Social Informatics Journal
Business, Politics, Law & Technology
Vol 6, No 1, March, 2020

Internet of Things and Smart Buildings in Developing Countries: Practical Implementation in Nigeria

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ABSTRACT

Over the past years, there has been a consistent advancement in technology, alongside a noticeable increase in population of urban areas settlement in developing countries according to the United Nation, 2019 report. With this increase comes accommodation problem, enviromental challenges and human problems in sectors like health and safety, energy management, sustainability, and cost efficiencies. Internet of Things (IoT) has a lot of application potentials to solve these challenges thereby having a great impact on developing countries like Nigeria. The term "Internet of Things" (IoT) describes a system where the digital world is connected to the physical world forming a global network, it exploits sensors, actuators, and data communication technology embedded into physical objects and enable those objects to be tracked, coordinated, or controlled across a data network or internet with the goal of creating value for the user over the system life-cycle. Therefore, this paper discusses the importance of IoT based Smart building in developing countries and how IoT can be applied in a country like Nigeria. The research method adopted for this paper was based on an in depth literature review, the study concluded that developing countries such as Nigeria should begin to inculcate and implement the vision of IoT based Smart Building due to its packaged benefits to improve human life and environment.

Keywords: Internet of Things, Smart building, developing countries, Nigeria, Envromental challenges

Journal Reference Format:
Oladunmoye, O.M., Ajayi, S.A., Obakin, O.A. & Taiwo, J.O (2020): Internet of Things and Smart Buildings in Developing Countries: Practical Implementation in NigeriaSocial Informatics, Business, Politics, L:aw & Technology Journal. Vol. 6 . No. 1, Pp 70-81
dx.doi.org/10.22624/AIMS/SIJ/V6N1P8 www.isteams/socialinformaticsjournal

1. INTRODUCTION

The world has gradually moved from the traditional way of solving problems especially in building and construction to technology based approach and as the world becomes more technologically advanced and digitized, many smart devices can be found in homes, offices and buildings at large to meet their needs. The increase in the world population is also a major factor that drives the need for smart cities, to meet environmental problems and to improve people's quality of life. (DiChristina, 2011). The widespread consensus acknowledges that leveraging new technologies stands as a crucial prerequisite for realizing the potential of smart buildings (also referred to as intelligent buildings). This encompasses an array of elements, including but not confined to deploying sensors, engineering and analyzing vast amounts of data, utilizing cloud and fog computing, advancing software engineering, and developing human-computer interaction algorithms.

Within these technological facets, the burgeoning realm revolves around Internet of Things (IoT) development. Smart buildings face a significant challenge in navigating a complex network of interconnected functional components across various aspects of a building." (Stojkoska & Trivodaliev, 2017; Hui et al., 2017). In an attempt to proffer solutions to fast urbanization and growing population, which presents enormous tasks and pressure in urban areas especially in a country like Nigeria (Abdulkadir, Adamu, & Abdul-Fatou, 2017), the government should start to look to incoporating in cities smart technology solutions by leveraging the Internet of Things to build a smart city that will enhance efficiency and quality of living. (Adejuwon, 2018). This will help in addressing issues like building temperature control, Smart water usage, Pest control, Fire detection, Security and access control, and Structural health monitoring.

In recent years, the IoT has made significant inroads into the building industry. Notably, companies like IBM and Intel have introduced their smart building products to the market, showcasing the competitive advantage and future direction of IoT technology within this domain. Therefore, it is necessary to understand the importance and benefit of integrating IoT into smart buildings in developing countries. However, surveys for IoT-based smart buildings exist (e.g. smart home technologies) (Stojkoska & Trivodaliev, 2017; Alaa et al., 2017), but has not been well understood in Nigeria in terms of their numerous benefits, therefore the need to review and analyze comprehensively.

2. INTERNNET OF THINGS [IoT]

The exponential growth in internet-connected devices is increasingly enriching the digital realm. (Cisco, 2011The term 'Internet of Things' (IoT) refers to a system that interconnects the digital and physical realms, establishing a global network (Ashton, 2009; Goetz, 2011). Pretz (2013) defines IoT as a network where various objects are wirelessly connected via smart sensors. In practical terms, IoT leverages sensors, actuators, and data communication technologies embedded within physical objects. For instance, within a Smart Building context, these objects encompass doors, walls, furniture, windows, facades, lifts, ventilation modules, heating/cooling systems, lighting setups, water systems, roofs, electrical power systems, communication setups, office equipment, data storage systems, and more. These embedded technologies enable the tracking, coordination, or control of these objects over a data network or the internet. The ultimate objective is to generate value for users throughout the entire life-cycle of the system (Manyika & Chui, 2013).

