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Utilisation of Solid Waste to Create Affordable and Sustainable Buildings in Reducing Housing Deficit

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Abstract: Currently, there are increasing demands for sustainable development and such demands will not only be satisfied without robust efforts in the increase of affordable housing which will reduce Housing deficit. Millions of tons of materials from Municipal Solid Wastes (MSW) are generated periodically and finding their paths to landfills in Nigeria which pollute underground water supply. This does not encourage sustainable livelihood and the strengthening of our local economy through effective waste management for healthy environment and provision of affordable living that will assist in increasing Housing stock. In employing the case study method in appraising extant true studies, this study describes the central role of the architect in creating a greener economy through effective integration of waste products in building construction. The waste materials explored in the cases evaluated include; used plastic bottles and drinking cans; discarded vehicle tyres, disused papers, broken bottles, construction and agricultural by-products. It will go a long way to significantly reduce the environmental impact both in terms of CO2 reduction and conserving natural resources by using reclaimed materials to construct environmentally friendly building for people. Moreover, the challenges militating against the use and adaptation of waste products in building construction in Nigeria were identified to include inter alia-deficiencies in the required regulatory framework and codes, requisite technical skills and the appreciation of the gains of such innovative practices. It is therefore recommended that architects should play a pivotal role in the propagation of these innovative and eco-friendly approaches in utilizing Municipal Solid Waste Products that constitute environmental nuisance in constructing affordable building that have aesthetic, functional and structural integrity.

Keywords: Sustainable development, alternative building materials, integrated systems, greener economy, role of architects.

INTRODUCTION

Waste generation is on continuous increase in the world. As people continue to consume and discard various goods - worn-out materials, packaging for goods and products whose intended purpose are considered to have reached an end - valuable resources are endlessly sent to landfills. These solid wastes which are generated from a myriad of sources (including agricultural, domestic, commercial, and industrial processes) as several true studies have indicated constitute severe environmental nuisance (Ogunbode *et al.,* 2012; Nwokocha, 2006). Amongst the environmental problems is the depletion of resources and greenhouse gas emissions, (Zeng *et al.,* 2010).

However, as the earth is faced with global warming and resource depletion, the need for an urgent change in paradigm has brought about the emergence many concepts of sustainability. Among such initiatives which strive to ensure a sustainable existence of man in our planet earth are green architecture and the cradle-to-cradle concept. These novel techniques perceive materials as objects that should circulate within the technical or biological framework, by replacing the conventional approach of waste management to resource management through integrated systems design and de-construction approaches, for economic, social and ecological remediation, (Ogunbode *et al.,* 2012; Donough *et al.,* 2003). Thus, recent studies seeking to proffer solutions to some of the teething challenges of solid waste management have demonstrated that many of the materials hitherto considered as wastes - such as palm kernel shells, scrap tyres papers, cement bags, plastic bottles and drinking cans - have the properties of good construction materials (Cossu, 2010).

The process of recovery and re-using of these items resonates to effective resource use, employment of human labour and wealth creation amidst environmental benefits; hence a greener economy. Creating a green economy entails the possibility of meeting the basic needs of man, amongst which are food and shelter, using readily available resources. Some of these waste materials could be of great benefit in food production and provision of shelter for human habitation, (Nwokocha, 2013; Donough *et al.,* 2003). The provision of affordable houses and development of integrated systems are some of the principal roles of environmental designers which the architect is a pioneer. This study therefore, seeks to explore the potentials and role of the architect and other stakeholders in the utilization of these "waste resources"

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as alternative building and landscape materials in creating a greener economy which will ultimately contribute in ameliorating housing deficit.

CONCEPTUAL CLARIFICATIONS AND REVIEW OF RELEVANT LITERATURE

Waste and waste management

The term waste came into existence as a result of man's perception that a given resource has lost its original value and thence, serves no other use than to be discarded. From this perspective all solids, liquids or things we consider as unfit and unwanted due to economic reasons or ignorance of alternative uses, are discarded. Recent studies reveal that often wrong handling of such substances poses environmental and health threats like death, illness or injury to people (Okenyi *et al.,* 2011; Okebukola 2001; Tchnobauoglous *et al.,* 1993).

