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Identifying Challenges of Internet of Things on Construction Projects Using Fuzzy Approach

Benedict Amade[1] and Cosmas Ifeanyi Nwakanma[2]

[1]Lecturer, Department of Project Management Technology, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria. E-mail: benedictamade@futo.edu.ng (corresponding author).

[2]Ph.D. Researcher, Department of IT-Convergence Engineering, Kumoh National Institute of Technology, Gumi, South Korea. E-mail: cosmas.ifeanyi@kumoh.ac.kr

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Abstract: This study presents a fuzzy decision-making trial and evaluation laboratory (DEMATEL) analysis of the internet challenges of the internet of things (IoT) implementation of construction projects in Nigeria. The identification of the IoT challenges was carried out through a thorough literature search and discussions with 27 built environmental experts. In addition, DEMATEL, an expert judgement-based tool, was used to pick, design, and evaluate a structural model consisting of a causal relationship between defined IoT challenges. Subsequently, the fuzzy DEMATEL was deployed with a view to constructing a structural relationship between the various challenging factors by visualising the dynamic associations between them. Based on the findings of the literature survey and expert evaluation, 18 obstacles to the implementation of IoT in construction projects were classified into cause and effect classes based on their relative parameters of impact. The results suggest that 8 challenges were categorised into the cause group, while 10 were listed into the impact group. The results of this study will enable construction companies, construction industry experts, project managers in Nigeria to enhance their search to design and execute an effective and productive IoT application for their construction projects.

Keywords: Fuzzy DEMATEL, construction projects, internet of things, challenges.

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1. Introduction

In the race for the deployment and implementation of the fifth generation (5G) and the industry 4.0, a number of emerging disruptive technologies are bringing change and innovation to the various industries. While some countries are seen to have taken the lead in the effective use of these emerging technologies (Jahng and Park, 2020), many developing or less developed countries have yet to leverage them (Saka and Chan, 2020). In Korea, for example, Hyundai Engineering & Construction Co., Ltd. has implemented a safety management system using a safety helmet with an IoT-based sensor (Park et al., 2019). Key among the disruptive technologies are the internet of things (IoT), 3D printing, digital twin, artificial intelligence (A.I.), big data, cloud computing and cyber physical system (C.P.S.) (Thomas, 2019) as well as drones, radio-frequency identification (RFID), wireless sensors etc. (Osunsanmi et al., 2020). (Osunsanmi et al., 2020). IoT has been described in various ways. However, one unifying aspect in its description is that IoT can be seen as linking objects in the world in such a way that they share information in an intelligent and sensory manner (Colakovic and Hadžialic, 2018; Long et al., 2018; Tran-Dang and Kim, 2018). Perhaps one of the main advantages of IoT is that it facilitates the cross-industrial use of data, such as the use of building site-generated data to direct the development of building materials or to guide the logistics and supply chain management of building goods (Tran-Dang and Kim, 2018; Gloukhovtsev, 2018). According to Jia et al. (2019), the IoT architecture is built in such a way as to enhance all entities with the ability to recognise, make sense of the network, thus enhancing processing speed with a view to enabling individual objects to exchange and share information leading to the creation and advancement of state-of-the-art services over the Internet. IoT has been applied to the building industry and has been used to aid in construction. Despite the widespread existence of IoT in various fields and construction, little work has been done to investigate the challenges facing the implementation and adoption of IoT in construction, particularly for developing countries. Chen et al. (2020) argued in their submission that the willingness of construction industry practitioners to incorporate IoT applications was not quite impressive. This assertion is no different from that of Saka and Chan (2020), who reiterated that the problems facing the Nigerian construction industry are further compounded by the disaggregated nature of the industry, together with an increase in the number of stakeholders, a lack of information management and a consistent dependence on traditional methods. Amade et al. (2019) and Saka and Chan (2020) further claimed that, as a result of this, there have been calls to shift the tide and leverage the use of modern information and communication technology as it is obtained in developed climates. The goal of this study is to identify the challenges of the IoT implementation of construction projects in Nigeria. This paper is further organised as follows: the next section shows the relevant works where the paper provides a brief description of IoT and its application in the construction industry.

2. Related Literature

IoT includes putting together computers or items known as things for the purpose of storing, sharing, and supporting data on the Internet. In different cases, these things can be anything from sensors, smart devices, or anything with the ability to receive or transmit information over the Internet. If IoT is extended to the industrial situation, it is called the industrial internet of things (Long et al., 2018). According to Nwakanma et al. (2019), IoT has affected various sectors of the economy, including manufacturing, automotive, energy, health, agriculture, and construction (Osseiran et al., 2017; Reja and Varghese, 2019). While Zhao et al. (2020) are of the view that IoTs promote the traceability and visibility of industrial processes intending to facilitate the dissemination of knowledge and bid data analytics. Recently, researchers in Rwanda have shown the potential of using IoT to monitor and manage the construction of biogas digesters. With IoT in the construction of digesters, Rwanda can ensure that temperature monitoring, feed material moisture and gas pressure are critical to energy management. Mining and mining construction will benefit from the IoT giving rise to what researchers have called "smart mines." Following Zhao (2020), IoT was integrated into the mine design and development of low-power sensors and computers, cloud computing, and successful data collection and monitoring of mining activities. Not only has this been shown to be reasonable and safe for workers, but it has also enabled the possibility of monitoring and early warning of mine disaster management.

2.1. IoT for Construction

Unlike manufacturing and agriculture, the construction industry is still at an early stage in the adoption of IoT (Hill, 2020; Reja and Varghese, 2019; Chen et al., 2020). During construction, a slowdown in activity can lead to a delay in all other tasks, while the inability to detect oil leakage in construction machinery can be disastrous, just as accidents and fatalities can be of serious concern if moving objects across workers is not monitored. IoT is claimed to cause a paradigm shift in the construction industry as construction startups hope that IoT will help in data collection and automation of construction processes (Higginbotham, 2019). Fig. 1 shows the IoT generic architecture as adapted from (Nwakanma et al., 2019). Bucchiarone et al. (2019) proposed "smart construction" as a cloud-based IoT platform that supported construction sites in the collection, feedback, and management of complex construction projects. As shown in Fig. 1, IoT devices may be in the form of cranes, vehicles, 6 or wearable devices attached to construction workers. The data is moved via the gateway or cloud and streamed to the storage area on a continuous basis. The data collected may further serve the purpose of other decision-making processes by project managers and other stakeholders through the available analytical tools.