There are a number of different domains in which Internet of Things (IoT) is facilitating and improving human life and work efficiency (Bashir, 2017). There is an increasing interest in using IoT devices for making buildings more smart and efficient (Rathore,et al., 2016). IoT plays a key role in the transformation of residential and any kind of buildings to being “smart”. Smart buildings aim to provide solutions that are energy efficient, environment friendly, disaster manageable and comfortable. Therefore, any solution that can potentially increase the comfort level and provides the fore-mentioned services can be incorporated into smart buildings. Indeed it is a system that allows for the buildings to have a “brain”’ (Snoonian, 2003), so that they can handle the human and natural disasters properly, maintain the energy expenditure (hence reducing the greenhouse gas emission) while at the same time provide the level of comfort that the tenant asks for.

The term Internet of Things was first coined by Kevin Ashton in 1999 in the context of supply chain management (Gubbi et al. 2013). However, the exact definition of IoT is still in the forming process that is subject to the perspectives taken (Hepp et al. 2007; Joshi and Kim 2013; Pretz 2013). IoT was generally defined as “dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols; physical and virtual ‘things’ in an IoT have identities and attributes and are capable of using intelligent interfaces and being integrated as an information network” (IERC 2013; Kirtsis 2011; Li et al. 2012a, b).

social Informatics Journal
Business, Politics, Law & Technology
Vol 6, No 1, March, 2020

The term over the years has incorporated various applications that can range from health care, transportation and utilities. The fundamental idea for IoT is the interconnection of various "Things" such as sensors, smartphones, actuators, or physical items tagged/embedded with sensors such as chemical containers with temperature sensors.. The cooperation among these devices forms the basic pillar upon which IoT stands and makes it possible for them to achieve the common goals (Giusto et al., 2010). Basically, the IoT can be treated as a superset of connecting devices that are uniquely identifiable by existing near field communication (NFC) techniques (ETSI 2013). The words "Internet" and "Things" mean an inter-connected world-wide network based on sensory, communication, networking, and information processing technologies, which might be the new version of information and communications technology (ICT) (Kranenburg 2013; Marry 2013). A major part of these IoT devices are installed inside buildings (Duffy & O'Donnel, 1998); hence, leading us to concept of Smart Building. IoT is strongly tied to the Big Data era due to the enormous data that the"Things" can generate. For the interconnection of these devices, different wired or wireless standards exist (Vermesan & Friess, 2013).

There are number of domains in which IoT is enabling human life and work in a noteworthy way, including automation, transportation, disaster management and health-care. IoT enables an object to listen, hear, see and communicate at the same time (Cisco, 2011). IoT thus transforms the devices from being smart by incorporating its pervasive and ubiquitous computing, communication technologies, embedded devices and many other applications to influence and revolutionize human life (Bashir, 2017). Smart homes provide the ability to the residents to access smart devices remotely from anywhere across the globe (UN, 2009)