All types of waste, solid wastes which are both biodegradable and non-biodegradable are oftentimes classified as hazardous wastes; as their varying properties pose many difficulties in their handling (Cossu, 2010; Altaf, Deshazo, 1996). These difficulties - ranging from the explosive tendecies of some in combustion, the contamination of water bodies through leaching by others and the inability of bio-degrading micro-organisms to digest many - have led to the development of various approaches to waste management, depending on the peculiarities of each region (Njoku, 2009). Some of these methods include recycling, composting, combustion and landfilling, (USEPA, 2002).

Studying the systems for effective waste handling, Zeng et al. (2010) presented two hierarchies of integrated waste management (Fig. 1). Their study highlights the need for a new paradigm (Fig. 1b) as the conventional system (Fig. 1a) has no consideration for the delivery of an environmentally sensitive and sustainable waste management system which are the aspirations of such principles as recovery and eco-design. These aspirations development paved the way for some other concepts to waste management as discussed hereunder.

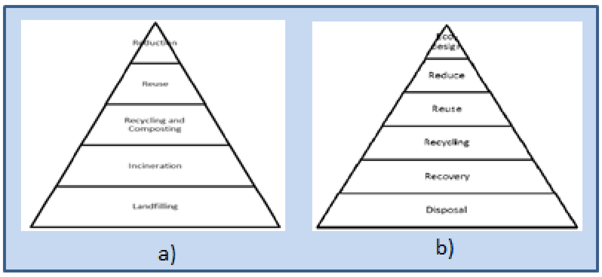

Figure 1: a) Conventional System of integrated solid waste management
b) New System of integrated solid waste management
(**Source:** Zeng *et al.,* 2010)

Integrated Systems Design, Cradle-to-cradle concept and De-constructivism

Towards the achievement of the goals of efficient waste management, the concepts of integrated design/holism, cradle-to-cradle and deconstruction have emerged. The cradle-to-cradle, restorative and regenerative approaches allow an integrated approach to development that extends beyond the design profession, to include project stakeholders, professional institutions and governing bodies. By doing so, such approaches present the means of bridging the gap between current ways of working and the desired outcomes of a sustainable built environment (Yang *et al.,* 2005). While an integrated systems design deals with the design of built systems which fosters a complex mutual relationship for order and stability, as deduced from nature; the cradle-to-cradle approach perceives materials to be in an endless close-loop-system in which valuable, high-tech synthetics and mineral resources circulate in an continuous cycle of production, recovery and reuse, (Mollison, 1988; McDonough *et al.,* 2003).

However, the de-constructivists pioneer the philosophy that demolition programs should be patterned to ensure the recovery of valuable building items for retrofit or entirely new projects, hence reducing the pressure on our landfills and loss to national economy. Workers in this field are mainly transitional labourers in a changing economy which observes a shift from the wasteful brute force of conventional demolition to the clean system of designed disassembly (Milani, 2005).

Alternative building material & Greener economy

The creation of a green economy stems from the development of local resources towards the advancement of alternative approaches to the utilization and re-use of local and readily available human resources, energy and materials.

Thus, in search of a greener economy such the strategies of localism are currently being reinvented to encourage the development of alternative building materials and the use of locally available resources including "resource waste" and human capital, (NY WasteMatch, 2004). When buildings are deconstructed and alternative building materials are developed through innovative approaches to material re-use, design and construction, and the employment of the abundant human resource whilst reducing the current burden on our unsustainable landfills, a greener economy can be attained in a developing country like Nigeria.

Sustainable development

According to the Brundtland Commission Report, renowned for its proposition of Sustainable development - a concept which it defined from ethical, social and economic considerations - the term refers to a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Osuocha *et al.,* 2012; Acuff *et al.,* 2005; WCED, 1987). However, Sustainability in its broadest sense refers to the ability of a society, ecosystem, or any such living system to continue functioning into the future without being forced into decline through exhaustion or overloading of the key resources on which that system depends.

