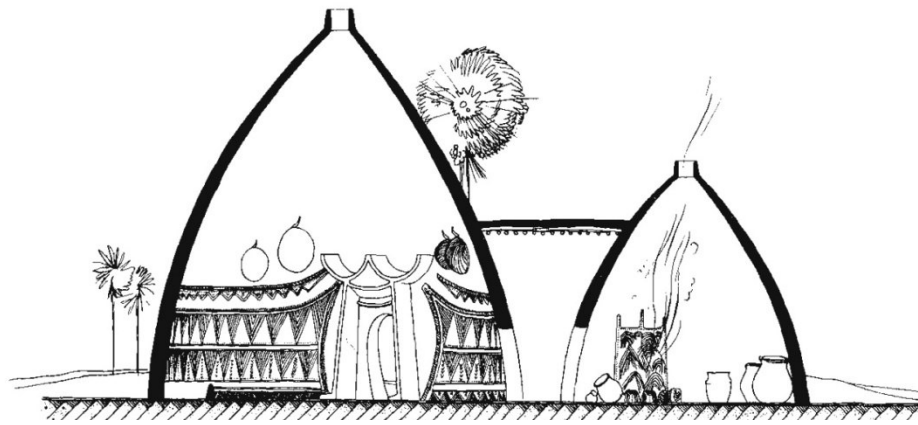


Figure 6 Section AB of the woman's hut and her kitchen

It's important to remember that it represents a technical feat whose simple and aesthetic result meets many needs. A lesson in architecture, construction and respect for the environment. The need for them to be preserved is therefore obvious. But it is above all based on the preservation of knowledge.

WEST CAMEROON WITH ARCHITECTURE ADAPTED TO THE ECOLOGICAL CONTEXT AND THE LOCAL CLIMATE

The traditional Bamileke habitat, which is also a cultural curiosity, is built with these local materials, including dried mud brick (*commonly known as poto-poto*), wood (bamboo), and straw or sheet metal for roofing. Its structure and solidity are astonishing, as evidenced by the large huts of the chiefdoms of the surroundings of Bafoussam (*locality of west Cameroon*) with their conical roofs (**Figure 8**) The façades are made of bamboo patiently bound with vegetable fibers; some are decorated with geometric patterns. The doors, framed with carved panels, are raised 50 cm from the ground so that the flow water and animals do not pass through them. The assembly is topped by a heavy conical roof thick enough not to let rain drops filter through. The exterior of the hut tends to change more and more, despite the desire of some notable bamilekés to preserve the old local architecture. The thatched roof is replaced by a corrugated sheet metal roof and the bamboo curtains no longer cover the facades. However, the interior of the huts remains the same everywhere. The hearth is in the center of the large room; three stones are enough to support the pots. All the furniture is made of bamboo: the ladder to climb to the attic where are stored peanuts, corn and wood, shelves to store household utensils, beds and even stools.

The family hut is not really one. The rooms are generally numerous and are intended to accommodate an entire family. Very functional, they are equipped with an attic to store cereals. The steep thatched roof and raised foundations provide a safe way to endure the harsh rainy season in the Western Province.

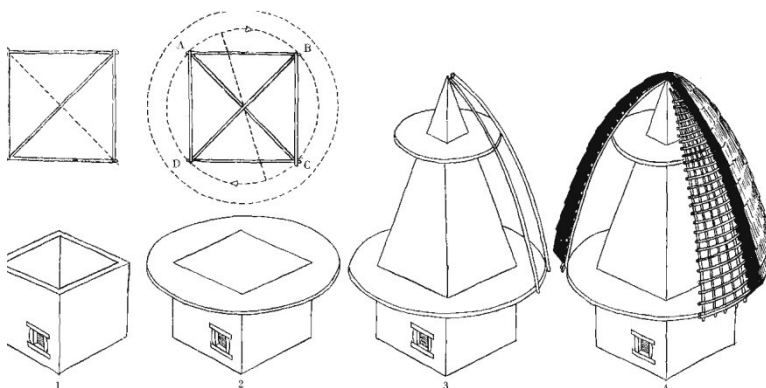


Figure 7 Bamiléké construction house diagram



Figure 8 Example of a traditional hut in force among the Bamiléké. Source Testa Olivier,2011

The Bamiléké hut is an architectural and technical masterpiece, a work of art in itself. It's characterise by square plan, red earth walls on which are placed conical roofs of gray thatch, this is in a few words the description that a traveler could make of them. In fact, it's not as simple as that. If you want to build a hut, you must first ask your leader for permission. The latter is the sole depositary and distributor of the land. The plot obtained, it remains to

build the box. Every Bamiléké, has always more or less participated in the construction of his chief's or his father's village. The art of building is therefore known to him, but not being able to do this work alone, he will call on friends and specialists for the work. In his home country, nothing is improvised, all the contrary is regulated as a precision mechanism. A construction site is the most striking example. While the masons build the walls of the future construction, the carpenters make the elements of the roof, the roofers prepare the thatched hoods. Once the walls are finished, the framework only needs to be assembled and assembled; once the structure is finished, the number of boots required for the cover is waiting at the foot of the walls. All the teams work simultaneously and none is behind the other; everything is ordered like a real ballet.