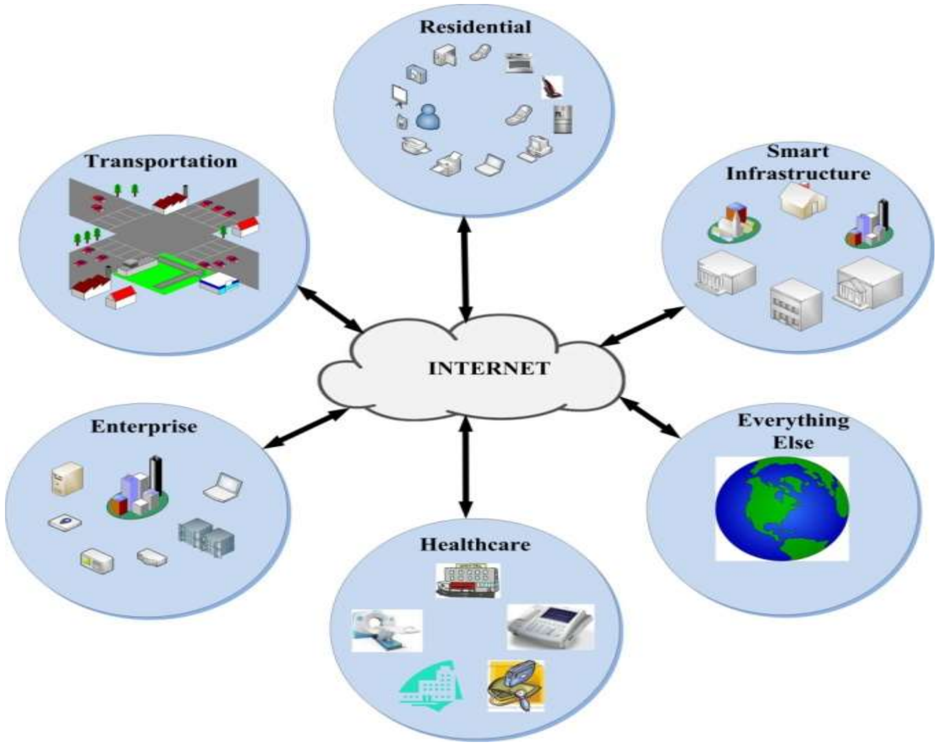

Fig. 2. IoT: Connecting everything through the Internet (Zafari et al., 2016)

.The above mentioned development initiatives formed the foundation of IoT (Xia et al., 2012). The IoT's application spans across both residential and commercial domains, encompassing diverse services such as e-health (Atzori et al., 2010), intelligent parking systems (Faheem et al., 2013), intelligent transportation (Weiland & Purser, 2000; Bayram & Papapanagiotou, 2014), automation, and logistics. Presently, there's a continuous deployment of new IoT-based services, with projections indicating that by 2025, IoT will permeate numerous aspects of daily life, including appliances, food packaging, documentation, and furniture (PRC, 2014; DCT, 2008).

For comprehensive integration of IoT into reality, various enabling technologies must be integrated. Numerous challenges persist, including device interoperability, smartness, security, privacy, energy consumption, processing capabilities, and network addressing (Atzori et al., 2010). Figure 2 illustrates an exemplary IoT infrastructure where multiple systems and devices interconnect through the internet, showcasing the potential for connectivity across residential, transportation, enterprise, healthcare, and various other environments worldwide. However, connecting all these devices to the internet necessitates a substantial number of Internet Protocol (IP) addresses (Zafari et al., 2016).

2.1 Why Use IoT In Buildings

Internet of Things (IoT) is used to collect and analyze data in real-time with the purpose of Improving the energy efficiency and sustainability of buildings, Reducing maintenance costs, and enhancing occupant comfort, security, safety and to also bring out massive innovation, automation, and optimization of resources. The core of the Internet of Things concept is the gathering of devices around a single controller. Furthermore, to optimize energy consumption, lower costs, and improve safety and security, the sensors in the house collect the needed data and enhance the functionality of household appliances. IoT installations help improve employee daily life by automatically adjusting: temperature, · lighting and blinds based on preferences and the conditions outside. Smart buildings can also improve energy consumption, management, improve real-time communication, improve customer relationship, predict equipment failure in industrial facilities and optimise the working space.

IoT is not limited to the listed function and can be further used when incorporated for the following;

1. To improve construction site safety
2. To improve construction productivity and efficiency
3. To improve construction quality
4. To improve the maintenance and sustainability of construction projects
5. To improve communication and collaboration among stakeholders: contractors, project managers, sub-contractors, suppliers, and building owners.
6. Resources Management and Budgeting
7. Concrete Curing
8. Structural Health Monitoring
9. Waste Management
10. BIM Optimization and Digital Twins

IoT AND SMART BUILDINGS

Various bodies took the responsibility to define Smart Building. Some of them, like European Intelligent Building Group (UK) or Intelligent Building Institute (USA), are focused on Smart Building from performance perspective (Sinopoli, 2006). Thus, the focus from this point of view is on user comfort, capability to adapt quickly to changing needs of the users, efficient management of resources and minimization of life-cycle costs. Japanese Intelligent Building Institute focused on providing more attractive administrative services at lower costs, as well as flexible and economical responses to sociological changes (Harrison & Loe, 2005) while Chinese Intelligent Building Design Standard

GB/T50314-2000, definition sees Smart Buildings from a technological point of view (building automation, office automation, communication automation, safety, and convenience) (Wang, 2010). A smart building is a super system of interconnected building systems. Like the Internet, it connects individual computer networks into one larger supernetwork (BEI, 2011).