Architecturally, this implies designing buildings and neighbourhoods that have benign environmental impacts whilst fostering the quality of life of the individual users on the one hand, and the health and productivity of the community, on the other. Therefore, a sustainable built-environment development comprises the articulation of the totality of human efforts geared towards the provision of shelter and human settlements such that man's present needs are satisfied, without compromising the ability of future generations to meet theirs nor the quality of the supporting ecosystem (Nwokocha, 2013). This implies that achieving sustainable development within the built environment involves the hybridization of sustainable design and green architecture.

Sustainable Design and Green architecture

Architectural design plays a significant role in climate change control. Several scientific studies indicate that while architecture is responsible for about 45% of the greenhouse gas emissions (GHGs) in the UK, construction works and built systems contribute over 40% and about 24% of global primary energy intake amd carbon dioxide emissions, respectively (RIBA, 2012; Daramola *et al.,* 2012; Howe, 2010).

Therefore, the sustainable design approach seeks to foster continuing human existence by advocating the integration of environmental protection and resource preservation strategies in human settlements planning. This archetype which plays an indispensable function in the sustainable development is what we now refer to as green architecture. Green architecture involves a design system that uses natural building materials (such as earth, wood, and stone) that are energy efficient - not involving pollution in its treatment - in creating settlements with little or no impact on the nature of a site and its resources (Ghani, 2012). Green architecture can therefore be regarded as a design strategy applied by environmental designers towards achieving the sustainable built environment aspirations of economic resource use, efficient social order and resilient ecosystems (Nwokocha, 2013). It can also be perceived as an environmentally responsible design which is based on moral values and care, producing quality spaces modeled on nature's effectiveness, thereby generating delightful, productive places for people to work (Nwokocha, 2013; Ghani, 2012; Donough *et al.,* 2003). This calls for a positive perception towards the effective utilization of all materials, waste resources inclusive, in pursuit of sustainable development.

CASE STUDIES ON THE UTILIZATION OF WASTE RESOURCES AS ALTERNATIVE BUILDING MATERIALS

In this section true studies on the sustainable 'good practice' of adapting waste resources for reuse and recycling as construction materials are presented. The presentation of these case studies follow the common template of giving basic information about the application of each waste resource to construction, highlighting the innovative aspects, the challenges of each scheme and how these have been incorporated in a live project.

However, though the cases explored cover solid wastes from diverse sources, but they are by no means exhaustive, as the object of presenting these cases is to give examples of good projects that will influence and inspire practitioners.

Case Study I – Earth bag construction

An impressive model of emerging creative building forms, Earth bag construction technique is basically flexible-form rammed earth (Milani, 2005). Typically, in earth bag construction sacks are filled with material found on-site and then laid in courses onto the wall in a staggered fashion, like bricks, and then tamped in place before laying the next layer (fig.2a). However, to achieve Superadobe construction, sometimes, two parallel strands of barbed wire are laid between courses to act as a kind of mortar (fig.2b). Furthermore, earth bag construction offers a very economic construction method that results in strong structures (including domed structures) that can be built fast, worked in many ways and can be finished by plastering or stuccoes. Nonetheless, earth bag construction is limited to low-rise buildings.

Conventionally, sacks often used in earth bag construction are made of burlap or polypropylene. This study however champions the use of discarded cement bags and/or grain bags for the same purpose. Also, such construction and demolition debris as earth from excavation and land clearing are viable sources of earth bag construction material.

Figure 2: (a) Earth bag wall construction with bags filled with earth and laid in courses like bricks
(b) Superadobe earth bag wall construction tied with parallel strands of barbed wire are laid between courses to act as a kind of mortar.
(**Source:** UN-Habitat, 2012 based on Pura Vida 2012.)