As for the layout of the plan, the team first realized with four bamboos of the same length $AB = BC = CD = DA$, a more or less perfect quadrilateral, then with a bark strap it ensures that $AC = BD$ and thus obtains a square. On this perimeter, the workers will dig a channel a few centimeters deep, twenty centimeters wide and then place blocks of earth to serve as a base for the walls. The height of these blocks is always greater than the depth of the channel; the workers will fill the surface thus defined with earth up to the upper face of the blocks. It is this raised area that will serve as the ground for future construction.

A circular tray having as base a bamboo frame is built on the section of the hut, square frame whose sides are extended from 0.50 to 1 meter. By reaching the end of these bamboos, we would obtain an irregular octagon which takes the form of a more or less regular circle, thanks to the elasticity of the material used. Inside this circle, the carpenters inscribe other concentric circles until they reach the corners of the square. They thus obtain a rigid plate which they will then tilt on the top of the walls of the compartment; it is the plate which will serve as the base plane for the roof and the second attic.

CONTEMPORARY ARCHITECTURE IN CAMEROON AND THE ECOSYSTEM OF TRADITIONAL BUILDINGS

It may be pointed out here that construction material is becoming increasingly scarce. Indeed, the climate and environmental transformations that the planet has undergone for decades have not gone unnoticed in Africa. The climates are becoming drier and drier. Soil, clay and bamboo, the most important materials for traditional construction, are becoming increasingly scarce as they require a lot of moisture and water. The great winds, the endless rains, etc. are now a great danger to these traditional huts when we know that they are built with materials that in the time of the ancestors were perfectly resistant to all this weather. In addition, bamboo is mined and used for construction, but no reforestation methods are planned. Not only is it becoming increasingly scarce, but it can only be found on the market at prices that no longer have anything in common with those of the ancestral times when they were available to all.

For several years, the architectural landscape of Cameroonian cities and countryside has been deteriorating at high speed. Indeed, the megalomania of the newly rich is all too often observed, because they believe that building a European-style house is an outward sign of wealth. As a result, huge multi-story villas proliferate on all sides, whether in town or in the countryside. Often inspired by examples taken from books, they do not correspond at all to African harmony and lifestyle. Moreover, the authorities issuing building permits with a cookie cutter do not care much about aesthetic considerations. The garden, a traditional element of the African concession, is mostly absent. The country's fast-growing population probably plays a part in this, as housing is so difficult. Cameroon would, however, benefit from exploiting its cultural heritage in the construction of houses.

Colonization had a very strong influence on traditional societies and brought modern cultures while neglecting theirs. Here the notion of traditional and modern finds all its meaning, without having much to do with the type of construction, but rather with the class of man in society. The man is therefore classified in society according to the type of construction he has adopted. *Traditional architecture* is no longer a symbol of cultural identity, but rather an outward sign of poverty. *Modern architecture*, on the other hand, is an outward sign of wealth, prestige, and openness to the modern world. In general, it can be seen that the habitat tends to evolve towards the "European villa" type (kitchen, dining room, living room...), object placed in the middle of the field with stages in this evolution according to the resources available.

Contrary to what one might think, it is not the architects who impose these villas on their client because they have themselves been sensitized to the traditional architecture of their country in foreign countries. But it is the customers themselves who are not asking for a house built of local materials, here considered rather as "materials of the poor". They want to be able to live in a villa that reflects what they think is the ideal solution. So the earth

material is reserved for the poorest, and no one makes that choice deliberately. For a type of construction to become a reference model for all, it must be adopted by those who have the power to choose a mode of construction and are not constrained for reasons to build in earth and straw. These models could therefore come from public buildings, thus showing the state's confidence in the chosen technique, but also its willingness to implement a given policy. The problem is that the state may not be it convinced of the usefulness of preserving traditional architecture and promoting local materials.