The basic motive behind the construction of Smart Buildings is to provide the highest level of comfort and efficiency. For example, once a tenant enters an enterprise the temperature, humidity and the lighting are adjusted according to his personalized levels of comfort, his computer and the corresponding applications are turned on (Snoonian, 2003). Smart buildings are designed to offer occupants a secure, productive, and comfortable environment while ensuring optimal operational efficiency and energy performance. These buildings incorporate diverse infrastructural components dedicated to maintaining occupant comfort. Examples include highly efficient HVAC systems, intelligent metering for electricity, gas, and water, occupancy monitoring systems, and even technology for hybrid vehicle charging (Mullassery, 2016).

The global energy consumption within buildings, encompassing both commercial and residential spaces, has steadily increased, accounting for a significant 20% to 40% in developed countries (UN, 2009). This proportion surpasses energy consumption in transportation and industrial sectors. Factors such as population growth, heightened demands for comfort, expanded building services, and longer occupancy periods contribute to the escalating energy demands. Notably, HVAC systems rank as the most energy-consuming component within building operations compared to other energy systems (Bashir, 2017). A smart building also has some level of energy independence. It has to have its own power generation through renewable energy resources, and incorporate energy efficient technologies; solar photovoltaic windows can collect energy (Yin et al. 2012).
Figure 1 presents an insight into characteristics and components of a smart building. Various sub-systems work together and constitute a smart building.

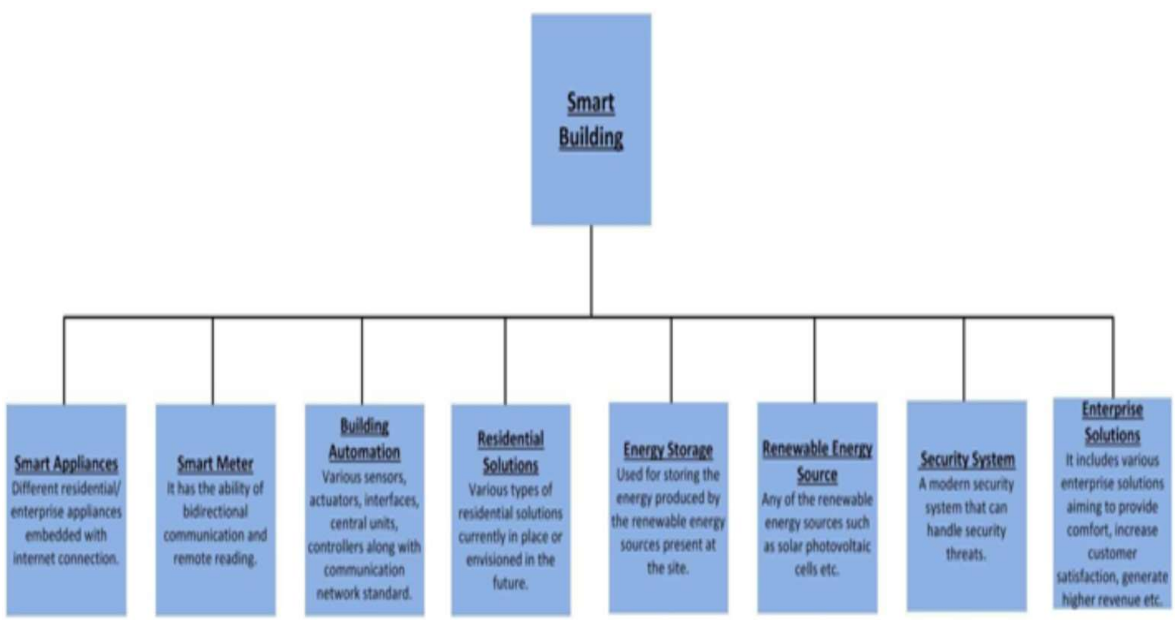

Fig. 1. Various sub-systems of a smart building.(Zafari et al., 2016)

Smart building can react to the internal and/or external environment changes without human interaction in order to provide comfort to the occupants and, while taking into consideration financial and energetic perspectives (Harris, 2012).
Smart Building combines real-time monitoring with event management and data analytics to help managers to optimize the available resources, and enhance reliability (IBM TRIRIGA). Some of the main characteristics of Smart Buildings are (IBM TRIRIGA):

i. They improve reliability and performance to reduce energy consumption.
ii. Lower maintenance and management are needed, as consequence, operating costs are reduced.
iii. Captured data can be used to perform energy analytics.
iv. All the metrics can be collected in a repository for future analysis.
v. Real-time events can be centralized for consolidation, correlation or to initiate certain action when a service is requested.
vi. Anomalies can be detected by applying analytical rules.
vii. Analyze historical data to identify trends and perform corrective actions.
viii. Create scenarios to perform context awareness.

