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Incorporating Circular Economy into Passive Design Strategies in Tropical Nigeria

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***Abstract*—**The natural environment is in need for an urgent rescue due to dilapidation and recession of resources. Passive design strategies have proven to be one of the effective ways to reduce CO_2 emissions and to improve building performance. On the other hand, there is a huge drop in material availability due to poor recycling culture. Consequently, building waste pose environmental hazard due to unrecycled building materials from construction and deconstruction. Buildings are seen to be material banks for a circular economy, therefore incorporating circular economy into passive housing will not only safe guide the climate but also improve resource efficiency. The study focuses on incorporating a circular economy in passive design strategies for an affordable energy and resource efficient residential building in Nigeria. Carbon dioxide (CO_2) concentration is still on the increase as buildings are responsible for a significant amount of this emission globally. Therefore, prompt measures need to be taken to combat the effect of global warming and associated threats. Nigeria is rapidly growing in human population, resources on the other hand have receded greatly, and there is an abrupt need for recycling even in the built environment. It is necessary that Nigeria responds to these challenges effectively and efficiently considering building resource and energy. Passive design strategies were assessed using simulations to obtain qualitative and quantitative data which were inferred to case studies as it relates to the Nigeria climate. Building materials were analysed using the ReSOLVE model in order to explore possible recycling phase. This provided relevant information and strategies to illustrate the possibility of circular economy in passive buildings. The study offers an alternative approach, as it is the general principle for the reworking of an economy on ecological lines in passive housing and by closing material loops in circular economy.

***Keywords*—**Building, circular economy, efficiency, passive design, sustainability.

I. Introduction

THE concept of passive design as a strategy for promoting circular economy has in recent years been a major area of discuss. Geissdoerfer et al. [1] reported that circular economy as well as sustainability has gained great popularity in industries, academics, and other sectors. The European Union has deemed it fit to create a shift from a linear system to a circular system, thus reducing economy loss by regarding waste materials from buildings as resources [2].

Passive design involves an architectural concept of a self-sustainable building, especially in the area of energy economy [3]. Passive designs are usually recognized by their sustainable features. The design of passive buildings has variety of merits amongst which energy conservation and CO_2 emission prevention is of paramount importance. Passive designs are similar to conventional designs; however, the major standout is in the standard of the designs [4]. Across the globe, the adoption of passive design strategies is imperative in the preservation of our climate. Warm regions with extreme temperatures are forced to seek for measures in order to maintain habitable thermal comfort. Sometimes these measures do more harm than good. In Nigeria, electrical power is inadequate and alternative power sources are employed which may increase the concentration of CO_2. Passive design strategies can help reduce energy cost in the cooling and heating of buildings.

It has been reported that construction industries are one of the major sources of waste production globally [5]. Statistically, an approximate amount of 45.8 m tons are derived from waste demolition in the United Kingdom [6]. The demolition and disposing of building materials has been a general practice, which has resulted in financial losses and the excess creation of waste materials. Deconstruction of buildings is now preferred over building demolition, thus benefiting the environment and economy [7]. Thus, the concept of circular economy was established to reduce building demolition and encourage building deconstruction for reuse or recycling.

Geissdoerfer et al. [1] defined circular economy as a regenerative model that minimizes waste and emission. Moreover, several researchers have been making unrestrained effort in establishing a relationship between Circular Economy and Building Sustainability [8]. The European Commission stated that the circular economy has an invaluable role to play in design sustainability as well as the adoption of this strategy in Europe [9]. Economics, environmental and social merits are some of the major benefits in the use of circular economy system. The social perspective of circular economy is in the provision of more job opportunities [10] [11].

The concept of circular economy is focused on prolonging the longevity of assets. A framework known as “ReSOLVE” was introduced by Ellen MacArthur foundation, McKinsey & Co., and SUN. The framework explores recycling options in maximizing a product’s potential with an increased longevity. “ReSOLVE” depicts; Regenerate, Share, Optimize, Loop, Virtualize, and Exchange [12].

- **Regenerate:** The concept of “REgenerate” in circular economy aims at the renewal of materials and energy, retaining, reclaiming as well as the regeneration of the elements in the ecosystem [12].

