Sustainable cosntruction and architecture in Guinea-Bissau: Opportunities and Challenges

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ABSTRACT: This paper presents the results of research developed under the European Project SURE - Africa , on construction and architecture in tropical warm and humid regions, such as the Guinea-Bissau, in which climatic, social, and economic conditions pose additional concerns for planners, architects and engineers. The main question analyzed was whether comfort is achievable solely by the use of passive design strategies, or if energy consuming mechanical systems are required. The aim is to reduce of both cooling and artificial lighting energy loads through passive design strategies, which can be complemented with active systems, powered by renewable energies, such as solar photovoltaic. Conclusions were drawn about the most relevant passive design strategies for comfort maintenance, those who protect from solar radiation, and promote ventilation. Exploring the use of local resources, produced from natural raw materials like earth, is one of the essential measures in the path for sustainable construction, in Guinea-Bissau.

1 INTRODUCTION

Building in Guinea-Bissau involves facing particular climatic conditions and the urban problems common to tropical countries. The lack of urban identity, particularly in the capital, Bissau, together with unregulated construction projects, the degradation of urban buildings, a housing deficit combined with a massive influx of poor rural people, urban growth without planning, and low comfort levels inside buildings are the general problems (Pereira, 2001). Powerful climatic agents such as high levels of solar radiation and air humidity, and torrential rainfall, challenge builders and architects to create sustainable ways of providing security, comfort, and economic satisfaction for the final building users (Lauber, 2005; Bay & Ong, 2006).

Within this context, more research is necessary, concerning the behaviour of traditional materials and building techniques, and new approaches such as the so-called bioclimatic or passive design. By harnessing this philosophy, sustainable strategies become available, and will result in positive economic benefits, both for the energy efficiency of buildings and the maintenance of comfort levels, in addition to benefits of the well-known concept of reasonable use of existing resources without compromising their use by future generations[i].

The aim of this research is to assess the characteristics of sustainable construction in Guinea-Bissau and, in doing so, to: Study the main strategies for sustainable design in tropical warm and humid regions; Analyse energy and comfort performance of typical building types existing; Produce best-practice recommendations for sustainable design in Guinea-Bissau.

2 THEORETICAL CONSIDERATIONS

The term "sustainable construction" appeared for the first time in a communication from Professor Charles Kibert, in an effort to relate the responsibilities of the construction industry to the aims of sustainability (Pinto & Inácio, 2001). It was defined as the creation and responsible management of healthy construction, based on ecological principles and efficient management of resources, which meant focusing on placing a minimum burden on natural resources and waste production and maximising the recycling process. It also included the life cycle of buildings, with regard to their use, maintenance and the possibility of adapting to local needs (Ramos, 2007).

Bioclimatic or passive design strategies aim at achieving building comfort and internal environmental quality. In the present case, as they are designed for warm, humid regions, the main strategies are based on heat protection, and heat dissipation (Fig. 1). The former includes mechanisms such as shading, orientation, and insulation strategies, which protect buildings from solar radiation by preventing heating gains entering the buildings (Yao et. al, 2006). In addition, heat dissipation systems act upon the heat inside the building, seeking to eliminate or reduce thermal sensation by passive means[ii], (Gonzáles, 2004). Daytime or nigh-time cross ventilation, night radiation, and thermal inertia are some of the most important dissipation techniques for humid tropical regions. Materials with high thermal mass provide efficient thermal inertia, increasing the time lag before exterior temperature levels reach the interior of the building (Lanham, Gama & Bráz, 2004), in regions with significant temperature variations, e.g. between day and night.

