282: Sustainable Techniques for Modular Construction

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Low-Income Housing in Lagos; Sustainable Techniques for Modular Construction

Twenty-one new inhabitants migrate to Lagos, Nigeria everyday in search of a better quality of life. This creates a fundamental need for housing which is met through formal and informal means. This paper explores the climatic deficiencies of both forms of housing and proposes an alternative which is climatically responsive. As professionally built developments, the density of formal housing is regulated by building codes. However, as unplanned settlements, informal housing constructed by non-professionals is only constrained by the means and materials available.

Due to this lack of regulation, the living conditions within and without these developments are relatively poor, disregarding strategies, which could improve occupant comfort. As a result, the occupants endure thermal discomfort, poor hygiene and air quality and the dwellings lack outdoor amenity. This proposal draws together the observations of the climatic deficiencies of the existing typologies by 'formalising' the informal through the use of a modular frame system. In this way, a level of organisation is imposed on an otherwise haphazard development and climatic strategies may then be integrated.

Keywords: Construction, Modular, Developing Economies

Sustainable Techniques for Modular Construction

1. Introduction - Housing Provision

In the 1980's, most developing countries reduced government participation in the direct provision of low income housing. This policy was advocated by the World Bank and other agencies who developed an 'enabling strategy' for public sector support of private market activity in housing provision.
The two main structures of housing provision: the conventional/formal and the unconventional/informal, are subdivided into several secondary substructures. The conventional or formal mode can be divided into public, private and co-operative substructures, while the unconventional or informal structure can be divided into squatter settlements, illegal subdivisions and low income rental housing.

The building industry in Lagos faces many problems including:

- Low productivity on construction sites
- Expensive building materials and high construction costs
- Inadequate supply of qualified/skilled manpower
- Implementation of quality control

The conventional methods of construction are slow, the inflation rate of 16% and scarce financial resources make construction speed a very important parameter. Studies of numerous building collapses as a result structural failure have revealed serious deficiencies in the quality of materials and workmanship. To overcome these problems, a re-evaluation of the conventional building techniques is essential to determine how to lower production costs, speed-up output whilst ensuring quality construction. The situation can be enhanced through: improved design, development of new building materials, and a change of construction techniques.
Current government strategies for maintaining sustainable human settlements include:
a) Squatter upgrading, (more of relocation and demolition)
b) Site and services projects

2. Weather Analysis

The climate of Lagos can be classified as warm-humid. Data from the diurnal chart illustrates that the temperature throughout the year is relatively stable with an average yearly temperature of 27.5° C. The temperature is particularly warm from November to April while the mid year rain drops the temperature in the months from May to August.

At the sensory level, a useful notion is Thermal neutrality (Tn), which is a temperature averaging from a large sample, when one feels neither cold nor hot. The 'adaptability model'[1] takes the results of physiological acclimatization and habits into consideration and the result is the expression for thermal neutrality:

$$Tn = 17.6 + .31 \times Tav$$

(Tn= Thermal neutrality, Tav = Average temperature)

A differentiation of the day-time and the night-time temperatures would enable each time frame to be analysed more accurately for comfort calculations. This is particularly relevant as each space is used differently during the course of the day.

As a means of increasing thermal neutrality, an investigation into the cooling effect (physiological) of air movement results in the expression for apparent cooling effect (dT)[2] which follows that:

$$Dt = 6 \times (v - 0.2) - 1.6 \times (v-0.2)^2$$

(v is air velocity at or near the body surface of occupant, in m/s)

The results were used to generate figures 1 and 2 which illustrate the effect of air movement at .5, 1 and 1.5m/s over average day-time and night-time temperatures respectively.

With air velocity at 1.5 m/s the temperature range expands by an average of 17.4% over thermal neutrality. However, with a fan circulating air at 1.5 m/s, figures 1 and 2 illustrate that the average temperatures are still well below the upper limits (Tu) derived by the formula. Whilst internal gains would contribute to an increase in the temperature within the space, it is feasible in the low income context to reduce the air velocity and therefore the amount of energy required to power a fan.