RELATION TO THE ECOSYSTEM ON THE EXAMPLE OF SOLARIS BUILDING DESIGNED BY TR HAMZAH & YEANG

Holistic and consequent approach to bioclimatic architecture can be observed in Solaris (2011, Singapore,) designed by TR Hamzah & Yeang. This 79-meters high structure is situated in Fusionopolis, in the area of the former military base which now became a fast developing business and research area of Singapore. Since the existing ecosystem was seriously damaged, one of the main goals of the architects was to restore and enrich its biodiversity in purpose to create equilibrium of the natural and built environment. Therefore the continuous perimeter ramp, with a length of 1500 meters, was designed to introduce maximum amount of green area into the building. The landscaped ramp established the link between One-north Park that reaches directly the building façade and Solaris towers. The higher tower has 15 and the lower 9 floors. Both of them house research facilities and offices. All the areas of the building are connected to the spiral ramp and passively ventilated atrium. The service path that goes through the ramp provides direct access for plants maintenance and is used as the linear park that leads up to the roof gardens on the top of each tower. This continuous landscaped spiral with a minimum width of 3 meters was designed for the benefit of the environment, as it enables fluid movement of small organisms between green areas of the edifice and thus contributes to biodiversity and health of the ecosystem. At the building corners the ramp expands to the terraces. As a consequence total landscaped area of the project covers 8,363 m², with the site area 7,734 m². That results with 108% ratio of landscape to site area and 95% of the landscaped area located above the ground level.

Bioclimatic concept combines traditional solutions developed for hot and humid climate zones with the most contemporary technology and knowledge. The climate-responsive façade design is based on studies of local climatic conditions, including the sun-path analysis. The specific building location at the equator and the east-west sun-path affected specific requirements of the façade shading. The first element of this strategy is the ramp with deep overhangs and the abundance of shade plants. The second solution in favor of the ambient cooling are the sunshade louvers with shape and depth determined directly by the solar-path analysis. The louvers and the green ramp created a pleasant buffer space which significantly reduced solar gains and glares. Consequently the heat transfer through the low-e double-glazed façades was also considerably decreased. The external thermal transfer value (ETTV) of the whole system is 39 W/m².

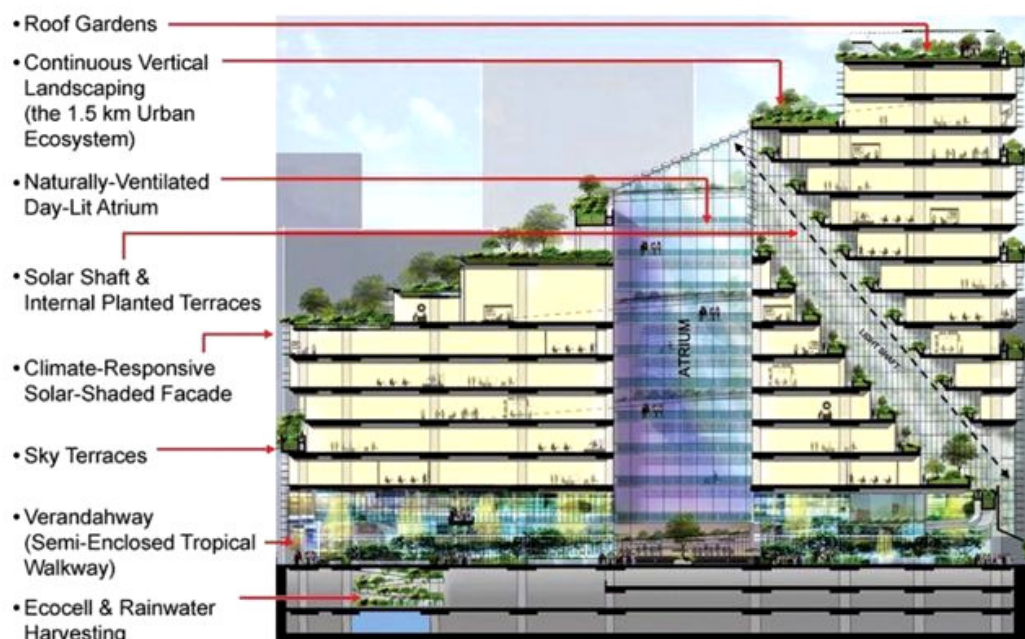


Figure 9 Solaris (2011, Singapore), by TR Hamzah & Yeang, bioclimatic section. © TR Hamzah & Yeang.

An atrium situated between the two towers is fully passively cooled and supports natural ventilation and daylight distribution within the internal areas of the building. An operable glass-louvered skylight system was installed on the roof over the atrium to enable stack effect cooling. Computational Fluid Dynamics (CFD) simulations were carried out to provide optimal thermal comfort with the controlled air flow in the atrium. Simultaneously, the active energy use was diminished. Both the louvers and the rainscreen walls are controlled by climate-responsive sensors to ensure protection against the precipitation and to allow natural ventilation during the rain. The atrium is directly connected to the landscaped area on the ground floor, linked to One-north Park which allows for cross ventilation. In order to provide optimal daylight penetration within the building's interior, the diagonal solar shaft was designed. It crosses the structure from the top of the higher tower down to the street level. The solar shaft gained more attractiveness with the landscaped terraces situated inside. Additional daylight is received from the façade shading louvers that create also double light-shelves and redirect the light into the building. To optimize the system performance a series of sensors measure the illumination level. When the sensors register a sufficient amount of daylight, the artificial lighting is automatically switched off. Thereby the energy consumption is reduced. As pointed out by Council on Tall Buildings and Urban Habitat (CTBUH), the reduction in overall energy consumption in Solaris building reached 36% compared to relevant precedents (CTBUH, 2012).