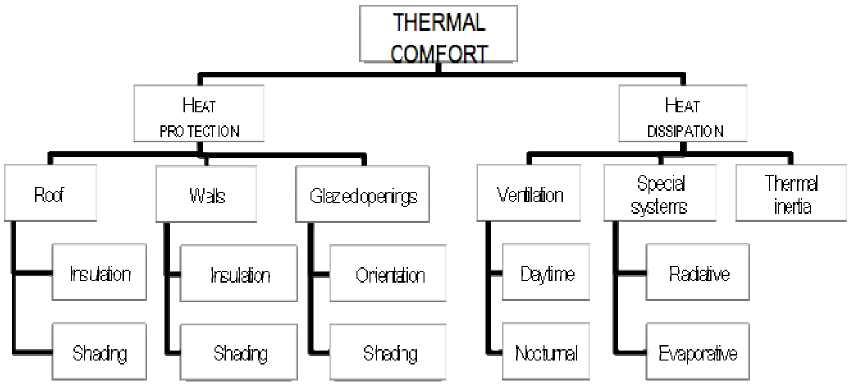

Figure 1. Passive design strategies for tropical warm, humid regions (adapted from Baker, 1987; Gonzáles, 2004; Silva, 2006).

The main strategies cited on studies developed for tropical climates are the promotion of ventilation trough openings (Salmon, 1999) and the prevention from climate agents (Lengen, 2004). In terms of town planning, regulations regarding regular road planning for the passage of breezes, and shade from trees, are crucial (Stango & Ugarte, 2006; Gonzáles, 2004), protecting buildings from overheating, and protecting roads from the consequences of rainfall.

Thermal comfort[iii] or human being's thermal sensation is mainly related to the thermal balance of the body as a whole, influenced by physical activity and clothing as well as environmental parameters (Yao et al. 2006; ISO 7730:2005(E)), and parameters related to the main body heat loss mechanisms (Baker, 1987).

In tropical regions where the temperature averages 24 to 28ºC throughout the year, higher temperature comfort zones are expected, corresponding to a dry bulb temperature as high as 31ºC, together with a relative humidity ranging from 35% to 75% (Salmon, 1999).

3 ARCHITECTURAL AND CONSTRUCTIVE TYPOLOGIES

Local architecture can be classified in terms of construction properties and by function type: on the one hand, the public sector serves families with no economic power, whilst the private sector promotes housing for economically stable and socially stratified wellbeing. In the middle, the cooperative sector meets the needs of the low middle class, organized by ministries or institutions, generally for their employees. Independent building is common in rural areas or in peri-urban environments, linked to spontaneous construction (Mota, 1948; Pereira, 2001).

The architecture of Guinea-Bissau is characterized by three main typologies:

i. Vernacular architecture - traditional housing with rammed earth or adobe walls and straw fibre roofs (Fig. 2 - left), now with the straw roof being gradually replaced by zinc foil, especially in rectangular housing (Fig. 2 - right), providing durability, light, waterproof properties and low maintenance requirements, but, on the other hand, poor thermal and acoustic insulation and requiring additional care in preventing corrosion. A better practice could be a double covering of zinc and straw, adapting the durability of the former to the better insulation properties of the latter, Figure 3 - left;

ii. Colonial architecture - colonial dwellings built with concrete blocks and a tile or Fibre-cement panels cover, in the urban centres of the main cities; Generally tall buildings, with a covered veranda at the front and overhangs above openings (Fig. 3 - right);

iii. Contemporary trends - dwellings built with prime materials such as reinforced concrete for structure, bricks or concrete blocks on the walls, and clay tiles on the roof (Fig. 4 - left); Ecotourism constructions are considered a contemporary trend as well, using natural raw materials such as earth, straw and timber; In the image below (Fig. 4 - right), the elevated floor of the house prevents humidity and promotes ventilation from below; It is also relevant to describe cooperative neighbourhood housing, characterized by dwellings built with reinforced cement, adobe and covered with zinc, in the periphery of urban zones, or high-rise housing consisting of 3 or 4 floors, built with the aid of international protocols;

Figure 2. Vernacular architecture (left). Replacing straw roof with zinc (right).

Figure 3. Double roof system, with zinc foil under a straw-covered roof. Colonial dwelling.

Figure 4. Contemporary trends - modern dwelling (left). Ecotourism housing (Picture from Schwarz).