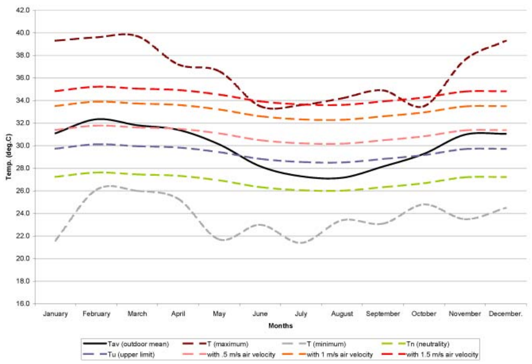

Figure 1. Daytime thermal comfort limits

As a dwelling is used predominantly at night, night-time comfort is of particular importance. Figure 2 illustrates that with a fan circulating air at 1.5 m/s the occupants should be comfortable. At 1 m/s, only the hottest month of the year (March) is out of the comfort zone.

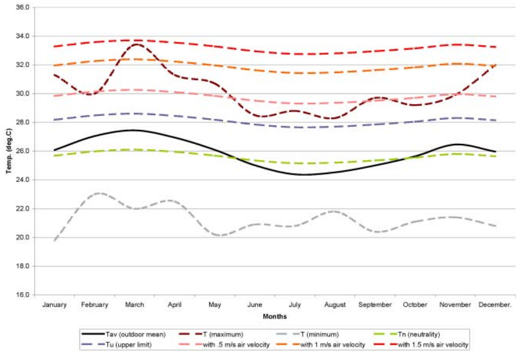

Figure 2. Nighttime thermal comfort limits

3. Element Analysis

In warm – humid climates, the temperature profile of an open indoor space air temperature follows a similar profile to the outside shade temperature. As a result, the interface areas of a structure with the exterior are the most important elements of the proposed structure. They are the means of modulating the difference between the outdoor conditions and the indoor conditions.

The three main boundary points are (a) the roof, (b) the walls and (c) the floor.

3.1 ROOFS

From the major elements in consideration, the roof (roof structure, outer coverings, layers of insulating materials or membranes and the ceiling) represents the highest percentage of the total cost of a single element in low cost housing in the tropics. As such, a roof should last at least as long as it takes it to amortise the debts incurred to pay for them.

The roof element as a single surface receives the highest amount of solar radiation. Depending on the construction, heat can be conducted to the underside of the roofing sheets and re-radiated to the occupants of the room. Therefore, the roof construction must absorb as little radiant heat as possible and offer complete resistance to heat flow from the outside to the inside.

Using TAS 9.0 (dynamic thermal simulation software), a series of parametric tests was performed to determine which materials had the greatest impact on the internal environment, and in what manner. This is particularly important because it would be beneficial to prospective homebuilders to invest only in materials that have maximum impact. The roofing assembly investigated was of lightweight construction with the following elements:

- Reflective Surface
- Radiant Barrier
- Felt
- Insulation
- Ceiling

[1] Auliciems (1981)
[2] Szokolay (2000)

The outer reflective surface is intended to reflect direct solar radiation, the radiant barrier to prevent against radiant heat again and the air gap is intended to prevent convective heat transfer. The felt is for water protection and the insulation is for prevention against heat transfer into the ceiling.

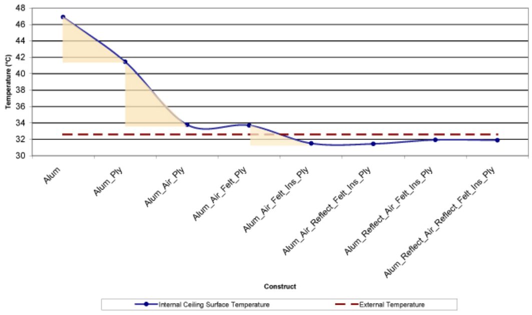

Figure 3. Parametric roof constructs test series

The three most impactful additions are the inclusion of the plywood to the aluminum sheeting (a), the air gap between the aluminum sheeting and the plywood ceiling (b), and the addition of the insulation(c).

3.2 WALLS

The cumulative walls of an un-shaded building in the climatic context of Lagos, receive the highest amount of solar radiation. As such the reduction of the amount of heat transfer across walls into the interior space is an important factor in providing indoor thermal comfort.