An impressive earth bag house is the Hart's house in Colorado, owned, designed and built by Kelly and Rosanna Hart, of Hartworls, Inc. (fig.3). The walls of this house were constructed of misprinted rice bags filled with coria – a very porous, pumice-like volcanic stone sourced locally – and tied together with poly bailing twine running between each course. This exceptional earth bag structure incorporates many other novel techniques and recycled materials such as old wagon wheels for the window frames, timber pole as roof rafters, papercrete, with silica-lime, sand and white Portland cement for plaster. This material use although sustainable, has been identified of presenting poor space management challenges and options of laying it vertically may also need to be considered.

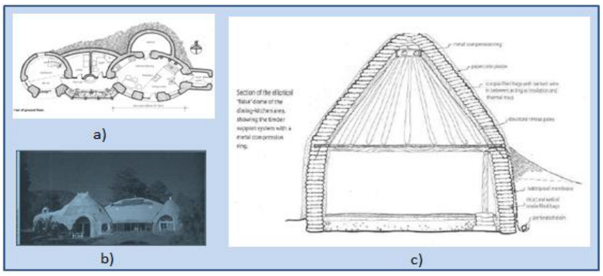

Figure 3: The floor plan (a), pictorial view (b) and longitudinal section (c) of the Hart House
(**Source:** Wojciechoska, 2001)

Case Study II – Old tires and the Earth ship construction

Earthship construction is an innovative building technique – developed by the New Mexico architect Michael Reynolds – which puts old tires to good construction use in an eco-friendly design that integrates the use of passive solar, earth-berming, photovoltaics, and water-conservation energy efficient low carbon construction (Milani, 2005; UN-Habitat, 2012). Generally, as illustrated in Fig.4, recycled steel belted car tire units that are stuffed with earth manually or with a pneumatic tamper are used like bricks, stacking one layer atop another and then plastered to create a strong, earthquake resistant, fire and termite-proof structure. Also, interior none-load bearing wall partitions are often built of recycled bottles and cans with cement (UN-Habitat, 2012). However, in very wet climates the need for water-proofing requires that the tires are wrapped in plastic sheets before filling them with earth (UN-Habitat, 2012). Since the Reynold's classic Earthships which are typically constructed in U-form so that a glazed opening is oriented to the sun, its systems design approach to autonomous housing has inspired builders who explore quite different materials, but particularly those who create different kinds of "tire houses" and earthship derivatives (Milani, 2005).

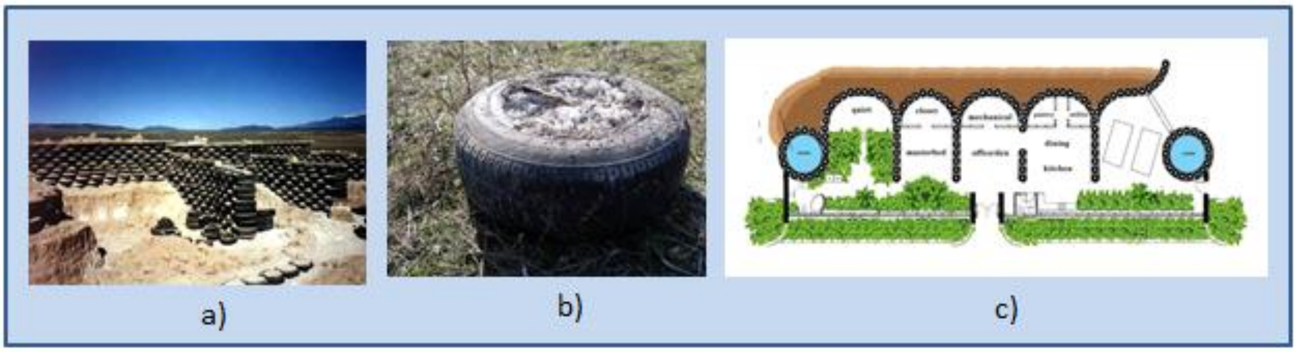

Figure 4: (a) Nest modules under construction in Taos, New Mexico
(**Source:** Earthship Biotecture cited in Howarth, 2004),
(b) Unit of construction, a tyre rammed with local chalk from the Brighton Earthship (**Source:** Howarth, 2004), and
Typical Earthship Configuration
(**Source:** Earthship Biotecture cited in Milani, 2005)