4 CASE STUDY ANALYSIS

The case study focuses on an analysis of the typologies of existing buildings, specifically with regard to comfort, cost and reduction of the energy loads.

4.1 *Methodology*

In order to study building performance in the architecture of Guinea-Bissau, fieldwork was carried out in the country from April 11 to May 9, when measurements of comfort levels in the interior of buildings were taken, and users' comfort perceptions and opinions of their residences' performance and sustainable construction concepts recorded through questionnaires, in addition to producing an extensive collection of photographs of the architectural heritage.

Four instruments were used to develop the study, as Figure 5 illustrates:

i. Temperature and humidity measurement, using data loggers;
ii. Fieldwork questionnaires;
iii. Climate analysis, using *The Weather Tool*, an *Ecotect 5.20* software tool;
iv. Model simulation, using *Ecotect 5.20* software.

The climate analysis and building simulation were carried out using *Ecotect*, environmental building analysis software that allows the thermal response of a building, in terms of energy efficiency, or discomfort levels. The main aim was to optimise the performance of a representative house, according to local climatic conditions, materials and available technologies, thus reflecting the economic viability of the chosen solution. The four building models that were developed made it possible to unequivocally understand the best practices in building design, which are listed in the final chapter of this paper.

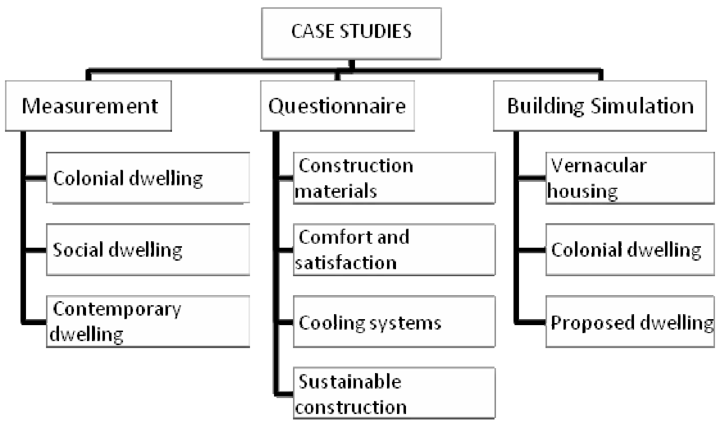

Figure 5. Illustrative draft of case studies.

4.2 *Results*

4.2.1 *Measurement of temperature and humidity*

The main characteristics of the three dwellings analysed in specific urban zones are described below:

- Colonial dwelling - concrete blocks on walls and clay tiled roof (Chão-de-Papel's neighbourhood);
- Social dwelling - cooperative housing, with adobe walls and zinc roof (Plano's neighbourhood - coastal zone);
- Contemporary dwelling - brick walls, and clay tiled roof (Quelélé's neighbourhood);

The results of the relative humidity measurements specified in Table 1 show that the closer a building is to a coastal zone, the higher the relative humidity inside the building.

The outside temperature results, Table 2, confirm that the worst outside temperature is in the Quelélé's neighbourhood, which has a temperature range of 10ºC. For this outside temperature range, strategies such as night purge ventilation and thermal inertia are important prescriptions.

Although it has a similar mean exterior temperature, the social dwelling in the Plano's neighbourhood shows higher comfort values for inside temperatures (Table 3) because of the benefits of the coastal breezes, highlighted in the humidity range.

Even with clay tiled roofs and clay brick walls, better-known for their thermal insulation properties, the contemporary dwelling in Quelélé does not reveal the best thermal behaviour, due to its location.

Table 1. Relative humidity inside buildings.

	Plano neighbourhood	Chão-de-Papel neighbourhood	Quelélé neighbourhood
	ºC	ºC	ºC
Max.	68.4	66.6	64,9
Mean	65.9	63.3	61,3
Min.	62.8	60.0	56,5

Table 2. Outside temperature.

	Plano neighbourhood	Chão-de-Papel neighbourhood	Quelélé neighbourhood
	ºC	ºC	ºC
Max.	29.8	31.8	32.1
Mean	26.4	26.9	26.6
Min.	23.6	23.5	22.3

Table 3. Inside temperature.