A building with an envelope consisting of a high mass core insulated externally, with a thinner internal insulating layer, will have a high thermal transfer coefficient (TTC) and therefore heats up very slowly in the daytime hours but if ventilated in the evening, it's interior air cools down rapidly. Minimising the indoor temperature swing and/or in lowering the indoor daytime temperature below the outdoor maximum by means of the thermal mass, the building should be closed during the day. In this case, the TTC represents the effective heat capacity of the building. The TTC also enables evaluation of the effective thermal mass of a building build of envelope elements containing several layers of different materials.

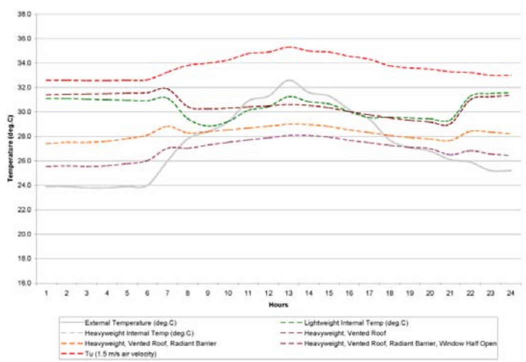

Figure 4. *Day-time performance of wall construct*

Figure 4 clearly illustrates the differences at each stage of the test series. The installation of an open-able radiant barrier for radiant cooling is the most significant intervention. The reflective lining is applied on top of the insulation panels which are hinged and can be rotated. During the daytime, the panels are placed in a horizontal position (closed), forming an insulation panel under the roof, reducing the heat flow into the interior space. At night, the panels are rotated into a vertical position (open) enabling radiant and convective heat flow from the interior space to the metal ceiling, which is cooled by long wave radiation to the sky. Although the radiant cooling is effective, figure 4 shows that with a fan circulating air at 1.5 m/s thermal comfort can still be achieved. As such, considering the relative cost of a heavyweight structure to a lightweight structure, one could still make a case for a lightweight structure.

4. Design

The fundamental idea behind the design proposal is the concept of the 'manner' and the 'matter.' The 'manner' refers to the structure of a modular construction system which ensures that the building is structural stable and serves as the framework on which the matter depends. The 'matter' can be described as the materials that complete the structure. The environmental design strategies investigated in the analysis section define the articulation of the matter.
The structure/'manner' is important in that it is the foundation of the module. In a situation where the module doesn't require any vertical elements, the structure must serve as a stand alone element. Surfaces can be installed at a later date dependent on need. It is important for the structure to comprise as few elements as possible. The literature review of various structural systems resulted in the investigation of space frames[3] and their applicability in this context.

There are three distinct parts to the frame, the roof structure, the vertical supports and the base.

[3] Adapted from Gabriel, J. F (1997)

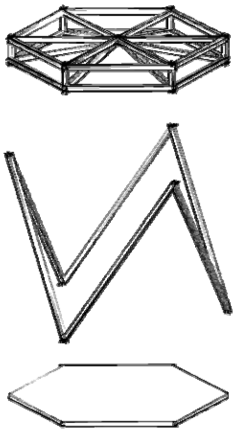

Figure 5. the structure / 'manner'

The manner represents the surfaces of the module. Whilst the structure by itself, can create a space, the manner defines the purpose of the space through the materials utilised. It can be separated into two distinct parts; the horizontal elements and the vertical elements.

The horizontal element consists of the roof construct as derived from the analysis. A corrugated metal sheet serves as the reflective element which is the initial barrier against direct solar radiation. The metal sheet is attached to the top of the frame of the roof structure.

On the sides of the roof structure are air inlets which may be fabricated from metal sheets or wood depending on the site. A wire screen prevents pests from entering the air cavity. The hinged radiant insulation barrier is attached to the base of the roof structure. Fabricated from an insulation board and lined with a reflective foil, the panels are capable of rotating to facilitate radiant cooling.

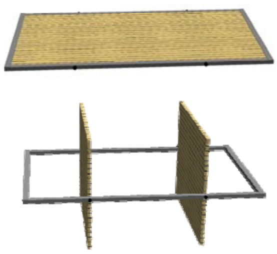

Figure 6. Hinged radiant barrier

The wall construct as derived from the analysis comprise a double wall construction on all sides of the module with air vents at the top and bottom of the external wall to vent the air cavity between the external insulation wall and the internal block wall.