A typical example of this novel building technique is the Brighton Earthship, in the northern part of Stammer Park, near Stanmer Village. A three module system, comprising a conservatory serving as a buffer zone between the main nest module, and a hut module to the left of the plan, the Brighton 'Earthship' (fig.5) was made from tyres, aluminium cans, glass bottles, wooden internal fittings, and stone off-cuts for the nest floor – all locally sourced recycled materials (CSBE, 2005). Based on an integrated autonomous energy system – that is entirely off grid with no mains water, or electricity – this earthship incorporates such sustainable energy systems as photovoltaics, Solar hot water heating, Passive solar, a Wind turbine, the conservatory module, and a thermal Mass composite of car tyres rammed with local chalk and infilled with glass bottles and aluminium cans.

Figure 5: Floor plan a) and pictorial view b) of the Brighton Earthship. (**Source:** CSBE, 2005)

Case Study III – Construction made of bottles and Cans

UN-Habitat (2012) observes that since the 1960's, bottles have been used in the construction of houses whether in part or as an entire house made of bottles. As she explains, one construction method involves the use of bottles and such wastes as plastic – where the former is filled hard with the later and loaded inside a chicken wire on both sides as bricks using plastic bags as infill in between (fig.6). Then, the structure is plastered from outside.

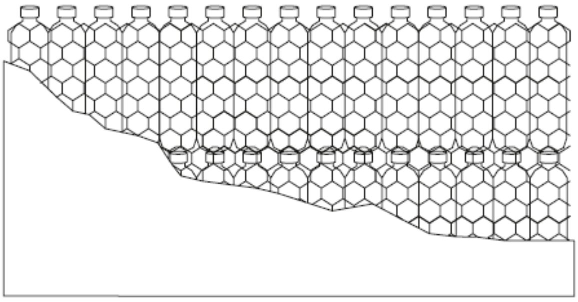

Figure 6: Illustration of Walls built with stuffed bottles between chicken wire. Concrete mix is applied on the surface.
(**Source:** UN-Habitat, 2012. Based on Pura Vida 2012)

Other derivatives of this technique are also being explored. A sample of method demonstrated in Kaduna State; Nigeria is the bottle brick construction comprising using earth-filled plastic bottle 'bricks' and mud (fig.7). The three-room structure is the product of a humanitarian project launched in December 2010 by Katrin Macmillan in collaboration with the Development Association for Renewable Energies (DARE). The main material for this innovative project is used plastic bottles and their lids, thousands of which were collected from hotels, restaurants, homes and embassies to build Nigeria's first bottle house. Also, the design of this bottle building erected on a land donated by engineer Chris Vassilou integrates a renewable energy system that incorporates photovoltaics, with a fuel-efficient clean cook-stove, urine filtration fertilisation systems and water purification tanks, to create an energy-autonomous structure from recycled materials.