	Plano neighbourhood	Chão-de-Papel neighbourhood	Quelélé neighbourhood
	ºC	ºC	ºC
Max.	29,0	30,1	30,5
Mean	27,8	28,9	28,4
Min.	26,6	27,8	26,9

4.2.2 *Results of questionnaire*

The answers to the questionnaire are presented below, for a population of 100 individuals in Bissau City, 31% of which were female. It is also significant that 21% of the respondents were planners, architects or building technicians employed in the city. The questions were organized into the following topics: materials, comfort and satisfaction inside the building, cooling systems, and sustainable construction.

Concerning materials, 37% of the respondents lived in an adobe and zinc dwelling, and 21% in a block and zinc dwelling, meaning that 58% of the dwellings analysed were zinc-covered, followed by tiled roofs in 26% of cases, with block or brick walls. However, the users' preferences revealed that 64% preferred a concrete block wall and 83% a tiled roof, based on perception of high resistance, durability, availability, aesthetic qualities, and thermal insulation.

With regard to comfort conditions, most of the users experienced climate discomfort, generally caused by high temperature levels and humidity (Table 4), the latter mostly in the rainy season. The worst period cited for temperature discomfort was from midday to 6 pm in general, and more specifically from midday to 3 pm. In other hand users revealed satisfaction with shading systems in their residences, as well as natural lighting, ventilation and security.

Table 4. Users' satisfaction levels.

	Very satisfied	Satisfied	Dissatisfied	Very Dissatisfied
	%	%	%	%
Temperature	3	31	44	22
Humidity	5	52	29	14
Ventilation	16	55	18	11
Shading	13	76	8	3
Natural lighting	14	66	16	4
Security	20	55	17	8

With regard to cooling systems, the users showed a preference for no system at all, although, due to temperature levels, air-conditioning systems were considered essential or better than nothing in 60% of the cases (Table 5), and almost 50% of the users have an artificial ventilation system (Table 6). While answering, the users shared concerns about the public electrical power shortage. When questioned about the relevance of passive means of cooling, 87% of the users showed an interest, as Table 7 illustrates, and those who didn't (13%), think that the high levels of diurnal temperatures are difficult to attenuate by passive means.

Users were also freely questioned about the characteristics they think Guinea-Bissau buildings should have. 27% cited isolated dwellings with a maximum of two floors, 20% indicated security and comfort as important properties, and 15% referred to colonial type with concrete block or brick walls, followed by 13% of answers for tiled roof. On the subject of renewable energy and sustainable construction, more than 90% of the users revealed interest in knowing more and applying the systems in question, with regard to energy shortage problems.

Table 5. Opinions on air-conditioning.

	Essential	Better than nothing	Unnecessary	Rather not have
	%	%	%	%
Answers	31	29	21	19

Table 6. Opinions about the use of cooling systems.

	Ventilation	Air-conditioning	Both	None
	%	%	%	%
Answers	49	6	17	28

Table 7. Level of interest in passive cooling systems.

	Not interested	Low interest	Interested	Very interested
	%	%	%	%
Answers	0	13	46	41

4.3 *Climate analysis and building Simulation*

Bissau's climate was analysed by Auliciem's adaptive model cited by A.J.Marsh (in Ecotect), showing that the square vernacular house performed best.

Table 8. Air temperature in the rooms in each house (ºC) on a typical day.

	Circular dwelling*	Square dwelling**	Colonial dwelling***	Outside temperature
	ºC	ºC	ºC	ºC
Mean	29.32	28.80	29.65	28.5
Standard Deviation	0.14	0.38	0.49	3.9
Mean Radiant Temperature at 3 p.m.	0.14	0.38	0.49	3.9

* Rammed earth 300 mm, Straw 150 mm;
** Rammed earth 250 mm, Straw 150 mm;
*** Concrete block 250 mm, Fibre-Cement panels 8 mm.