Users such as project managers and construction site workers make use of reporting tools, on-site monitoring of human and material requirements, as well as temperature and other important site details to help decision-making. The application and advantage of IoT are not limited to construction sites and machines on their own. In accordance with He and Peansupap (2018), IoT was designed and tested to help construction workers monitor the safe distance between moving objects on site. The construction industry, on the other hand, is very different; it consists of many complexities, such as fractured and haphazard work environments, multidisciplinary design, unstructured processes, and remote work sites. The application of IoT in construction would also require the introduction of suitable policies and technologies. Hong Kong, Lam et al. (2017) developed and tested the efficiency of the IoT monitoring system to ensure real-time and continuous monitoring of construction and civil engineering sites. The IoT device allows the tap to be held at the threshold of operations and site circumstances such as tilting and underground water table level control during the construction process of a high-rise residential building and a ground retaining wall prone to movement. IoT may also be incorporated into building information modelling to enhance construction and civil engineering programmers, as well as link health monitoring and safety applications. In doing so, IoT and Building information modeling (BIM) provide real-time data required to direct the construction process and serve the purpose of tracking on-site human and material resources. In their research, Awolusi et al. (2019) argued that the use of IoT enables wearable sensing devices and emerging technologies with a strong potential to transform many aspects of the safety, monitoring, and tracking of construction workers as well as the distribution of safety information online-real-time.

2.2. Challenges of IoT Implementation on Construction

Studies on the challenges underpinning the implementation of IoT with respect to other industry sectors abound in the literature to some extent, although similar studies also exist in the construction industry with little or no specific experience in the construction project management sector. Among them are studied by Mohammadzadeh et al. (2018), Gamil et al. (2020) in construction, Malaysia; AlEnezi et al. (2018) in smart government development in the US, India, and Kuwait; Qi et al. (2020) in industrial construction in the U.S.; Lau et al. (2019) in construction in Malaysia and Kunle et al. (2017) in Nigeria. It is important to note that despite increasing research on implementation obstacles, little or no research effort has been made to resolve the challenges that impede the implementation of IoT in the Nigerian project management sub-sector. Given the advent of complex technology such as IoT in construction, it is important to examine the critical challenges that impede its adoption and implementation in the Nigerian construction industry. For example, Bucchiarone et al. (2019) highlighted the following challenges: the use of magnetic mounting and weather-proof housing for smart nodes, the challenge of antenna design and mounting due to distance restriction of antenna coverage. Another challenge for IoT is the increase of data and complexities of future buildings based on IoT and 5G development. As a consequence, Wang et al. (2017) described a problem as to how to improve the efficiency of data storage and simultaneous communication. Aside from taking note of the technical challenges, the acceptance and adoption of technology by construction and project managers is another challenge to IoT deployment, as already reported by Nwakanma et al. (2013), which is typical of all information and communication technology projects. IoT's application for mine construction is faced with the following challenges identified by Zhao (2020), lack of standards for IoT integration in mine construction, lack of existing ubiquitous sensing networks capable of managing the complexities of mining construction, the poor knowledge base of IoT by practitioners, and challenges of multidisciplinary cooperation by the workforce and lack of skills. In summary, Bamigboye and Ademola (2018), Attia (2019), Rad and Ahmada (2017), Nord et al. (2019), Biggs et al. (2016), among others, are some of the main challenges or factors affecting the implementation of IoT in the construction sector in developing countries. Table 1 shows IoT's challenges and their respective sources.

The DEMATEL procedure is notable for its exhaustiveness and is used to guide the structural modelling of an easy connection between complex real issues. In addition to previous research on IoT and its construction challenges, the focus was more on other analytical methods that lack the capacity to demonstrate the relationship between the individual challenges. The aim of this study is to model the relationship between the different challenges of IoT implementation in construction projects using the fuzzy DEMATEL approach, known for its ability to visualise the causal relationship between certain factors. The strategy is better than the analytical hierarchical process (A.H.P.) given its ability to represent the dependence that exists between factors in the causal graph framework, which is generally ignored by conventional methodologies (Başhan and Demirel, 2019). In the same way, as the regular approach provides clear findings once in a while, they are hampered by their inability to recognise individual problems, usually because of their complexities in relation to human variables (Pandey and Kumar, 2017).