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- **Share:** This concept helps to reduce the loop process of a product and enhance product reuse by undergoing peer to peer sharing of products. This can help to prolong the lifespan of the products through maintenance and repairs [12].
- **Optimize:** The optimization of products can help to improve the efficiency and performance, as well as the reduction of waste in the supply chain. Hence, products can be upgraded, calibrated and enhanced. [12].
- **Loop:** This involves the prioritizing of materials in an enclosed loop, by recycling and remanufacturing materials at the end of their lifespan. This can reduce building demolition and promote deconstruction and reconstruction, hence reducing landfills and waste in the ecosystem [12].
- **Virtualize:** This involves the dematerialization of resources through a virtual delivery of utilities such as e-books, and smart home systems [12].
- **Exchange:** There are resources that are non-renewable, these resources can be replaced with advanced and recent technological products in order to enhance the durability and functionality of the building [12].

However, in ensuring an effective circular economic system, it is expedient that materials required for building are recyclable materials and can be recovered for reuse. This can cause a great reduction in environmental landfills. Also, the use of recyclable materials is economical, thus reducing the cost of heating and cooling. Furthermore, this study will help to identify ways to promote circular economy as well as factors to consider in the incorporation of passive designs.

A. Scope and Objectives of Study

This study focused on conducting a qualitative and quantitative study on circular economy as a passive design strategy in tropical Nigeria. Also, a simulation study was conducted, which was compared with the quantitative study. In order to accomplish this task, the objectives of the study are as follows:

- Identification of passive design strategies for tropical Nigeria.
- Determination of the compliance level of buildings to passive design strategies in the study area.
- Analysing recyclable building materials in Nigeria using the ReSOLVE framework.
- Incorporation of a circular economy system for an effective passive design strategy in Nigeria buildings.

However, through a well-structured model as discussed in this study, and illuminative reports from previous studies, the objectives of this study can be implemented in tropical Nigeria, which will bring about economic efficiency and conventional design patterns in tropical Nigeria.

B. Research Questions

During the cause of this study, several research questions were raised in other to actualize the scope of study:

- RQ1. What are the adoptable passive design strategies in the Nigeria environment?
- RQ2. What is the compliance level of residents/ developers to passive design strategies in the study area?
- RQ3. What building materials are recyclable and adoptable to circular economy principles in Nigeria?
- RQ4. What circular economic principles can be incorporated into passive design strategies in tropical Nigeria?

II. Related Studies

Construction companies impact greatly in the economic, social and environmental aspect of sustainability. This has greatly affected the productive rate of different establishments, as well as the provision of employment [13], [14]. The European Union parliament has adopted a zero-waste policy through the employment of circular economy [9]. Several studies have shown that in order to ensure an efficient circular economy system, it is expedient that a high percentage of materials used for building should be recyclable and recoverable [15].

Another study on “design for deconstruction in the design process state of the art” was based on the sustainability of embodied energy, through the reuse of construction materials that have elapse their lifespan. The study termed “design for deconstruction” focused on the materials used for construction (reusable materials), the design patterns, process of construction as well as deconstruction phase [16]. An effective technique for the recovery of building materials that have lived their lifespan is by recovering waste resource through the process of recycling materials such as metals and fibre materials [17]. Moreover, the preferred method of prevent wasted materials and economic loss is through the adoption of preventive measures. It is required that all materials and resource needed for the construction of a building should be calculated and the resource should be reusable and recyclable materials [18]. The preparation of materials for reuse is the second step in the waste hierarchy [19].

Passive design can easily be recognized from their sustainable features and energy efficiency. A passive design tends to provide high levels of comfort at a very low cost. Some of the features in passive designs that help to promote energy economy are natural ventilation systems, insulation, dry lining, solar panels, roof wind turbines, etc. [20]. During renovation, passive design structures might be very expensive to maintain, hence it is very important that the right design and durable materials are used during the construction stage.

The concept of passive design helps to structure a building as a single interconnected system. Hence the building itself should be constructed with reusable, recyclable and materials that can be deconstructed.

III. Methodology

The research started by identifying basic passive design strategies for tropical Nigeria. These strategies included building orientation, day lighting, natural ventilation and thermal mass. Optimal requirements for these design considerations were obtained which was also useful in assessing the compliance level of residential buildings with passive design strategies. The second stage of the research was to ascertain the compliance level of residential buildings with passive strategies using obtained standards.