Due to the large amounts of vegetation located within the building, it was necessary to solve the problem of irrigation in an efficient and environmentally safe way. Based on the concept of bioclimatic design the attention was focused on the high average of rainfall in the area. Consequently a large-scale rainwater recycling system was proposed. Rainwater is harvested on the roof via symphonic drainage and on the perimeter ramp with the drainage downpipes. It is then stored in rooftop tanks and at the lowest basement level, beneath the place called Eco-cell. Eco-cell is located on the ground level at the building's north-east corner, at the beginning of the ramp. It allows for penetration of natural light and ventilation air as well as for the plants extension into the car-park area below. A total storage capacity of Solaris rainwater tanks is over 700 m³, which almost entirely covers the demand for watering plants. An integrated fertigation system provides plants with essential organic nutrients.

The project of Solaris building is adapted to local context on many levels. Similarly to CSET the design concept is based on analysis of the environmental factors, such as sun-path, sun angle, temperature and humidity. Moreover, the project's bioclimatic strategy seriously takes into account the individual character of the ecosystem, including the need to restore and enrich its biodiversity. Consequently, the idea of bioclimatic architecture is created in equilibrium with the natural environment.

Two of the edifices described: CSET Solaris building and ARPT are illustration on large scale. Promotion of such an approach is extremely important, as it helps to establish a model for developing countries. However, it is worth to notice that on a local scale it is possible to create bioclimatic architecture also with much lower budget.

ARPT ALGERI DESIGNED BY MARIO CUCINELLA ARCHITECTS



Figure 10

Bioclimatic architecture: *Orto dei Tu'rat*



Figure 11 Architettura ARPT algeri (2013), Mario Cucinella. Drawing © MCA

The project is inspired by the Algerian desert landscape where the dunes appear as ‘natural’ buildings, constructed by wind and sand. An analysis of the urban fabric, the location of the lot along a thoroughfare of great significance and above all the new urban park to overlooking Bab Ezzouar, offer the opportunity to create a highly visible and symbolic building. An institutional building providing a new home for ARPT should serve as a point of reference within its neighborhood and a city where tradition and modernity merge to create new symbolic and cultural scenarios.

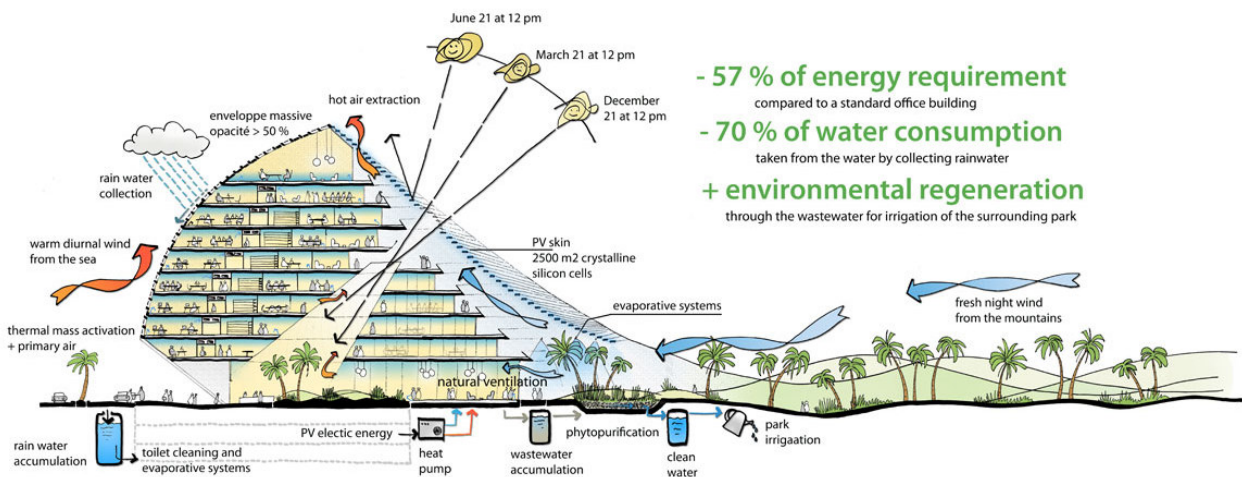


Figure 12 ARPT Algeri (2013) Mario Cucinella - environmental strategies – summer. Drawing © MCA.