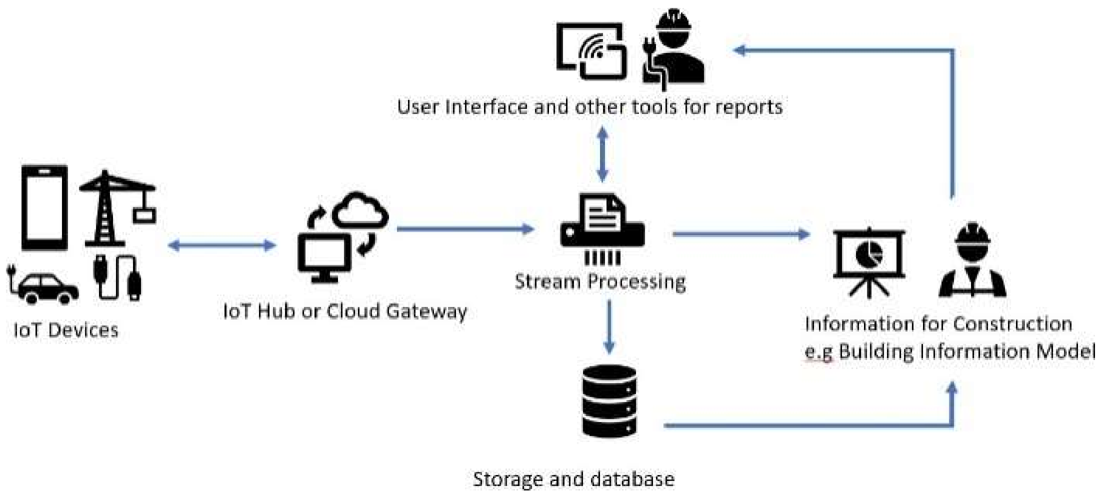

Fig. 1. IoT architecture for typical construction

Table 1. Challenges of IoT implementation on construction projects

I.D.	Challenges	Sources
C1	Environmental factors that can cause sensor breakdown	Bucchiarone et al. (2019)
C2	Technology acceptance and adoption (resistance to change)	Qi et al. (2020); Nwakanma et al. (2013)
C3	Supporting and existing infrastructure	Bucchiarone et al. (2019); Bamigboye and Ademola (2018); Kunle et al. (2017);
C4	Clear requirements of the unique need of each construction sites	Nwakanma et al. (2013),
C5	Inadequate power supply	Bamigboye and Ademola, (2018); Kunle et al. (2017).
C6	Lack of benefit awareness	Gamil et al. (2020)
C7	Security (Cyber security) of IoT devices and gateways	Bucchiarone et al. (2019); Attia (2019); Mohammadzadeh et al. (2018); Gamil et al. (2020); Rad and Ahmada (2017); Nord et al. (2019); Qi et al. (2020); Awolusi et al. (2019)
C8	Technological awareness/poor knowledge base of IoT by construction stake holders	Biggs et al. (2016); Nord et al. (2019); Zhao (2020); Attia (2019); Mohammadzadeh et al. (2018); Gamil et al. (2020); Lau et al. (2019)
C9	Inadequate skill manpower	Bamigboye and Ademola (2018); Kunle et al. (2017); Qi et al. (2020)

Table 1. Challenges of IoT implementation on construction projects (continued)

I.D.	Challenges	Sources
C10	Support from management and project managers	Nwakanma et al. (2013),
C11	High capital cost of initial deployment and implementation	Qi et al. (2020); Attia (2019); Bucchiarone et al. 2019; Lau et al. (2019)
C12	Lack of standards and policy issue for IoT integration in construction	Zhao (2020), Attia (2019); Awolusi et al. (2019); Gamil et al. (2020); Lau et al. (2019)
C13	Desire for long term benefit versus short term benefit	Bucchiarone et al. (2019)
C14	Dearth of funding for multidisciplinary research and innovation by construction experts and government	Bamigboye and Ademola (2018); Kunle et al. (2017); Nord et al. (2019); Biggs et al. 2016; Zhao (2020)
C15	Integration of disparate data	Nord et al. (2019)
C16	Technical challenges of IoT deployments and the complexity of big data management and integration (interoperability)	Wang et al. (2017); Attia (2019); Rad and Ahmada (2017); Qi et al. (2020); Awolusi et al. (2019); Gamil et al. (2020); Lau et al. (2019)
C17	Issues related to development in emerging economies	Rad and Ahmada (2017)
C18	Dearth of cross departmental integration	Nord et al. (2019)

3. Methodology

As Ramachandran et al. (2015) pointed out, the use of the idea of fuzzy set theory as proposed by Lotfi A. Zadeh in 1965 provided an avenue for the transmission of these kinds of true-life issues, using the question of environmental uncertainty and fuzziness. As Boran et al. (2009), decision-making issues should be resolved by using certified circumstances under uncertainty generally due to the uncertainty associated with objectives, constraints, and potential solutions (Boran et al., 2009). Fig. 2 shows the three-sided fuzzy number, while the ersatz connection between the verbal terms and the three-sided fuzzy numbers is acquired depending on the subtleties in Table 2. As a consequence, the fuzzy evaluations and their functions are shown in Fig. 3.

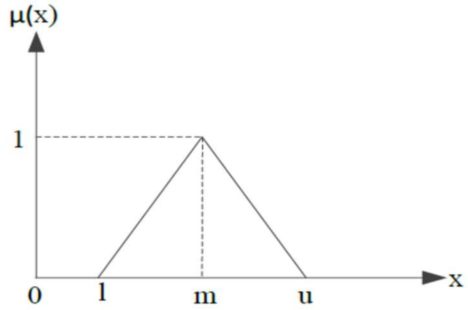

Fig. 2. Triangular fuzzy number

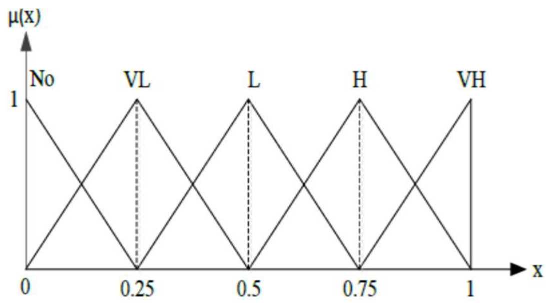

Fig. 3. Fuzzy ratings

The steps to perform the DEMATEL method of analysis consist of the following steps (Hatefi and Tamošaitienė, 2019; Jeng and Tzeng, 2012; Yadav and Barve, 2018):

(1) The initial step is to identify the components defined by the issue and the degree of impact between the components. From that point on, the primary variables of the unpredictable system are characterised in the light of the findings of the literature quest and expert knowledge.

(2) A direct relationship matrix shall be defined from that point onwards; a questionnaire analysis technique shall be performed prior to the sense of the nature of the estimation scale as stated in Eq. (1).

$$\begin{bmatrix} 0 & X12\cdots & X1n \\ X21 & 0\ldots. & \vdots X21 \\ Xn1 & \cdots Xn2\ldots. & 0 \end{bmatrix} \quad (1)$$

(3) The calculation of the normalised direct relationship matrix is then performed using the result of the direct relationship matrix via Eq. (2).

$$M = \frac{1}{3}\,(x_1 + x_2 + x_3) \quad (2)$$

(4) The total relation matrix (T) is obtained via Eq. (3).

$$\mathrm{T} = \mathrm{N}\,(I - N)^{-1} \quad (3)$$

(5) In the fifth step, the values in each row and column are summed with the total relation matrix. Hence, Ri depicts the sum of the ith row and Cj also depicts the sum of the jth column. Subsequently, both direct and indirect relationships between variables are shown as Ri and Cj, respectively using Eq. (4) and (5).

$$R = [\sum_{i=1}^{n} \mathrm{a}ij]\,nx1 \quad (4)$$

$$C = [\sum_{j=1}^{n} \mathrm{a}ij]\,1xn \quad (5)$$

(6) In the 6th point, the outline of the cause and effect relationship is drawn, the level (horizontal) hub (R+C) is drawn by adding R and C, while the vertical pivot (R-C) is achieved by removing C from R. R+C is known as a "prominence," a sign of the level of significance of the foundation, while R-C is pronounced as a "relations," a sign of the degree of effect. With a negative R-C value, the basis is compiled into the impact category, which infers that it is influenced by other steps. With a positive R-C value, it shows that the basis has a significant effect; thus,

it should be given adequate consideration and listed as a causal category.