Thermal transmittance recommendations are a total resistance (R-value) between 3.57 and 5.26 m^2K/W which is equivalent to R-20 to R-30, and a U-value within the range of 0.28 to 0.19 W/m^2K [21].

Daylighting recommendations: The Illuminance/lux recommendations for dwellings are as follows: [22]

- Bathrooms - 150 lux
- Bedrooms - 100 lux
- Hall/stairs/landings - 100 lux
- Kitchen - 150-300 lux
- Living rooms - 50-300 lux
- Toilets - 100 lux

Building orientation recommendations: Orientations of up to 20° west of North and 30° east of North is recommended in the Nigeria region Living zone should be oriented towards South and sleeping areas oriented towards North. East and West Façades have the smallest area and should be properly shaded.

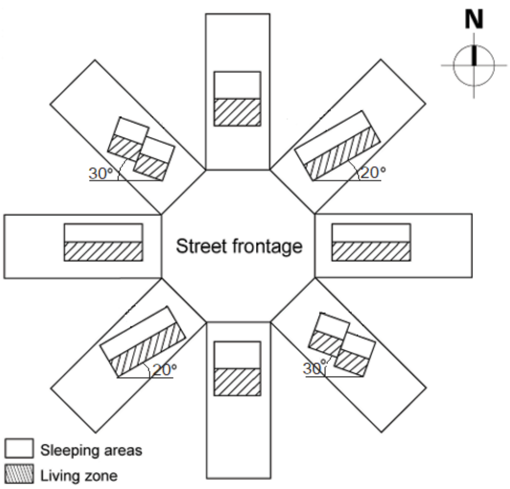

Fig. 1 Building orientation recommendations

Natural ventilation recommendations: Room depths should be 2 times the ceiling height for single-sided ventilation (W ≤ 2H). Room depths should be 5 times the ceiling height for cross ventilation (W ≤ 5H).

The study further sorted Nigeria building materials and components to various circular economy principles using the ReSOLVE framework. This provided relevant information and strategies to outline recommendations on incorporating circular economy into passive design strategies in Nigeria.

A. Structural Model

The structure of this study was the “ReSOLVE” framework which was adopted as a concept in the incorporation of circular economy into passive designs. The framework was developed by Ellen MacArthur Foundation [12]; the framework suggests possible recycling phases for products.

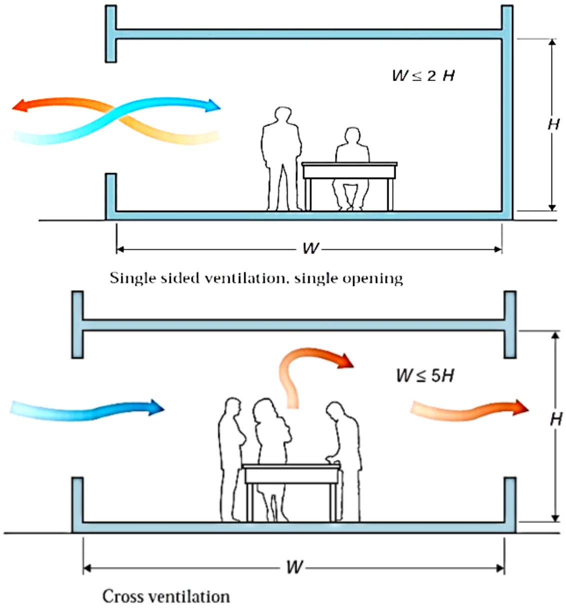

Fig. 2 Basic forms of ventilation strategy, (CIBSE AM10 and CIBSE Guide F)

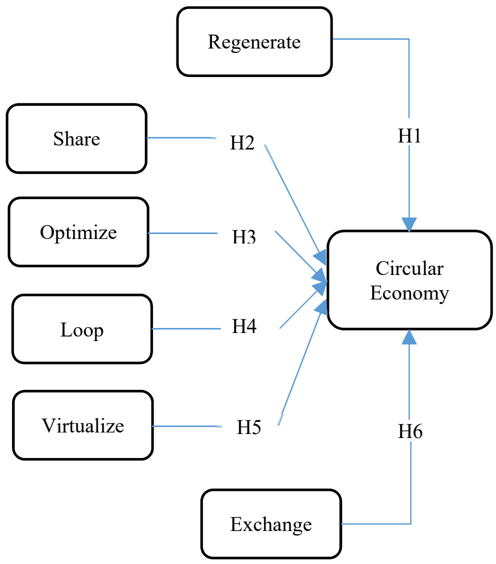

Fig. 3 Structural Framework

B. Survey

The study included a survey as one of its objectives to record residential building compliance with passive design strategies in the study area of Esan West Local Government area, Nigeria. This was necessary to determine the level of awareness and compliance of residents/developers with passive design strategies in Nigeria.