The project proposes a highly iconic building far from the predominant aesthetics of the area, exploiting its direct contact with the new park. It emerges from the desire to create a building that works according to the principles of bioclimatic architecture, and in particular by the natural cooling techniques of the past, such as the *tu'rat*, has suggested an aerodynamic shape, convex on the North to divert hot winds at midday, and concave to capture the cool breezes at night, and thus promoting the natural ventilation of the building. Form, energy and tradition are thus transformed into a new building that will have to become an emblem of Algeria's development. The building was conceived to relate to the urban fabric with the adjacent park by shaping itself as a "gateway" and "fifth scene". "The new project - says the architect - was conceived as a unicum in which, the rhythm of the large portals, creates a wide pergola overlooking the park. The intention is not to repropose another character in a place where, the architectures present are already strong and loaded with symbolism". The horizontal building defines a scan, a rhythm that accommodates the different functions, offices and the auditorium/kindergarten, and a square that becomes the gateway to the park and the park.

The project was created with an intention to take the maximum advantage of the local bioclimatic conditions and to minimize the environmental impact of the building. Following the results of the local climate analysis, the designers developed the structure that allows to reduce the energy demand.

BURKINA INSTITUTE OF TECHNOLOGY DESIGNED BY KERE ARCHITECTURE

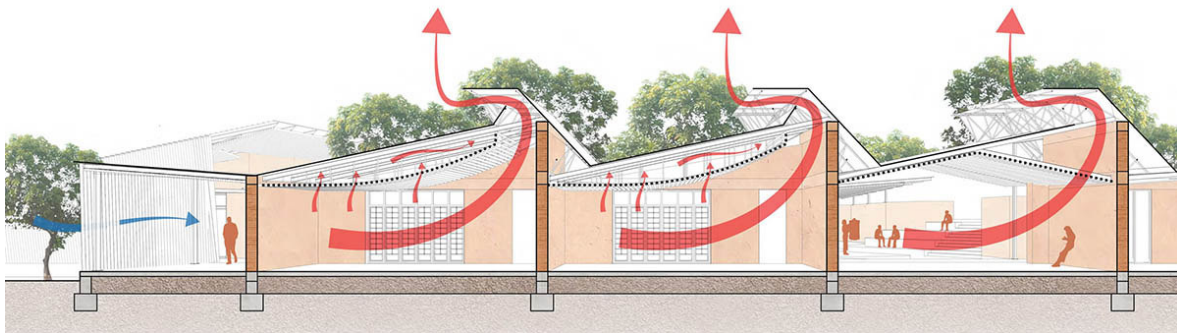
The Burkina Institute of Technology is designed using a system of repeated modules, housing classrooms and auxiliary functions, arranged orthogonally to define a rectangular courtyard.



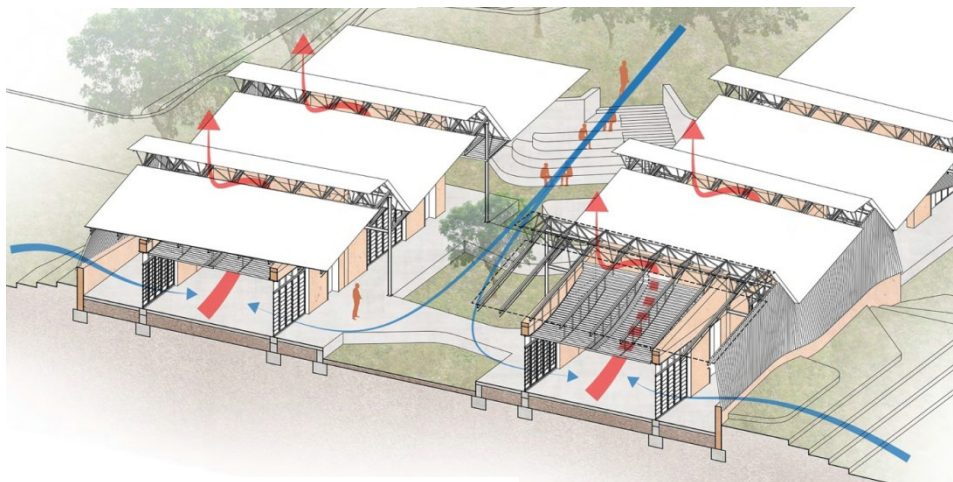
Figure 13 Burkina Institute of Technology (2021), Koudougou, Kere Architecture - Keré Architecture



Figure 14 Quality Architecture with locals materials



a. Longitudinal section – Keré Architecture



b. Axonometric view – Keré Architecture

Figure 15 a-b Burkina Institute of Technology (2021), Koudougou -Environmental strategies

The orthogonal arrangement of modules allows the campus to expand incrementally according to its needs. The modules are staggered, allowing air to flow through the central void, creating a cool space where students can relax and interact.