For the purpose of this analysis, the fuzzy DEMATEL technique was used to determine the causal relationship associated with the challenges to the implementation of IoT in construction projects. The use of internal sets as opposed to true numbers is used in a fuzzy set theory. The usage of the pair is primarily due to the unpredictable and emotional essence of human decisions, where linguistic words have been modified to fuzzy numbers. This strategy is useful in trying to uncover the relationship that occurs between specific variables by placing each of the criteria associated with the form of relationship as well as the impact of severity and degree on each norm (Abdullah and Zulkifli 2015; Chang et al., 2011).

The following is the framework used in the fuzzy DEMATEL strategy (Abdullah and Zulkifli, 2015; Altuntas and Yilmaz, 2016; Chang et al., 2011).

Stage 1. Initially, we describe the rules for evaluation.

Stage 2. Approach and pick a group of experts specialised in the field of the issue to determine the effect of known difficulties (factors) through a couple of clever correlations.

Stage 3. We describe the fuzzy linguistic scale of dealing with problems defined by the vagueness of human judgement. In the linguistic scale, the vector "effect" is characterised by a five-pronged scale containing accompanying items in the collective decision-making measure viz; no impact, very low impact, low impact, high impact and very high impact. The fuzzy quantity of the linguistic words is shown in Table 2.

Stage 4. The underlying direct relationship matrix is obtained using a couple of informative correlations, from which point the underlying fuzzy direct-relation matrix is generated by presenting a fuzzy pair-wise relationship between the sections in the nxn matrix where k is the number of specialists. Thus, the direct relationship matrix is set up as [ă ij], where A is a non-negative nxn matrix; aij represents the direct impact factor I on factor j; and, when i = j, the slanting components aij = 0. Table 4 reveals more about this using Eq. (6).

$$\breve{A} = \begin{bmatrix} 1 & ă12 \cdots & ăn1 \\ ă21 & 1 \ldots. & ăn2 \\ ăn1 & \cdots ăn2 \ldots. & 1 \end{bmatrix} = \begin{bmatrix} 1 & ă12 \cdots & ăn1 \\ 1/ă21 & 1 \ldots. & n2 \\ 1/ăn1 & 1/ăn2 \ldots. & 1 \end{bmatrix} \quad (6)$$

Stage 5. Calculation of the absolute relationship fuzzy matrix following the development of a standardised direct-relation fuzzy structure D by ensuring that lim $\omega \rightarrow \infty F\omega=0$. The complete relationship fuzzy matrix is resolved as shown in Eq. (7). Details of the analysis are shown in Table 5.

$$D = \frac{Z^k}{\max_{1 \le i \le n} \sum_j^n = 1\, zij} \quad i,j = 1,2,\ldots,n \quad (7)$$

Step 6. We break down the structural model after the matrix T, Ri+Cj and Ri−Cj are processed. From the equation, Ri and Cj are the total rows and columns of the matrix T. While Ri+Cj shows the significance of factor i, Ri−Cj shows the net impact of factor i. Eq. (8) shows the structural model and how it is shown.

$$T = D\,(1 - D)^{-1} \quad (8)$$

$$Where\ T = D + D^2 + \cdots += \sum_{i=1}^{\infty} D^i$$

Stage 7. We defuzzify Ri+Cj and Ri−Cj by using the C.O.A. (area focus) defuzzification strategy to determine the BNP (best non-fuzzy execution) value. The defuzzification cycle is completed using Eq. (9), (10) and (11). The details of this analysis are shown in Table 6.

$$T = [tij]nxn \qquad i,j = 1,2,3,\ldots\ldots n \quad (9)$$

$$R_i = \sum_{j=1}^{n} tij \quad \forall i \quad (10)$$

$$Cj = \sum_{i=j}^{n} tij \quad \forall j \quad (11)$$

Stage 8. Finally, the cause and impact connection graph are planned to be linked to the data set of Ri+Cj and Ri−Cj. Causal graphs change over complex inter-factor linkages into a simple basic structural model for critical thinking. The calculation is made using the 6th stage, while the details of the calculations are shown in Table 7.

This study adopted the fuzzy DEMATEL model to identify the challenges of IoT implementation and to evaluate their impact on construction projects.

Thus, the deployment of the fuzzy DEMATEL technique for IoT challenges and their implementation for construction projects is illustrated in Fig. 4.

3.1. Data Collection

In an effort to investigate the challenges of IoT implementation of construction projects from a stakeholder perspective, the researchers considered Owerri Municipality of Imo State, Nigeria as the location for the study. The main decision/expert panel consists of 27 experts from the construction industry, consisting of six (6) senior and middle-level executives, four (4) builders, six (6) project managers, four (4) quantity surveyors (government experts), three (3) academic experts, three (3) civil engineers and one (1) estate manager. The experts were approached on the basis of their relevance and experience with respect to their respective roles and capabilities, as well as their involvement in the work/tasks related to information technology. The selected experts have gained more than 10 years of experience and expertise in their field of expertise. A properly modelled questionnaire was circulated to the practitioners; the completed questionnaires were then retrieved through interviews, group discussions and visits to the project sites. Table 3 shows the details of the interviewees. The problems were identified and based on the results of a systematic literature review on the implementation of IoT in construction projects. Subsequently, a semi-structured questionnaire was formulated to gather information from experts on the final problems of IoT implementation of construction projects in Imo State, Nigeria. The experts evaluated the challenges on the Likert five-point scale with the sole intention of rating the initially identified twenty-five challenges identified earlier after a series of discussions with the experts. Subsequently, the low-rated and non-significant challenges were withdrawn, and ultimately, they were scaled down to 18. The calculations resulting from the fuzzy DEMATEL method are shown in Tables 4 through Tables 7. Table 4 displays the normalised direct-relations fuzzy matrix emanating from Eq. (6).