C. Research Tools, Simulations and Instrumental Measurements

The study employed the use of simulation software like U-value calculator by Kingspan in order to obtain the thermal properties and performance of building materials in Nigeria. Thermal conductivity calculator by Omni Calculator was used to determine U-values of materials, Revit Architecture was used to determine sun paths, thermodynamics theories and formulae were adopted for thermal transmittance and resistivity.

IV. Findings, Analysis and Discussions

A. Passive Design Strategies in Nigeria

Passive design considers the building as an interconnected whole. Hill and Bowen [21] stated that building sustainability begins at the design stage and spans throughout the building's life to its deconstruction and recycling in order to reduce waste.

There has been a vast interest in the concept of sustainability, focusing basically on the reduction of construction materials since building materials are receding and waste pollution is on the rise. The use of building appliances and equipment alone is insufficient if basic environmental factors are not considered [22].

Holistic concepts should be applied to the developmental process of a building. Passive design concepts explored in this study include natural ventilation, daylighting, building orientation, thermal mass. In Nigeria, there is a constant need to reduce temperature in buildings since it is in a warm climate region. Measures such as natural ventilation and thermal mass are yet to be fully explored. Nigeria building materials constitute a good thermal resistance and insulator if passive design standards are adhered to. Research findings suggest that a standard thermal mass to retard heat transmittance in the warm climate should have a total resistance (R-value) between 3.57 and 5.26 m^2K/W which is equivalent to R-20 to R-30, and a U-value within the range of 0.28 to 0.19 W/(m².K) [21]. Other standards such as ARUP (2018) recommend a U-value of 0.25 W/(m².K) to achieve a reduction in thermal conductivity.

GreenAge, recommends a U-value of $0.3W/m^2K$ for Warm Climates regions, ARUP recommends a U-value of 0.25W/(m².K) to achieve a reduction in thermal conductivity, according to House-Energy a U-value between 0.28 to 0.19 W/m^2K, equivalent to R-value of (3.57-5.26) m^2K/W is ideal for warm climates [21].

Lighting needs is of paramount importance in Nigeria since power is currently inadequate. Daylighting as a passive measure is beneficial in energy saving. Daylighting requirements for dwellings as recommended by CIBSE Guide A includes bathrooms – 150 lux, bedrooms – 100 lux, hall/stairs/landings – 100 lux, kitchen - 150-300 lux, living rooms - 50-300 lux, Toilets – 100 lux [23].

Other recommendation is that window/opening should have a minimum area of 10% of the floor area of the room [24].

Building orientation is a major consideration in any building as it sets the foundation or basis for other considerations. According to CIBSE Guide F [25], "North-facing windows suffer very little solar gain and benefits are often gained by having the major building axis pointing east/west" [25]. The acceptable orientation for Nigeria is solar north, with orientations of up to 20° west of north and 30° east of north, excluding direct sun by using trees and adjoining structures to shade every façade while capturing desired cooling breezes [26].

Naturally ventilated buildings can generate the driving force for air movement required to remove stale air. Natural ventilation has the tendency of maximizing the potential of the stack effect, using air passages and wind effects [23]. This strategy can save a quantifiable amount of energy and help cut down CO_2 emissions from buildings. According to CIBSE AM10 and CIBSE Guide F [25], room depths should be 2 times the ceiling height for single-sided ventilation ($W \leq 2H$), Room depths should be 5 times the ceiling height for cross ventilation ($W \leq 5H$).

These passive design strategies are applicable in the Nigeria and often require no extra cost to include in designs.

B. Building Compliance level with Passive Design Strategies in Nigeria

Buildings were assessed to ascertain the awareness level to passive design strategies in Nigeria. The survey documented attributes of residential building that followed passive design principles. The number of compliant buildings were recorded and categorized under the cost benefit pyramid. The cost benefit pyramid shows the cost implications of 3 major categories of design strategies that can be adopted in order to improve the performance of a building.