Building on the experience acquired on the *Naaba Belem Goumma* Secondary School, the walls are made of poured local clay, cast in-situ. This innovative method meant construction could be completed within a tight timeframe, using large formworks that allowed an entire module to be poured in one session.

Although the classrooms need mechanical air conditioning because of the IT equipment, the massive clay walls contribute significantly to cooling down the interior spaces.

The repetitive roof profiles create a dynamic rhythm and form a chimney at the back of each module where built-up warm air can be released. Hung ceilings, made of local eucalyptus wood, brighten the interior spaces and complement the smooth clay walls. To create a sense of unity with the rest of the campus, the buildings are clad in a transparent skin of eucalyptus wood to match the *Lycée Schorge*. Located on a flood plain, the project included extensive landscaping work to protect the buildings. During the rainy season, water is channelled into a large underground tank that is later used to irrigate the extensive mango plantations on the campus.

The project optimizes the natural chimney ventilation strategy. Fresh outdoor air that enters through large openings structured around the horizontal local wood Louvre heats up inside and exits on top through a roofing configuration designed to help evacuate this rising hot air.

ENVIRONMENTAL STRATEGIES IN THE CENTRE FOR SUSTAINABLE ENERGY TECHNOLOGIES (CSET) DESIGNED BY MCA

Centre for Sustainable Energy Technologies (2006-2008, Ningbo, China) was designed by Mario Cucinella Architects in cooperation with School of the Built Environment, University of Nottingham. The edifice is located in the Nottingham University new campus in Ningbo and it is dedicated to “(...) the diffusion of sustainable technology including solar power, photovoltaic energy, wind power and so forth” (Giorgi, 2006, p.90). The building itself represents advanced environmental strategies developed in direct relation to the local context. A very interesting hybrid system was applied in the project. It is based on the knowledge gleaned from vernacular architecture of hot climate areas (both dry and humid) and successfully combined with high-tech, environmentally safe technology. The non-conventional air-conditioning systems are supported with the cutting-edge technologies for the exploitation of renewable energy sources. The project was created with an intention to take the maximum advantage of the local bioclimatic conditions and to minimize the environmental impact of the building.

Following the results of the local climate analysis, the designers developed the structure that allows to reduce the energy demand for heating in winter and cooling in summer. During the intermediate seasons (spring and autumn) the natural ventilation, triggered by a series of automated openings, provides comfortable temperatures and humidity, so there is no need to use plant air conditioning systems. Regarding the climatic conditions it was essential to establish the proper thermal insulation and create massive structures with high thermal capacity. The crucial part of the heating and cooling concept was the carefully controlled air movement within the building. In hot and humid summer the passive cooling strategies are applied. Thereby the usage of plant systems is significantly diminished and limited only to the hottest days. During the warm part of the year the layer of the ground, located below the land surface, is colder than air. The incoming air is pre-cooled naturally when passing through the earth-to-air heat exchanger constructed in the form of a series of pipes buried in the ground as shown in **Figure 12**. Subsequently the air is further cooled and dehumidified by the air handling unit (AHU). Similarly the ventilation air coming through the air inlet in the tower is cooled and dehumidified by the AHU placed in a coverage. A solar chiller that pre-cools the external air for the tower ventilation is powered by hot water from solar tubes. Thus prepared air is distributed throughout the building. The chimney effect fastens the air exchange and the warm air is removed through the windows placed in the double skin south façade.

High thermal inertia of the green roof in the lower part of the building prevents overheating while thermal mass of the concrete surfaces supports the coolness distribution. The geothermal heat pump produces cold water for cooling the concrete floors. The radiant cooling from the ceilings is effective and healthy so that the mechanical cooling is required exclusively for pre-cooling the incoming ventilation air. In such a way the correct passive cooling design of the building and the high inertia of its concrete structure provide optimal indoor microclimate during summer.

The angles and materials of the southern part of the building were designed to pre-heat ventilation air in winter. The external air inlets are located on the ground level, at the bottom of the double skin façade so that during sunny days the air is naturally heated by the passive solar gains. After reaching the appropriate temperature the air is distributed in the edifice. Other air inlets are situated in the ground, outside the building. The incoming air is pre-heated by the earth-to-air heat exchanger. Further heating is provided by the geothermal heat pump, which is powered by energy from the photovoltaic panels. The air heating system is integrated with the radiant air-conditioning ceiling. The radiating coils embedded in the floors are activated when it is necessary to heat ventilation air. The heat is stored by the concrete ceiling slabs and released gradually to provide proper thermal comfort during the day. The northern façade is well insulated to avoid heat loss during the cold season of the year. The heat transfer coefficient of the opaque walls is $0,25 \text{ W/m}^2\text{K}$ and of transparent parts $1,2 \text{ W/m}^2\text{K}$.