Although Table 5 shows the total relationship fuzzy matrix that also emanated from Eq. (7). The total impact fuzzy matrix shown in Table 6 as well as the prominence relationship for casual effects in Table 7 is both the product of Eq. (8) through to (11).

Table 2. Fuzzy linguistic scale

Linguistic terms	**Triangular fuzzy numbers**
No influence (NO)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (V.H.)	(0.75, 1, 1)

Source: Başhan and Demirel (2019)

Table 3. Details of the interviewees

Area of expert	Number	Years of experience
Senior/middle level	6	Over 15 years
Builders	4	More than 11 years
Project managers	6	More than 12 years
Quantity surveyors	4	More than 10 years
Academics	3	13 years
Civil engineers	3	More than 10 years
Estate manager	1	11 years

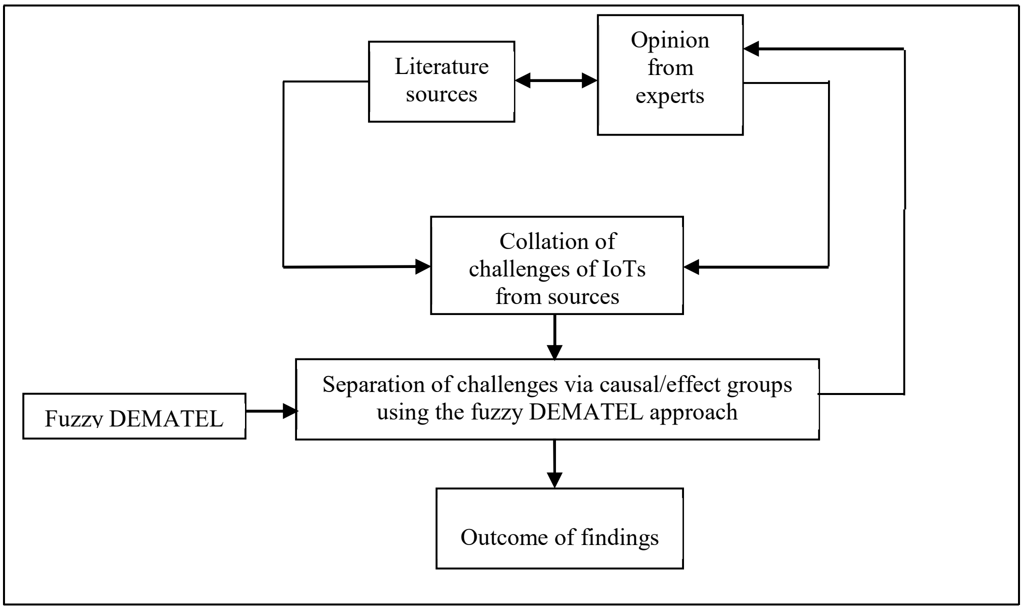

Fig. 4. Computational guide in developing the proposed framework

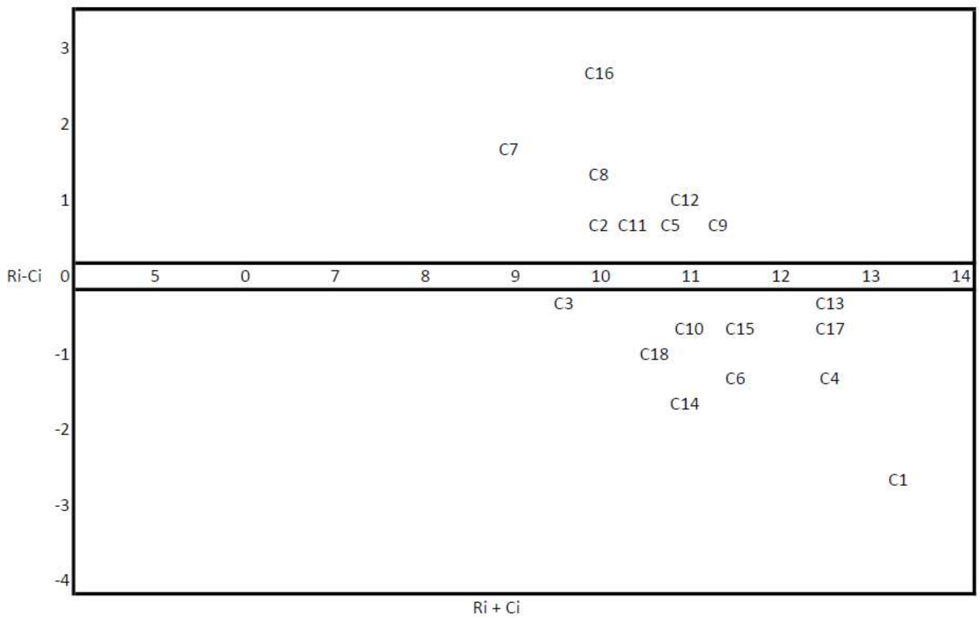

Fig. 5. Casual and effect path diagram

Table 4. Normalized initial direct-relation fuzzy matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0.083	0.250	0.750	0.917	0.083	0.917	0.750	0.750	0.917	0.083	0.500	0.083	0.750	0.917	0.750	0.083	0.083	0.250
C2	0.750	0.083	0.083	0.750	0.500	0.500	0.083	0.500	0.250	0.917	0.750	0.750	0.750	0.083	0.750	0.500	0.500	0.917
C3	0.750	0.083	0.083	0.500	0.083	0.750	0.917	0.750	0.083	0.750	0.083	0.917	0.917	0.083	0.083	0.250	0.750	0.250
C4	0.917	0.750	0.750	0.083	0.750	0.500	0.250	0.083	0.083	0.500	0.500	0.083	0.750	0.750	0.500	0.917	0.917	0.750
C5	0.750	0.917	0.917	0.083	0.083	0.750	0.083	0.500	0.500	0.750	0.250	0.500	0.500	0.500	0.250	0.750	0.750	0.917
C6	0.750	0.083	0.750	0.750	0.500	0.083	0.083	0.250	0.750	0.917	0.083	0.750	0.250	0.917	0.750	0.083	0.917	0.250
C7	0.917	0.500	0.500	0.500	0.250	0.917	0.083	0.083	0.750	0.750	0.083	0.500	0.500	0.750	0.500	0.500	0.500	0.750
C8	0.750	0.750	0.250	0.917	0.750	0.500	0.750	0.083	0.750	0.917	0.083	0.500	0.750	0.500	0.083	0.250	0.750	0.917
C9	0.917	0.500	0.500	0.750	0.500	0.750	0.500	0.083	0.083	0.750	0.500	0.917	0.917	0.917	0.750	0.083	0.750	0.750
C10	0.750	0.500	0.750	0.500	0.083	0.750	0.083	0.500	0.917	0.083	0.250	0.500	0.083	0.750	0.917	0.250	0.917	0.250
C11	0.917	0.917	0.917	0.917	0.750	0.083	0.250	0.250	0.750	0.750	0.083	0.500	0.917	0.750	0.083	0.750	0.083	0.083
C12	0.750	0.500	0.083	0.750	0.917	0.250	0.750	0.750	0.500	0.500	0.750	0.083	0.750	0.917	0.750	0.083	0.917	0.500
C13	0.750	0.500	0.250	0.500	0.500	0.750	0.083	0.500	0.750	0.917	0.917	0.750	0.083	0.500	0.917	0.250	0.750	0.917
C14	0.917	0.083	0.250	0.750	0.250	0.917	0.250	0.083	0.083	0.250	0.750	0.250	0.917	0.083	0.750	0.500	0.500	0.750