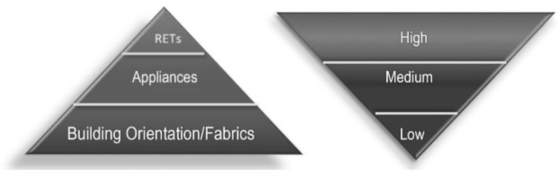

Fig. 4 Cost benefit pyramid

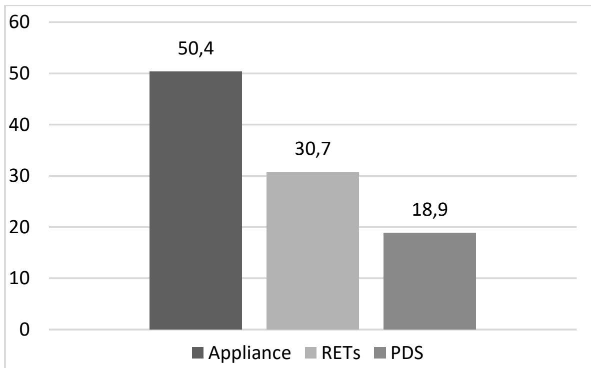

Fig. 6 Residential building compliance to PDS

Employing bioclimatic considerations is most recommended as it makes it easier for other strategies in improving building performance. The results of the survey revealed that most of the residential buildings made use of appliances – (50.4%) than other strategies to compensate for irresponsive (passive design strategies). Few buildings employed the use of Renewable Energy Technologies (RETs-30.7%) such as solar panels and inverters etc. On the other hand, very few adopted Passive Design Strategies (PDS-

18.9%) since many developers knew little or nothing about bioclimatic considerations in the study area.

The results of this survey were an indication to raise the awareness by recommending possible PDS for the tropical region of Nigeria.

C. Nigeria Building Materials and Circular Economy Framework

Common Nigeria building materials include sandscrete blocks for enveloping walls, reinforced concrete for structural members such as beam, column and slabs, sand-cement as plaster/rendering or wall panels, glazed windows/doors, PVC (polyvinyl chloride)/POP (plaster of Paris) as ceiling materials, timber doors/steel doors, tile/terrazzo/cement/rug floor finish, composite ceiling materials such as asbestos, aluminium/zinc/slate as roofing sheets.

In fitting materials into the circular economy, the ReSOLVE framework was used in sorting building materials for roof, floor, wall and fenestration into various recycling phases. Major Nigeria building materials were evaluated and sorted from research studies based on their properties, performance and ratings as best standards recommend considering the Nigeria environmental conditions. Table I shows possible recycling phases a material can undergo using the ReSOLVE framework.

TABLE I
SORTED BASIC BUILDING MATERIALS IN NIGERIA INTO THE RESOLVE FRAMEWORK

FRAMEWORK	SYMBOLS	ROOF	WALL	FENESTRATION	FLOOR
Regenerate (Re)		Aluminium, Zinc, Slate, POP, asbestos	Concrete, Hydraform bricks, sandcrete blocks, Steel reinforcements, Glass	Glass, steel	Timber, steel, terrazzo, ceramic tiles, concrete
Share (S)		Aluminium, Zinc, Slate, Timber, Steel members	Concrete, Hydraform bricks, sandcrete blocks, Steel reinforcements, Glass	Glass, steel, timber	Timber, steel, terrazzo, ceramic tiles, concrete
Optimize (O)		Aluminium, Zinc, Slate, Timber, Steel members	Concrete, Hydraform bricks, sandcrete blocks, Steel reinforcements, Glass	Glass, steel, timber	Timber, steel, terrazzo, ceramic tiles, concrete
Loop (L)		Aluminium, Zinc, Slate, Steel members	Concrete, Hydraform bricks, sandcrete blocks, Steel reinforcements, Glass	Glass, steel	Steel, terrazzo, ceramic tiles, concrete
Virtualize (V)		Ceiling lightings, varied colours, visual effects	Light fixtures, wall papers, visual effects, varied colours	Window components (Glass), varied colours	Light fixtures, varied colours, visual effects
Exchange (E)		Aluminium, Zinc, Slate, Timber, Steel members	Concrete, Hydraform bricks, sandcrete blocks, Steel reinforcements, Glass,	Glass, steel, timber	Timber, steel, terrazzo, ceramic tiles, concrete