Figure 16 Centre for Sustainable Energy Technologies (CSET, 2006-2008, Ningbo, China) by MCA

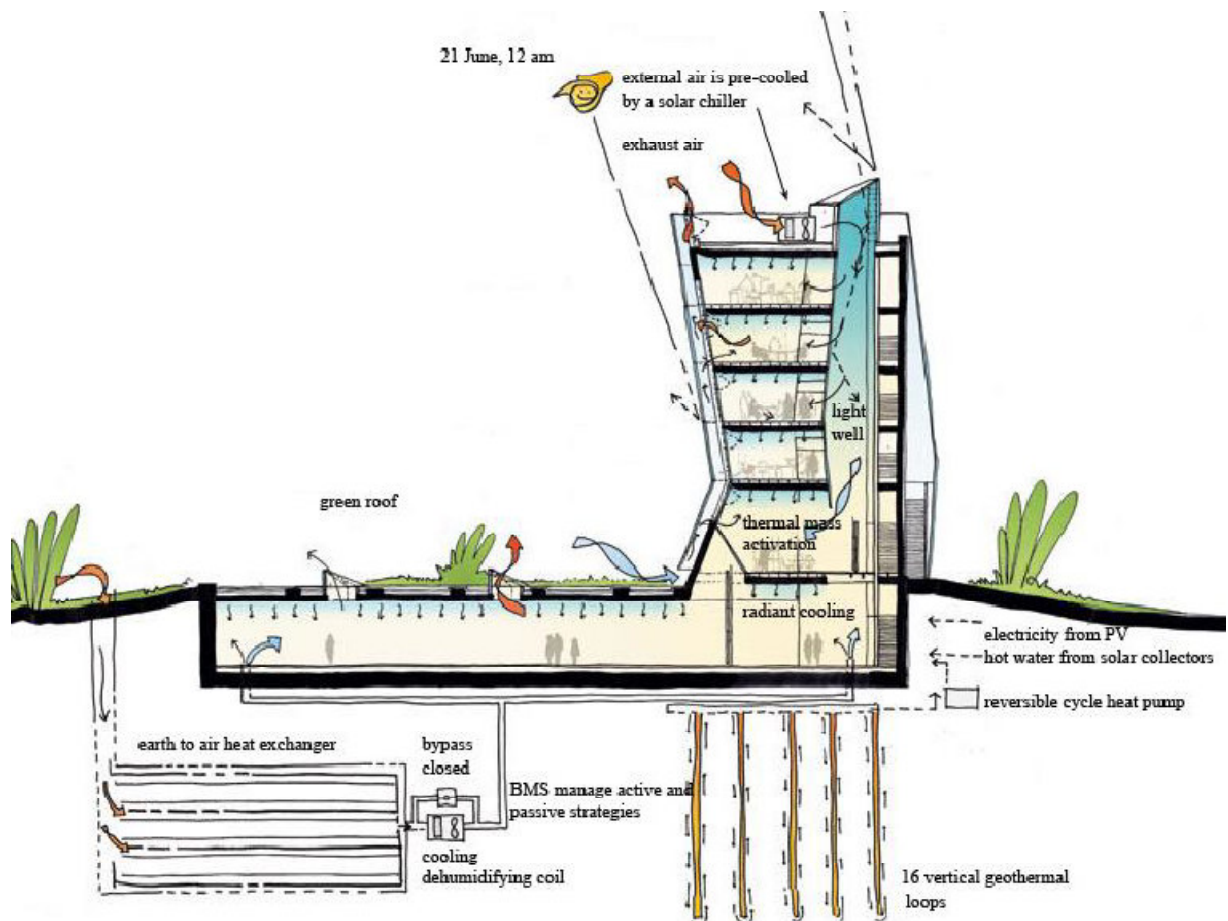


Figure 17 Centre for Sustainable Energy Technologies (CSET, 2006-2008, Ningbo, China) by MCA, environmental strategies – summer. Drawing © MCA.

The whole building envelope was designed in favor to provide maximum usage of natural light as it was possible without glare and overheating during summer. Such solution reduces the use of artificial lighting and thus also the electric energy consumption. All the necessary artificial lighting systems are characterized by high luminous efficiency and low power consumption. Electricity, required to power that lighting as well as the office equipment, comes from especially redesigned photovoltaic system. The energy surplus produced during maximum solar radiation periods can be stored in batteries or sold to the nearby sports center. The BEMS (Building Energy Management System) controls the building operation and manages active and passive systems to optimize comfort level, while reducing energy consumption.