C15	0.750	0.500	0.083	0.917	0.750	0.083	0.500	0.750	0.500	0.083	0.917	0.750	0.083	0.500	0.083	0.250	0.750	0.917
C16	0.917	0.250	0.500	0.750	0.750	0.500	0.750	0.750	0.250	0.500	0.750	0.750	0.500	0.750	0.917	0.083	0.750	0.750
C17	0.917	0.750	0.250	0.500	0.500	0.750	0.250	0.917	0.750	0.250	0.500	0.500	0.750	0.250	0.500	0.750	0.083	0.750
C18	0.750	0.083	0.250	0.917	0.500	0.917	0.083	0.083	0.500	0.750	0.500	0.083	0.750	0.750	0.750	0.083	0.917	0.083

Table 5. Total relation fuzzy matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0.007	0.022	0.067	0.082	0.007	0.082	0.067	0.067	0.082	0.007	0.045	0.007	0.067	0.082	0.067	0.007	0.007	0.022
C2	0.067	0.007	0.007	0.067	0.045	0.045	0.007	0.045	0.022	0.082	0.067	0.067	0.067	0.007	0.067	0.045	0.045	0.082
C3	0.067	0.007	0.007	0.045	0.007	0.067	0.082	0.067	0.007	0.067	0.007	0.082	0.082	0.007	0.007	0.022	0.067	0.022
C4	0.082	0.067	0.067	0.007	0.067	0.045	0.022	0.007	0.007	0.045	0.045	0.007	0.067	0.067	0.045	0.082	0.082	0.067
C5	0.067	0.082	0.082	0.007	0.007	0.067	0.007	0.045	0.044	0.067	0.022	0.045	0.045	0.045	0.022	0.067	0.067	0.082
C6	0.067	0.007	0.067	0.067	0.045	0.007	0.007	0.022	0.067	0.082	0.007	0.067	0.022	0.082	0.067	0.007	0.082	0.022
C7	0.082	0.045	0.045	0.045	0.022	0.082	0.007	0.007	0.067	0.067	0.007	0.045	0.045	0.067	0.045	0.045	0.045	0.067
C8	0.067	0.067	0.022	0.082	0.067	0.045	0.067	0.007	0.067	0.082	0.007	0.045	0.067	0.045	0.007	0.022	0.067	0.082
C9	0.082	0.045	0.045	0.067	0.045	0.067	0.045	0.007	0.007	0.067	0.045	0.082	0.082	0.082	0.067	0.007	0.067	0.067
C10	0.067	0.045	0.067	0.045	0.007	0.067	0.007	0.045	0.082	0.007	0.022	0.045	0.007	0.067	0.082	0.022	0.082	0.022
C11	0.082	0.082	0.082	0.082	0.067	0.007	0.022	0.022	0.067	0.067	0.007	0.045	0.082	0.067	0.007	0.067	0.007	0.007
C12	0.067	0.045	0.007	0.067	0.082	0.022	0.067	0.067	0.045	0.045	0.067	0.007	0.067	0.082	0.067	0.007	0.082	0.045
C13	0.067	0.045	0.022	0.045	0.045	0.067	0.007	0.045	0.067	0.082	0.082	0.067	0.007	0.045	0.082	0.022	0.067	0.082
C14	0.082	0.007	0.022	0.067	0.022	0.082	0.022	0.007	0.007	0.022	0.067	0.022	0.082	0.007	0.067	0.045	0.045	0.067
C15	0.067	0.045	0.007	0.082	0.067	0.007	0.045	0.067	0.045	0.007	0.082	0.067	0.007	0.045	0.007	0.022	0.067	0.082
C16	0.082	0.022	0.045	0.067	0.067	0.045	0.067	0.067	0.022	0.045	0.067	0.067	0.045	0.067	0.082	0.007	0.067	0.067
C17	0.082	0.067	0.022	0.045	0.045	0.067	0.022	0.082	0.067	0.022	0.045	0.045	0.067	0.022	0.045	0.067	0.007	0.067
C18	0.067	0.007	0.022	0.082	0.045	0.082	0.007	0.007	0.045	0.067	0.045	0.007	0.067	0.067	0.067	0.007	0.082	0.007