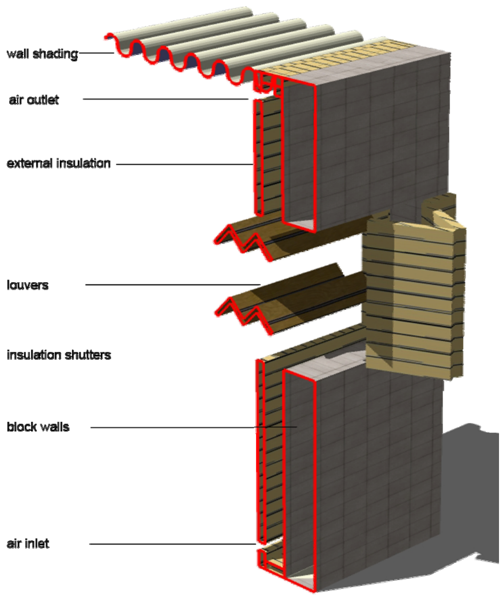

Figure 7. Wall structure

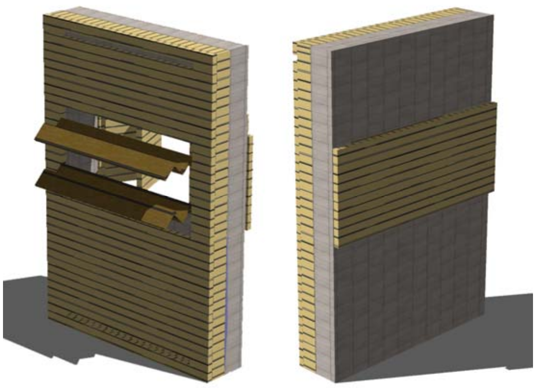

Figure 8. Open and closed wall unit

If the module is attached to another module, the shared wall may be omitted to create a larger space or it could be a single block wall or screen to define two seperate spaces.

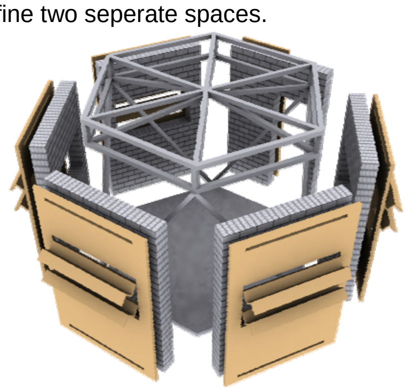

Fig 9. Complete module

If the module is in a transition stage or the owner is not financially stable, the structure may be left void or completed with materials such as vegetation, soil or found materials. (fig. 10)

Figure 10. Alternative materials

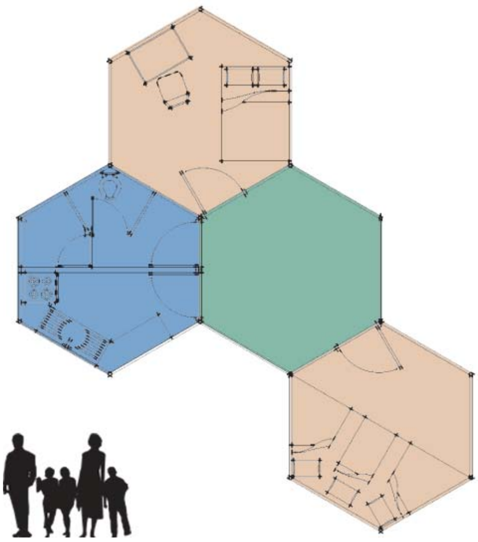

Fig 11. Plan of a single family cluster

Fig 12. A single family cluster

5. Conclusion

From the literature review and assessment of previous housing schemes, it is apparent that low income housing must be centrally supported and not centrally supplied. By decentralising the approach to the problem, it encourages local participation which enables the developments to grow organically.

The architecture derived from the literature review, tests and simulations results in a dwelling that is neither immediately permanent nor temporary. It proposes a place of 'post-immediate' occupation. The continued stay and expansion of individuals' modules enables the starting of relationships, neighbourhoods and communities.

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