All the environmental strategies were chosen in purpose to create contemporary bioclimatic building that provides proper balance between local climate factors (sun angle, air and earth temperature in different seasons, wind, humidity), ecosystem (plants and species of the area), technology (including renewable energy sources) and the occupant needs (indoor comfort, reference to Chinese culture). The educational value of the project is connected with promotion of the concept of bioclimatic architecture that derives from the environmental studies and therefore is very well adapted to the natural and cultural context

BENIN NATIONAL ASSEMBLY BY KERE ARCHITECTURE

Having outgrown its current building, which dates back to the colonial era of its past, the parliament of the Republic of Benin has entrusted Kéré Architecture to design a new national assembly that will embody the values of democracy and the cultural identity of its citizens.

The project takes inspiration from the palaver tree, the age-old West African tradition of meeting under a tree to make consensual decisions in the interest of a community. The palaver tree is a timeless symbol, having borne witness to previous generations and inspiring respect for the majestic forces of nature. The assembly hall is located on the ground floor, its spectacular ceiling created by the dynamic reach of the structure, which supports the functions above.



Figure 18 Benin national assembly - (2019, Porto Novo) by Kere Architecture



Figure 19 Benin national assembly - (2019, Porto Novo) - Environmental strategies

The crown is comprised of offices and auxiliary functions, set back from the deep façade, which filters the strong sunlight. The trunk is hollow, creating a central courtyard that allows circulation spaces to be naturally ventilated and indirect light to penetrate the plan. A spiral staircase in its centre connects the assembly hall on the ground floor to the offices above. On the top floor, a roof terrace offers sweeping views over the city and the lagoon in the distance

. A large part of the site is dedicated to a public park, which will showcase Benin's native flora while providing Porto-Novo with an extensive recreation space. To create a sense of openness and transparency, the park will extend to the foot of the palaver tree, offering a generous shaded space where citizens can gather and deliberate, analogous to the assembly hall on the opposite side.

In the southeast corner of the site, a public square marks the civic façade of the building, across from the former national assembly where Benin's independence was historically declared. Further facilities for government services are integrated into the park's topography with planted roofs, and form a façade along the southern limit of the site.

CONCLUSION

In the two main traditional regions of Cameroon with their architecture and in the five case studies presented above traditional solutions developed in vernacular architecture were used as the incentive idea as well as the source of inspiration for contemporary bioclimatic buildings. Basic methods of passive cooling and natural ventilation, commonly used in hot climate areas, were hybridized to achieve the optimal performance. In purpose to obtain the high level of indoor microclimate comfort, corresponding to modern user expectancies, advanced technology was applied. In first two edifices their budget allowed for some exemplary technological solutions, especially regarding climate responsive façade design as well as air preparation and distribution throughout the building. In CSET the non-conventional air-conditioning systems were supported with cutting-edge technologies

for the exploitation of renewable energy sources. In Solaris the issue of restored, enriched biodiversity and the equilibrium of natural and built environment was of the utmost importance.

The project of CSET proved that the contemporary knowledge and technology, well inscribed into the local conditions and determinants, can be implemented at minimal cost. While photovoltaic cells, solar panels and thermal technologies were used to improve the quality of life, the whole architectural conception is based on passive strategies, simple construction methods and locally available, renewable resources.

The study presents the concept of bioclimatic architecture through the proper balance between traditional ideas and modern technologies. This notion allows for practical and creative usage of contemporary knowledge transfer.

Nowadays original methods, dedicated to various climatic determinants, developed and verified in different parts of the world, can be supported and improved by the application of cutting-edge technologies. Although in-depth analysis of local biological and climatic conditions should always be a starting point, the worldwide information exchange can result in entirely new hybrid systems designed for the specific location needs. It is worth to note that such an approach may be used also in the areas where the lack of indigenous examples hinders the selection of the most appropriate bioclimatic solution solely on the basis of vernacular buildings studies.

Therefore the contemporary bioclimatic architecture can be defined as one that combines traditional knowledge about ways of adapting dwellings to the climate with advanced research, design and technological methods in purpose to create the built environment maximally integrated with the natural environment and especially with the ecosystem in which it is placed. It should be emphasized that buildings that are well adapted to bioclimatic conditions do not exceed the budget for comparable facilities while their environmental impact is minimal. Growing respect for ecosystems results with architectural projects that enhance biodiversity for the benefit of natural and cultural environment. Thus understood bioclimatic architecture creates great opportunities and should be perceived as the solution for developing countries.

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