The mean radiant temperature shows the temperature in the construction components, confirming the superior thermal inertia of rammed earth in comparison with the low thermal resistance of cement-based materials such as concrete blocks and cement board.

From the results obtained, a contemporary dwelling was designed, simulating the following parameters: orientation, glazing percentage, shading device systems, natural lighting, thermal inertia, insulation systems, and ventilation. The study was conducted in terms of reducing annual energy consumption and the best results for each of the simulated strategies are illustrated in Table 10. The solution initially tested had concrete blocks (200+50mm), tiled roof and no insulation system.

Table 9. Comfort analysis results for a proposed contemporary dwelling.

Strategy	Best result	Load consumption for cooling (kWh/m2)	Solution
Orientation	E-W axis	-	-
Glazing	30-30-15-15 (%)	6.11	1
Natural lighting	Architectural optimisation	5.75	2
Shading device	Veranda at front, overhangs around	4.39	3
Thermal inertia	Brick (200+50mm)	3.49	3.1
	Concrete block (250+50mm)	3.98	3.2
Insulation	Sandwich panels (Zinc + insulation)	4.44	3.3
	Ceiling - Fibre glass, concrete block	4.05	3.4
	Concrete Block + exterior insulation	3.37	3.5
	Double brick plus cavity - insulation	3.35	3.6
	Solution 3.3 combined with solution 3.5	3.43	4
Ventilation	Mixed-mode system	0.83	5

Bricks walls were simulated and this proved to be the best material (without insulation), nevertheless it is important to note that they are not produced or sold at present in Guinea-Bissau (Solution 3.1). Alternatively, when the thickness of the concrete blocks was increased the results were also satisfactory. In this study it was decided to proceed with default materials of the minimum legally prescribed thickness (MOPCU[iv], 2006), adding insulation systems (Solution 4). The best result is associated to ventilation promote, here simulated by the openings prescription, and a mixed-mode system, a combination of air-conditioning and natural ventilation where the HVAC system shuts down whenever outside conditions are within the defined thermostat range (20-28ºC);

5 CONCLUSIONS AND RECOMMENDATIONS

The main conclusions to be drawn from this study are:

i. Rammed earth walls on existent buildings have better performance than the usually used concrete block without insulation (on urban domains);
ii. For the Guinea-Bissau climate, the main concerns in climatic design involve prevention of overheating, meaning that the main loading requirements are for cooling systems;
iii. One of the good practices starts with orientation on E-W axis, minimum glazing distribution to East and West facades, and shadings;
iv. Natural ventilation is a relevant strategy, which acts on heat dissipation;
v. The use of mechanical cooling systems may be necessary, however it is possible to reduce its requirement to minimum;
vi. The use of insulation systems like polyurethane or expanded polystyrene, improves buildings thermal performance, without cost rise; Solutions like sandwich panels for roof can easily replace tiled roof, and concrete block walls exterior insulated, substitutes brick walls without compromising comfort levels.

Local materials production and the renewable energy resource such as the solar photovoltaic, should integrate the priorities of the local public administration. The improvement of the projects in terms of energy efficiency, reducing lighting and artificial cooling systems requirements, the change of mentality starting to consider buildings solution with 3, 4 floors for housing or office, are some of the goals for sustainable construction practice in Guinea-Bissau.

It is important to state as a final note that one of the limitations of Ecotect 5.20 is the fact that it does not provide system simulation; just cooling loads were here simulated. One way forward would undoubtedly be to use energy analysis tool such as EnergyPlus. In the present it was determined the potentiality of passive design strategies, but more investigation is required before taking any further conclusion.

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[i] Bruntland report (Our Common Future), United Nations Conference, Stockholm, 1987 (Pinto & Inácio, 2001).

[ii] Without the aid of mechanical equipment.

[iii] Defined as the mental condition in which an individual feels satisfied with the thermal environment, as in ISO 7730 (Yao et al.).

[iv]MOPCU - Guinea Bissau Ministry of Public Works, Construction and Urban Planning.