3. OPPORTUNITIES OF IoT IN DEVELOPING COUNTRIES

IoT in developing countries has a lot opportunities and in differennt field. Beyond all the current generated value of IoT, 40% economic added value has been predicted to be generated according to KfW Group's report (2016). IoT technologies have the potential to change our lives and habits and according to IoT technologies bring to the table various useful benefits to society. (Sandro et al,2020). IoT are applied in differennt ways but the most important ways are in industry and smart city concept(Sandro et al,2020). Different control options are possible within the smart home concept and enable an efficient integration of renewable energy technologies in homes (Stavrakas and Flamos, 2020), and their efficient balancing (efficient supply and demand) which will be key points in upcoming decades to be able to secure global energy transition goals. (Tzankova, 2020)

3.1 IMPORTANCE OF Iot BASED SMART BUIDINGS IN DEVELOPING COUNTRIES

Energy & Cost Efficiency
Increasing price of oil, gas and electricity are the main driver conducive to reduce energy usage, but energy efficiency is not only about cost cutting. Buildings are responsible for one third of total global energy consumption and an equally important share of CO2 (EEB, 2014). Global climate change is forcing us to reduce energy consumption to save the planet. In this context, smart buildings must prioritize maintaining optimal service levels for occupants without compromising on this objective, necessitating solutions that cater to both aspects. Presently, there are existing Commercial Building Energy Management Systems (BEMS, 2018) that aid in regulating, overseeing, and enhancing current building energy consumption. Using system of interaction and IoT in smart buildings will allow the energy consuming devices to be connected to Internet that will allow the user to control and monitor various appliances through a simple smartphone or any wireless terminal (Jeon et al., 2004).

Certainly! Here's a rephrased version:

The integration of IoT technology empowers smart grids to oversee energy consumption at a broader scale, specifically concerning building energy efficiency. Smart grids, comprising interconnected computer networks, collaborate with power infrastructures to monitor and regulate energy utilization (Farhangi, 2010).

Viswanath et al. (2016) devised a residential system integrating IoT components and software designs. Their experimental units include an array of sensors, actuators, smart plugs, smart meters, and a universal home gateway (UHG). The UHG serves as the central communicator between devices and a cloud server, facilitating data collection and processing. This system facilitates demand response adjustments in building systems to mitigate peak loads or high-priced periods, ensuring more balanced load control. Additionally, the user-end application offers functionalities such as energy monitoring, home automation, and security. Users can access dynamic pricing data to prioritize low-energy tasks based on their preferences. The implementation of IoT technology presents developing countries' industries with significant opportunities to achieve these objectives, ultimately contributing to global environmental conservation and resource preservation.

Comfort

Smart building implementation is not only about cost saving and environmental impact. It also involves using all the building automation to improve the overall user experience. The system senses the internal and external conditions and responds in the way users could feel safe and comfortable. The comfort metrics can be characterized in different metrics (Lachhab et al., 2017):

- **Thermal comfort;** the devices learn the occupant's habits and adjust the control accordingly. After a bit of time, it knows when to turn on heating and cooling or when nobody is at home and system can be put to energy saving mode. Furthermore, the system can be integrated with the local energy provider in the way, local utility company can reduce the load during consumption peak, offering discounts on the bill in return (NFS, 2016).
- **Visual comfort;** providing visual comfort is also a complex issue with a lot of influencing factors. In general, it depends on having appropriate amount of light for the performed task. Good visual comfort depends also on light source and light distribution. Direct lighting tends to create more shadows and contrast and is harsher than indirect lighting, therefore light colored walls and ceilings and indirect light may improve visual comfort (ABB, 2014).
- **Noise level;** although the acoustical environment in the building is mainly result of design, smart buildings control systems, can play some role in the providing acoustic comfort in the building. Sound masking using engineered background sounds distributed via loudspeakers in the ceiling to reduce impact of distracting sounds (Sinopoli, 2016).
- **Indoor air quality;** Studies showed that indoor air pollution levels are often many times higher than outdoor (Chiras, 2004).