D. Incorporation of a Circular Economy System for an Effective PDS in Nigeria Buildings

Most buildings in Nigeria are designed without considering passive measures. Consequently, these buildings use alternative means which are usually not efficient, effective and sustainable to maintain some levels of building performance as observed from the survey. PDS can easily be integrated at design stages of a building. However, existing Nigeria buildings can also be upgraded to meet passive design standards outlined above. In order to incorporate circular economy into PDS, clients and building developers are expected to take into consideration the end of life of a building, in other words, design for recycling. At design stages, it is necessary to account for expected life span of building, durability at end of life, what components/materials can be recycled, what circular economy principles can be adopted at end of life.

Using Table I, most building materials can undergo recycling phases as proposed by the ReSOLVE framework. This means that developers can select recyclable building materials based on PDS to be adopted. Therefore, first step is to:

- Design passive standards.(building orientation, natural ventilation, daylighting, thermal mass, etc.)
- Identify materials and components that can deliver expected building performance according to passive design standards.
- Design for circular economy by matching selected building components and (recyclable) materials to the ReSOLVE framework.
- Design for end of life and recycling of building (e.g. design for disassembling, modular design).

It is also important to speculate for required optimisation, repair, upgrade and maintenance during the life span of the building. Aside the ability of passive designs to be responsive to climatic conditions, they should also be able to respond to circular economy and recycling demands. This means that during the service period of a passive building, it can be repaired, deconstructed, upgraded, components regenerated, shared, optimised, looped, virtualised and exchanged for better ones. Hence, passive buildings should be designed flexible and dynamic to accommodate circular economy demands.

V. CONCLUSION

In the design and execution of a residential building, it is very imperative that the comfort and productivity of occupants are taken into consideration. This is an essential aspect in meeting the need of the residence. Most people spend more time indoors, studies suggest that most individuals spend more than 90% of their time indoors and above 70% of their time at home [27], [28]. Therefore, buildings should meet specific criteria in an affordable manner. PDS can keep buildings in optimal/functional conditions at the same reduce running cost and environmental hazards.

Circular economy on the other hand seeks to reduce waste and increase resource availability. The fusion of both principles (circular economy and passive design) produces a building that is energy and resource efficient. This will minimise energy demands and sustain buildings as material bank. The results from the compliance survey indicate that passive design practices are low in Nigeria. The passive design practice will reduce dependency on power grids and improve living conditions in buildings. A proper circular economy programme for buildings can allow new buildings to make use of 80-90% of deconstruction/demolition waste [29]. Following the outlined steps towards incorporating circular economy into PDS will produce an energy efficient building during its life span and produce resource for the construction of a new project at the end of life of the building. The ReSOLVE framework will reduce waste, increase resource, dynamism and creativity in building design.

References

[1] M. Geissdoerfer, P. Savaget, N. Bocken, and E. Hultink, "The circular economy – a new sustainability paradigm," J. *Clean. Prod.,* vol. 143, pp. 757–768, 2017.

[2] C. Clark, J. Jambeck, and T. Townsend, "A review of construction and demolition debris regulations in the United States," *Environ. Sci. Technol*., vol. 36, no. 2, pp. 141–186, 2006.

[3] N. Bhatt, "Buildings Using Passive Design Strategies for Energy Efficiency," Buildings Climate Colab, Cambridge, 2014.

[4] Feist W., Active for more comfort, Passive House Information for property developers, contractors and clients, International Passive House Association (iPHA), Passive House Institute (PHI), Darmstadt, Germany, 2018.

[5] C. Clark, J. Jambeck, and T. Townsend, "A review of construction and demolition debris regulations in the United States," *Environ. Sci. Technol.,* vol. 36, no. 2, pp. 141–186, 2006.

[6] DEFRA, "Department for Environment, Food and Rural Affairs? UK Statistics on Waste". [Retrieved 16 November 2016], 2015. Available at: https://www.gov.uk/

[7] A. Coelho, and J. deBrito, "Economic analysis of conventional versus selective demolition-a case study," *Resour. Conserv. Recycl*., vol. 55, pp. 382–392, 2011.