Table 6. Total influence fuzzy matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0.360	0.223	0.271	0.381	0.222	0.355	0.229	0.256	0.315	0.266	0.259	0.235	0.344	0.356	0.327	0.172	0.302	0.293
C2	0.439	0.228	0.230	0.388	0.276	0.336	0.181	0.258	0.282	0.350	0.300	0.302	0.359	0.307	0.349	0.219	0.358	0.366
C3	0.387	0.196	0.197	0.320	0.205	0.322	0.231	0.250	0.236	0.301	0.205	0.285	0.332	0.266	0.254	0.171	0.336	0.270
C4	0.464	0.285	0.292	0.338	0.297	0.350	0.201	0.231	0.271	0.322	0.285	0.256	0.370	0.364	0.335	0.261	0.397	0.360
C5	0.447	0.295	0.302	0.339	0.239	0.369	0.188	0.264	0.305	0.345	0.259	0.291	0.348	0.343	0.314	0.238	0.385	0.371
C6	0.415	0.210	0.269	0.363	0.255	0.285	0.173	0.223	0.302	0.326	0.226	0.287	0.300	0.353	0.328	0.172	0.372	0.291
C7	0.444	0.249	0.258	0.359	0.243	0.370	0.177	0.215	0.314	0.328	0.236	0.277	0.332	0.355	0.325	0.211	0.350	0.343
C8	0.470	0.299	0.261	0.423	0.309	0.368	0.248	0.234	0.342	0.374	0.259	0.300	0.385	0.363	0.318	0.212	0.404	0.391
C9	0.504	0.288	0.293	0.430	0.303	0.401	0.239	0.250	0.300	0.371	0.311	0.349	0.415	0.415	0.389	0.207	0.420	0.390
C10	0.413	0.243	0.266	0.345	0.221	0.338	0.174	0.243	0.314	0.257	0.239	0.268	0.286	0.337	0.340	0.183	0.368	0.290
C11	0.466	0.302	0.308	0.408	0.298	0.316	0.205	0.243	0.324	0.347	0.250	0.293	0.388	0.368	0.303	0.247	0.331	0.307
C12	0.481	0.289	0.253	0.420	0.332	0.351	0.254	0.298	0.329	0.344	0.323	0.272	0.394	0.404	0.375	0.207	0.421	0.367
C13	0.482	0.286	0.268	0.405	0.300	0.390	0.201	0.280	0.352	0.380	0.339	0.331	0.338	0.375	0.393	0.216	0.412	0.396
C14	0.408	0.198	0.219	0.349	0.225	0.337	0.174	0.195	0.235	0.260	0.271	0.231	0.338	0.270	0.314	0.198	0.317	0.315
C15	0.432	0.260	0.225	0.394	0.292	0.296	0.214	0.269	0.293	0.274	0.306	0.293	0.304	0.333	0.280	0.198	0.367	0.361
C16	0.517	0.278	0.302	0.441	0.333	0.389	0.270	0.313	0.323	0.360	0.336	0.342	0.391	0.411	0.406	0.215	0.428	0.402
C17	0.476	0.295	0.256	0.388	0.289	0.377	0.208	0.303	0.337	0.315	0.291	0.299	0.380	0.338	0.344	0.248	0.339	0.372
C18	0.409	0.208	0.228	0.372	0.252	0.350	0.164	0.202	0.280	0.310	0.258	0.227	0.334	0.336	0.325	0.171	0.365	0.270

Table 7. Prominence and relation for casual effects

	Ri	Ci	Ri+Ci	Ri-Ci
C1	5.166993	8.0122	13.17919	-2.84521
C2	5.529161	4.63035	10.15951	0.898811
C3	4.762967	4.69822	9.461187	0.064747
C4	5.677557	6.86474	12.5423	-1.18718
C5	5.641847	4.89001	10.53186	0.751837
C6	5.148969	6.29869	11.44766	-1.14972
C7	5.383397	3.72858	9.111977	1.654817
C8	5.961478	4.5235	10.48498	1.437978
C9	6.275205	5.45518	11.73039	0.820025
C10	5.12373	5.82857	10.9523	-0.70484
C11	5.70424	4.95138	10.65562	0.75286
C12	6.113804	5.13717	11.25097	0.976634
C13	6.14279	6.33799	12.48078	-0.1952
C14	4.852149	6.29409	11.14624	-1.44194
C15	5.389761	6.01721	11.40697	-0.62745
C16	6.454175	3.74772	10.20189	2.706455
C17	5.854137	6.67219	12.52633	-0.81805
C18	5.059265	6.15383	11.21309	-1.09457

The cause-effect direction diagram in Fig. 5 was obtained after the horizontal (Ri + Cj) and vertical (Ri-Cj) axes were extracted in Table 7 (prominence and relation for the casual effects). (Ri + Cj) indicates the degree of the influence existing between the criteria, while (Ri-Cj) indicates the extent of the influence relationship existing between the criteria. The cause-effect (casual and effect route diagram) diagram is shown in Fig. 5.

3.2. Discussions

In this study, we used the fuzzy DEMATEL technique to identify IoT challenges for the implementation of construction projects. The result of the causal relationship as shown in the diagram (Fig. 5) was the basis for the following results. Technology acceptance and adoption (Resistance to change) (C2), Supporting and existing infrastructure (C3), Inadequate power supply (C5), Security (Cyber security) of IoT devices and gateways (C7), Technological awareness/poor knowledge base of IoT by construction stakeholders (C8), Inadequate skill manpower (C9), lack of standards and policy issue for IoT integration in construction (C12), and Technical challenges of IoT deployments and the complexity of big data management and integration (interoperability) (C16) and High capital cost of initial deployment and implementation (C11) they are listed in the casual group category (Table 7) on the basis of their positive scores (R−C), the implication that they are important problems that can affect the overall implementation of IoT in construction projects, whereas the impact criteria group consists of the following: Environmental factors that can cause sensor breakdown (C1), clear requirements of the unique need of each construction sites (C4), lack of benefit awareness (C6), support from management and project managers (C10), desire for long term benefit versus short term benefit (C13), dearth of funding for multidisciplinary research and innovation by construction experts and government (C14), integration of disparate data (C15), Issues related to development in emerging economies (C17) and dearth of cross departmental integration (C18), an indication that they need to be improved upon.

As much as the cause factor affects the effect groups (Table 7), more attention should be paid to them. The factors in the cause group are, by definition, referred to as the influence criteria, while, by implication, the factors in the effect group are referred to as the influence criteria. In view of the outcome of the interdependence between the factors, it is imperative that the required attention be paid to the factors of the casual group on the basis of their impact on the factors of the effect group.

Therefore, a deliberate improvement of the factors of the cause group would invariably lead to an improvement of the factors of the effect group. It is therefore imperative to state that C16, C7, C8, C12, C2, C9, C11 and C5 are the most important challenges of IoT implementation on construction projects to be accorded adequate attention based on the outcomes of the expert's/evaluators' knowledge and experiences.