Bashir and Gill (2016) introduced an integrated IoT big data analytics (IBDA) framework designed for real-time monitoring and control within buildings. Their study involved simulating environmental data—oxygen levels, smoke/hazardous gases, and luminosity—across five distinct zones. These data were processed through the Cloudera Hadoop Distributed File System to initiate control decisions when values deviated from predefined comfort ranges. However, certain limitations emerged from this research: firstly, the focus was solely on occupant comfort with no consideration for energy efficiency in the control strategies; secondly, the absence of a practical IoT system test as the researchers concentrated on real-time data analysis and visualization. Similarly, industries offer solutions aligned with human comfort in smart buildings. Talon and Goldstein (2015) highlighted Intel Corporation's IoT system, demonstrating its potential collaborations with domain experts to enhance experiences for various stakeholders. One application involves transforming individuals into sensors within commercial buildings by providing a smartphone interface for office occupants to relay temperature comfort feedback to the analytics engine.

Based on these inputs from different zones across the office, optimal temperature settings are adjusted, and the HVAC system implements measures to maximize occupant comfort. In addition, a high CO2 level in the air influences badly the well-being of occupants, therefore more and more building automation systems integrates CO2 sensors (ABB, 2010) to include it into HVAC control loop. To reduce energy consumption while maintaining adequate air quality, demand controlled ventilation can be implemented. Instead of fixed air replacement rate, CO2 sensors can be used to adjust ventilation throughput to actual emissions of building occupants.

Safety and health security

The emphasis on indoor safety and healthcare remains a priority for building occupants, and the integration of IoT can significantly enhance these concerns. For instance, Demirkan (2013) exemplifies automated, intelligent, and sustainable healthcare systems driven by IoT implementation.

Expanding on this, Li et al. (2013) proposed a smart community architecture across three domains, highlighting IoT applications in healthcare. They introduced the deployment of wireless body sensors around individuals, designed to detect health emergencies. In case of an emergency, these sensors or home surveillance systems would trigger immediate alerts, transmitting vital readings and personal information promptly to healthcare facilities for swift aid.

Piscitello et al. (2015) proposed a Danger-System which is able to detect safety-related emergency and provide alert and rescue solutions for building occupants. The system utilized the application installed in users' smartphones to detect events such as user running or loud noise, and aggregate all the information to generate potential emergency activation. After the message is confirmed by building manager, notifications are sent to all users according to their current situation (e.g. location) and the building alarm is switched on.

Building health control

For health monitoring of building structures, Wang et al. (2017) proposed an IoT-based integrated information system with early warning function. The system architecture incorporates sensor data collecting layer, data management layer, and structural health monitoring service layer. For the sensor data collection layer, steel stress gauge, inclinometer, and earth pressure cell sensors were employed at the pivotal locations of monitoring target, and multi-standard communication was applied for data transfer and processing. The system also had a module for uniform data parsing to abstract the different message formats of heterogeneous devices for data integration. Finally, the structural health monitoring layer directly linked to supervision department to inspect potential failure conditions.

4. CONCLUSION

IoT technology development is an important factor influencing the way smart buildings are implemented. It is a tool to facilitate and improve functionalities of buildings. Researcher has identified some key importance of IoT based Smart Building in the developing countries such as energy and cost efficiency, comfort (thermal, visual, noise level and indoor air quality), safety and health security, and building health control. In the developing countries such as Nigeria, energy are scarce and there are much demand due to population growth, therefore introduction of IoT based Smart Building will help reduce energy consumption. In addition, IoT based Smart Building has its own power generation through renewable energy resources, and incorporate energy efficient technologies, hence this could result in an enormous reduction of greenhouse gas (GHG) emissions and global warming which by extension causes climate change. In the area of comfort, it involves using the building automation to improve the overall user experience by sensing the internal and external conditions and responds in the way users could feel safe and comfortable. Safety and health security of the building occupant is also very important, and this is achieved by by IoT implementation. Building health control uses sensor that transmit warning information to the supervising department in case of any failure in the building.

Since the utmost idea of IoT based Smart Building is to connect any individual, system and the entire environment together from any location and at any time in order to improve human life with positive environmental impact, safe and sound health security, and cost reduction, it is therefore very important to inculcate and begin to implement the vision of IoT based smart Building in Nigeria and developing countries at large.

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