[8] A. Rashid, F. Asif, P. Krajnik, and C. Nicolescu, "Resource conservative manufacturing: an essential change in business and technology paradigm for sustainable manufacturing," *J. Clean. Prod.* Vol. 57, pp. 166–177, 2013.

[9] COM, "Commission of European Communities". Communication No. 398, 2014. *Towards a Circular Economy: A Zero Waste Programme for Europe.* (Retrieved 30 October 2016) 2016.

[10] B. Su, A. Heshmati, Y. Geng, and X. Yu, "A review of the circular economy in China: moving from rhetoric to implementation," *J. Clean. Prod.* vol. 42, pp. 215–227, 2013.

[11] J. Morgan, and P. Mitchell, "Employment and the Circular Economy – Job Creation in a More Resource Efficient Britain". Green Alliance, (Retrieved 13 July 2013), 2015.

[12] Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth within: A Circular Economy Vision for a Competitive Europe. Based on S. Heck, M. Rogers, P. Carroll, Resource Revolution, 2015.

[13] A. Lukman, O. Lukumon, O. Olugbenga, O. Anuoluwapo, D. Manuel, B. Muhammad, and A. Sururah, "Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator," *Resources, Conservation & Recycling,* vol. 129, pp. 175–186, 2018.

[14] O. Gencel, C. Ozel, F. Koksal, E. Erdogmus, G. Martínez-Barrera, and W. Brostow, "Properties of concrete paving blocks made with waste marble," *J. Clean. Prod.* vol. 21, no. 1, pp. 62–70, 2012.

[15] M. Smol, J. Kulczycka, A. Henclik, K. Gorazda, and Z. Wzorek, "The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy," *J. Clean. Prod*., vol. 95, pp. 45–54, 2015.

[16] S. Pan, M. Alex, I. Liu, I. Liu, E. Chang, and P. Chiang, "Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review," *J. Clean. Prod.* vol. 108, pp. 409–421, 2015.

[17] K. Jouri, "Design for Deconstruction in the Design Process: State of the Art," *Buildings*, vol. 8, pp. 150-156, 2018.

[18] M. Bilal, L. Oyedele, J. Qadir, K. Munir, O. Akinade, S. Ajayi, H. Alaka, and H. Owolabi, "Analysis of critical features and evaluation of BIM software: towards a plug-in for construction waste minimization using big data," *International Journal of Sustainable Building Technology and Urban Development*, vol 6, no. 4, pp. 211-228, 2015.

[19] S. Liu, Z. Meng, and C. Tam, "Building information modelling based building design optimization for sustainability," *Energy Build*, vol. 105, pp. 139–153, 2015.

[20] Z. Alwan, P. Jones, and P. Holgate, "Strategic sustainable development in the UK construction industry, through the framework for strategic sustainable development, using building information modelling," *J. Clean. Prod*., vol. 140, pp. 349–358, 2017.

[21] R.C. Hill, P.A. Bowen, Sustainable construction: Principles and a framework for attainment. Construct. Manag. Econ. 15: 223–239. 1997.

[22] C.A. Boyle (2005). Sustainable buildings, *Proceedings of the Institution of Civil Engineers Engineering Sustainability,* 158 March, Issue ES1, pp. 41–48.

[23] Design, CIBSE Guide A. Environmental. *"The Chartered Institution of Building Services Engineers."*, 2018.

[24] Board, Australian Building Codes. *"NCC 2019, Energy Efficiency"*, 2019.

[25] CIBSE Guild F, CIBSE AM10, Energy efficiency in buildings. Chartered institution of building services engineers. 2012.

[26] C. McGee, C. Reardon, D. Clarke, C. Reardon, *Australia's guide to environmentally sustainable homes - tropical considerations*, Australia, 2013.

[27] A. Sev., How can the construction industry contribute to sustainable development? *A conceptual framework.* Sustain. Dev. 17: 161–173, 2009.

[28] J.L. Adgate, G. Ramachandran, G.C. Pratt, L.A. Waller, K. Sexton, Spatial and temporal variability in outdoor, indoor, and personal PM2.5 exposure. Atmos. Environ. 36: 3255–3265. 2002.

[29] Resource-deutschland, *Recycling concrete*, VDI Zentrum Ressourceneffizienz, 2014.