With the value of Ri-Cj as negative, it is imperative to identify such a factor (challenge) in the impact category and, as such, its presence would have been primarily influenced by other factors. The outcome of this work has shown that (from Table 8) the most important causal factor or problem that hindered the implementation of IoT is "technical challenges of IoT deployments and the complexity of big data management and integration (interoperability) (C16)" and possesses the highest (Ri - Cj) score of 2.706, this means that enough attention should be given to (C16) with regards to the difficulties of integrating IoT in construction projects. Previous research by Wang (2017); Attia (2019); Rad and Ahmad (2017), Qi et al. (2020), Awolusi et al. (2019) and Gamil et al. (2020) also lend credence to the outcome of this finding that the technological difficulties of IoT implementations and the difficulty of big data management and integration (interoperability) (C16) are the most instrumental challenges to be taken into account when contemplating the implementation of IoT. In order to achieve significant value, both organisations (practitioners) and institutions (government) must work closely together to develop a flexible platform for software engineers to design IoT platforms that can be interoperable and flexible, thereby increasing value creation in services and products to customer satisfaction. Table 7 further found that (C16) had the highest impact (Ri) degree value of 6.454, ranked first among all causal factor groups. In short, (C16) is the main challenge (factor) that requires adequate attention when faced with the challenge of how to implement IoT in the delivery of construction projects. "Security (cybersecurity) of IoT devices and gateways (C7)" had a significant impact on the cause group factor with the second highest (Ri-Cj) value of 1,655. (C16). (C7) had the twelfth (12th) highest Ri score (5.383) among the group factors responsible for the degree of prominence. This result seems to be consistent with that of Attia (2019), Gamil et al. (2020), Bucchiarone et al. (2019), Mohammadzadeh et al. (2018), Rad and Ahmada (2017), Nord et al. (2019), Qi et al. (2020), and Awolusi et al. (2019), which states that security concerns are often connected to information leakage, which will lead to the unveiling of sensitive data and information. As Colakovic and Hadžialic (2018) have reported, security features should be incorporated into the IoT architecture to allow for efficient and effective management of the entire system. Various security countermeasures, such as data encryption algorithms, intrusion detection kits, and hardware limitations on smart devices. In addition, "technological awareness/poor knowledge base of IoT by construction stakeholders (C8)" is another significant factor, with the Ri-Cj score ranked third (1.438), whereas (C8) has the fifth Ri value. Lack of standards and policy issues for IoT building integration (C12), technology acceptance and adoption (C2), inadequate skills manpower (C9), high capital costs for initial deployment and implementation (C11), and inadequate power supply (C5) are other significant factors with Ri-Cj values ranked fourth, fifth, sixth, seventh and eighth respectively. Given the outcome of this work, it was found that, among other difficulties, "environmental factors that can cause sensor breakdown (C1)" had the highest (Ri + Cj) score (13.179), even though its Ri-Cj value was the highest compared to the other factors in the effect category (-2.845). The consequence of this is that this aspect (challenge) has the greatest effect on the other challenges.

4. Conclusions

This paper presented a review of the challenges facing IoT and its application to construction projects by identifying the global challenges that hinder its implementation. An analysis of these global challenges was made using fuzzy DEMATEL to identify 18 factors identified in the literature. The outcome of this research would help relevant stakeholders in the construction industry to make informed decisions on the implementation of IoTs for the efficient delivery of construction projects. This study attempted to define the dimensions and variables of crucial obstacles (factors) that could hinder the implementation of IoT in construction projects. In the context of the fuzzy DEMATEL method, the interdependencies between the IoT problems have been assessed with a view to improving the process of adoption of construction projects. As a result of this work, the technological challenges of IoT implementation and the complexity of big data management and integration (interoperability) (C16) are considered to be the most significant challenge, primarily due to its high degree of inter-relationship with other challenges. Based on the outcome of the cause-and-effect relationship between the challenges of IoT implementation and the expert opinion and judgement, we can comfortably conclude that (C16), the technical challenges of IoT deployment and the complexity of big data management and integration (interoperability), (C7) security (cybersecurity) of IoT devices and gateways, (C8) technology awareness/poor knowledge base of IoT by construction stakeholders, (C12) lack of standards and policy issues for IoT incorporation in construction, (C2) acceptance and adoption of technology (resistance to change), (C9) insufficient skills, (C11) high capital costs for initial deployment and implementation and (C5) Inadequate power supply are important in the successful implementation of IoT within the Nigerian construction industry. This means that improving on other IoT challenges without correspondingly attending to the (important) challenges mentioned above would certainly not achieve the desired result. On the basis of the conclusion, we, therefore, suggest that, in order to better enhance the activities of the construction industry via the application of IoT, it is important to look at the technicalities of the complexity involved in the implementation of IoT in order to prevent any unforeseen problems with regard to interoperability. There is also a need to establish the much-needed protection of IoT devices and gateways to avoid unauthorised access to facilities and systems. This study is not entirely absolved from any limitation. First, given the nature of the study, its findings should not be generalised to other parts of Nigeria. Second, it should be considered that this report identified 18 challenges to the implementation of IoT, which is why it is important to undertake a further study, probably on a larger scale, with a view to finding more challenges than those identified in this study.

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Dr. Benedict Amade (CIPMN) is a Lecturer and holds a Ph.D. at the Department of Project Management Technology, Federal University of Technology, Owerri, Nigeria. He is a Certified Project Manager and Registered with the Chartered Institute of Project Managers of Nigeria (Chartered Member). He received his Ph.D. in Project Management Technology (Construction Project Management). He teaches Computer Based Project Management and Management Information Systems courses at the Undergraduate and Postgraduate classes. His current research interests include Information Technology Project Management, Construction Project Management, Construction Supply Chain Management, and Information Technology in Construction.

Engr. Cosmas Ifeanyi Nwakanma (IEEE-M'19) is a Lecturer at the Department of Information Technology, Federal University of Technology Owerri, Nigeria since 2009. He is currently a full time Researcher at Networked System Laboratory, IT-Convergence Engineering, Kumoh National Institute of Technology Gumi, South Korea. He received his Bachelor of Engineering in Communication Engineering, Master's in Information Technology and Master of Business Administration in Project Management Technology all from the Federal University of Technology Owerri, Nigeria. He was intern with Asea Brown Boveri (ABB) Nigeria in 2003. As a member of IEEE, he has served as a volunteer reviewer for IEEE Access. His research interests are reliability and adoption of Emerging Technologies in Africa and Nigeria.