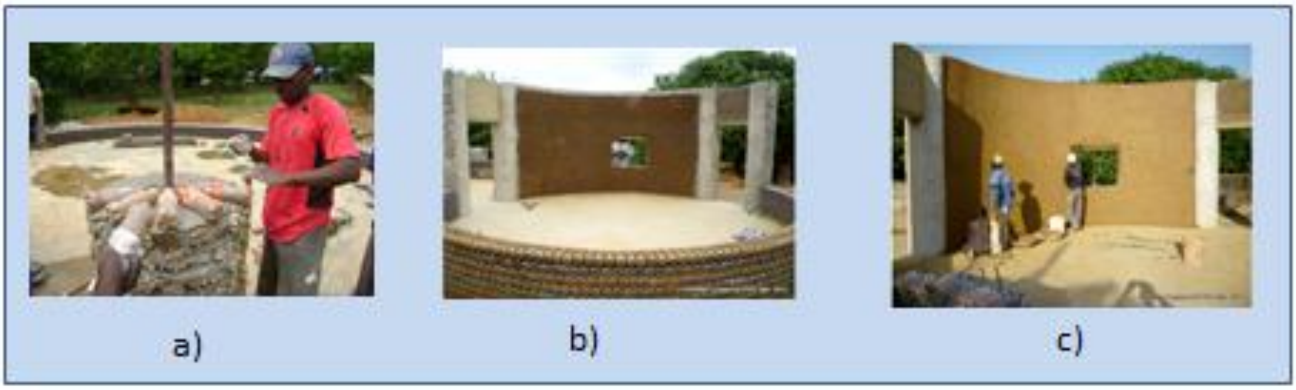

Figure 7: The construction of Nigeria's First Bottle House in Kaduna State.
(a) Bottle brick pillars, (b)bottle-brick walls and pillars, (c) plastering of the bottle-brick house
(**Source:** http://greennigeria.files.wordpress.com)

Case Study IV – Waste Paper and Papercrete Construction

Another innovative and adaptive recycling of a waste resource for use in construction is the conversion of used paper to papercrete. Basically, the technique involves the mixing of re-pulped paper fiber from newspaper, for instance, with Portland cement, clay, fidobe or dirt. Afterwards, papercrete can be used for plastering walls (UN-Habitat, 2010), the production of adobe bricks (UN-Habitat, 2012; Milani, 2005) or poured into forms as a structural material (Milani, 2005). An imaginative use of local waste material, papercrete is most suitable for application in dry climates as it absorbs water. Also, it is pertinent to introduce some additive to the mixture make the material more fireproof (UN-Habitat, 2012).

Case Study V – Other Waste-as-an-alternative-construction-material

Globally, several agriculture-based by-products have been tested for use as alternative construction material. The options available in this category are vast, and very novel techniques are being developed annually. Fig. 8 illustrates some innovative use of such agric-based alternative construction materials as Bamboo, palm timber, Straw-bale and even palm kernel shells.

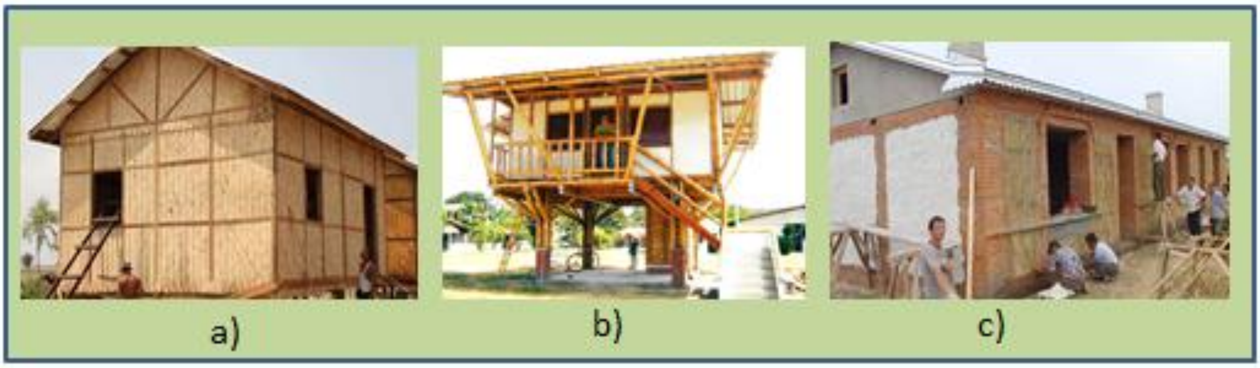

Figure 8: (a) A cyclone resistant housing for Internally Displaced Persons in Kungyangone Myanmar made of palm timber and bamboo
(b) Improved bamboo home prototype built in Olon community, Santa Elena province, Ecuador and
(c) Strawbale house with brick frame under construction
(**Source:** UN-Habitat, 2012)

Bamboo in particular, is naturally grown with the possibility of releasing about 30% more oxygen than normal trees. It is lightweight, can be grown between 3 to 5years; has excellent competitive properties in relation to steel and could serve very well low to mid precision construction projects. With further research and development, bamboo stands a great position in serving as alternative to the non-environmentally friendly material like steel. Table 1 below shows the properties of bamboo, steel and spruce wood:

KN/cm^2	Spruce wood	Bamboo	Steel
Elastic Modulus	1100	2000	2100
Compressive Strength	4.3	6.2-9.3	14
Tensile Strength	8.9	14.8	16
Bending Strength	6.8	7.26-27.6	14
Shear Strength	0.7	2.0	9.2

Source: Prathmesh V. S. and Danish A., 2021

Despite the potentials of bamboo in creating bridges and serving as stilts in riverine environments, poor cultivation and awareness on the applicability of bamboo, as well as paucity of research, development and data about bamboo construction has been a serious limitation, Efe *et al.,* 2023.

Source: Izunna Okafor, 2023

A recent construction at Umudiala Village, Ezinifite Nnewi South Local Government of Anambra State. This development also has witnessed divergent voices from different professionals; some arguing that it does not have regulatory backings, neither durable nor conform to standardization, others continued to stress its sustainable depending on expertise, area of use, species, size and treatment of bamboo.

Bamboo Reinforced Building

Segun Folarin, 2023

In furtherance to the support of bamboo use, the Nigerian Building and Road Research Institute has demonstrated the possible use of bamboo as structural components in its innovative building project.

SYNTHESIS AND RECOMMENDATIONS

Challenges to Alternative Building Materials Use

Several studies have identified many of the challenges of advancing such innovative approaches to sustainable waste management within the built-environment. The Institution Recycling Network (2005) and NYC-DDC (2003) noted the reluctance to change patterns by major stakeholders due to technical and knowledge deficiencies; inability to establish requisite codes and targets as regards quantity assessment and planning requirements, legal framework and supportive building codes; the lack of enforcement, coordination and awareness creation as the factors militating against the establishment of these novel construction techniques. Also, the difficulty in establishing demand and supply chain, intensive labour force required for sorting, processing and use of waste resource; the complex building assembly requirements, absence of the requisite standardization requirement for some recovered materials reuse, insufficient technical skills and the inadequacies in coordinating, storage and recycling centres, and workers safety were all outlined by Milani (2005) as working against the adoption of these alternative construction technologies.

Recommendations: The Integrated Waste Management and Material Reuse Model

Towards an enhanced utilization of the waste resource reuse and overcoming of the above challenges the architect has some critical roles to play in the construction sector. These specific roles of the architect in this respect are hereby presented using the concept of Material Reuse model. The model shows the various linkage and mechanism which need to be put in place if the ultimate goal of material reuse for creation of affordable housing must be achieved within the built-environment.

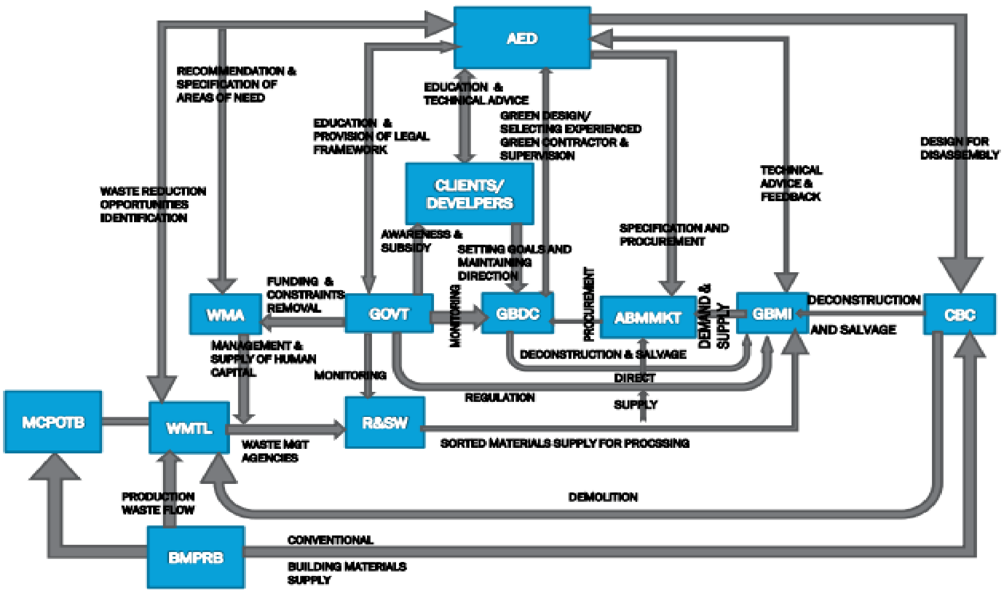

Figure 9: Integrated waste management and material reuse model
(**Source:** Authors)

LEGEND

- AED: Architects and Environmental Designers
- WMA: Waste Management Agencies
- GBMI: Green Building Materials Industries
- ABM: Alternative Building Materials Market
- GOVT: Government
- GBDC: Green Building and Developer Contractors,
- ABMMKT: Alternative Building Materials Market,
- R&SW: Recycling and Sorting of Wastes
- CBC: Conventional Building Construction
- BMPRB: Basic Materials Production and Resource Base
- MCPOTB: Materials Consumption Point other than Building

An examination of the model reveals that sustainable waste management involves:

1. The Waste Management Agencies, WMA, vested with the responsibilities of providing the managerial functions of waste material reclamation; sorting as well as coordination of their supply to Green Building Materials Industries, GBMI and sometimes direct supply to Alternative Building Materials Market, ABMMKT;
2. The Government charged with the responsibility of creating awareness campaign, removal of constraints through the supply of necessary funds, subsidy to material reuse, provision of supporting legal framework and monitoring of activities at various points;
3. The Conventional Building Constructions, CBC: which sometimes becomes the source of waste products like scaffolding bamboo, demolitions wastes etc., and provides the grounds for understanding what constitutes contemporary social acceptance indices;
4. The Developers / Clients who are to set goals and maintain directions;
5. The Green Building and Developers Contractors, GBDC who plan and implement the recycling, waste prevention and reuse on the job site;
6. The Alternative Building Materials Market, ABMMKT that establishes the demand and supply chain as well as facilitate procurement;
7. The Green Building Materials Industry, GBMI that facilitates the processing of the recovered waste resources into Alternative Building Materials, thereby enhancing standardization & procurement, while receiving technical advice from the design team and feeding them back with developments;
8. The Architects and Environmental Designers, AED: A glance at the number of linkages connecting to the design team aptly reveals the pivotal role the architect has to play in the material reuse for effective waste management towards wealth creation. These roles can be seen in the areas of identification of reusable items; provision of complete construction documents & details; designing for disassembly; specification of reusable waste; the use of specification language that promotes material reuse rather than prohibit; selecting contractors with requisite knowledge; evaluating construction reports and giving feedbacks to clients and governments; recommendations & specifications of areas of need as well as giving technical advice to government and the Alternative Building Material Industries.

It therefore necessary to educate all stakeholders on the gains such novel approaches offer to built-environment development, as a first step to eliminating every other constraint that jeopardizes its progress. The Nigerian government at state and federal levels is also urged to assist in developing pilot projects to facilitate its widespread adoption, adaptation and practice. When this becomes a widely acceptable practice, self-help projects can easily be executed with the architect providing the drawings and necessary supervision, thereby mitigating the inefficiencies and inadequacies of housing delivery in Nigeria.

Further research is also suggested on areas of establishing the quantities of these class of waste products in Nigeria and methods of developing them into a standardized building materials in line with existing and emerging building codes.

CONCLUSION

From the foregoing, the possibility of adapting waste products as alternative building materials has been demonstrated. When this becomes a norm in the Nigerian built-environment the potentials of such green practice can be efficiently taped. It will not only facilitate waste management solutions against Ozone layer and material base depletion; it will also help in job creation and building production which can be affordable to the average Nigerian income earner. This would ultimately offset housing deficit.

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