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Adoption of Internet of Things in The Construction Industry:
A Comparative Case Study of Construction and Manufacturing Industries in Kenya

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Abstract

Uptake of the Internet of Things (IoT) technology in the construction industry remains slower and less beneficial than in the manufacturing industry in Kenya. This technology has great potential to enhance organizational performance at the enterprise and project/site levels. This paper is a report of a recent research carried out in Kenya to investigate the adoption of IoT in the construction industry. Specific objectives of the study were: to describe the extent to which IoT has been adopted in Kenya; to compare the application of IoT in manufacturing and construction industry; to explore the opportunities that IoT presents in the construction industry; and to develop a framework for boosting adoption of IoT in construction to enhance project management in Kenya. A case study research design was applied whereby respondents in manufacturing, construction and IoT were engaged in online focus groups discussions. The data collected was fed into NVivo program for thematic analysis. Overall, the research revealed that IoT presents opportunities in construction, having already been adopted in areas such as Building Management Systems (BMS), security and smart utility metering. Moreover, cross-collaboration amongst various organizations in a project-oriented environment, both in the public and private sectors, is important in driving the uptake of IoT.

Keywords: Architecture, Engineering and Construction (AEC), Building Information Modelling (BIM), Building Management System (BMS), Internet of Things (IoT), International Organization for Standardization (ISO), Real Time Data (RTD), Radio frequency identification (RFID).

INTRODUCTION

The pace of innovation, with improved communications and increased productivity, has been remarkable in many sectors, including; agriculture, health, education, manufacturing and logistics. However, the construction industry, which is a major consumer of manufacturing products, is yet to register such disruptive changes, resulting in persistence of poor project performance. The industry is naturally fragmented, with minimal and often poor collaboration between parties; there are informal practices and insufficient knowledge transfer from project to project (World Economic Forum, 2016). The disparate project management processes and non-standardized information impede efficiency gains (Fulford & Standing, 2013). Information based applications introduce new ways to commercial real estate for streamlining project processes and enhancing collaboration, which directly influences the success of projects and program outcomes. Internet of Things (IoT) is among such applications.

IoT is an infrastructure of interconnected objects, people, systems and information resources, together with intelligent services, to allow them to process information of the physical and virtual world and react (ISO, 2014). The technology is fast penetrating the world and businesses are laser focused on it as an enabler of sustainability, safety and economic growth (Verizon, 2017). In Kenya, some of the applications for the technology include; enhancement of home/ business security, energy management, monitoring weather patterns, disaster monitoring, curbing wildlife poaching and in smart utility metering (Mwangi, 2017). Following the success of IoT integration in other sectors, especially in manufacturing, the construction industry can gain valuable insights on how to create value surrounding this innovative technology.

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Globally, the construction industry has undergone notable changes. For example, the move towards integrated project delivery approach enabled by virtual design and construction, and facilitated by the use of Building Information Modelling (BIM), is gaining traction (Lu, Lai & Tse, 2019). Still, much remains desired in terms of application of new tools and techniques to complement project execution, which is currently heavily dependent on traditional methods of management. This study was an effort to highlight the open possibilities presented by IoT in the construction industry, by borrowing the realized benefits from the manufacturing industry.

In a nutshell, IoT offers possibilities in modern construction methods, such as offsite construction, lean construction and smart assembly (Gbadamosi, Oyedele, Mahamadu, Kusimo & Olawale, 2019). The application of new technologies in the digital space will remarkably improve productivity, as well as reduce delays. In addition, the quality of buildings will be greatly enhanced, safety improved, and better working conditions and environmental compatibility promoted (World Economic Forum, 2016). Through IoT, project managers can make use of Real-Time-Data (RTD), analyse it, and eventually communicate useful information about the data to relevant parties much faster. Overall, construction firms stand to benefit from the uptake of digital solutions in dealing with new complexities, especially in the globalization era marked by increased information value and exchange.

THEORY

Communication Management in the Construction Industry

Information flow throughout the various construction phases can be the make-or-break factor in the delivery of a project. As defined in Project Management Body of Knowledge (PMBOK), project communications management includes the processes necessary to ensure that the information needs of the project and its stakeholders are met through the development of artifacts and implementation of activities designed to achieve effective information exchange (PMI, 2017). Effective communication management requires establishing a strategy, which is then followed by formulation of activities necessary for its implementation.

Communication management is composed of three parts. The first step involves establishing an approach to be used for the information needs of the project. The second part deals with the management aspect of communication, which involves, collecting, creating, distributing, storing, retrieving, managing, monitoring, and ultimately disposing the information. The third and final part entails monitoring the communications to ensure that the information needs of the project participants are met (PMI, 2017). The current practice of data collection in construction heavily relies on people. IoT offers an alternative. It is characterized by sensors and actuators that actively interact with the environment, sensing and communicating specific data, prompting necessary action.

Concept of the Internet of Things (IoT)

The International Organization for Standardization (ISO) defines IoT as an infrastructure of interconnected objects, people, systems and information resources, together with intelligent services, to allow them to process information of the physical and virtual world and react (ISO, 2014).

There are key existing technologies enabling the IoT technology. The two most important technologies are the wireless sensor networks (WSN) and radio-frequency identification, besides cloud computing and ubiquitous networks (Bi, Xu & Wang, 2014). Radio-frequency identification (RFID) utilizes electromagnetic fields in the transference of data for automated identification, as well as the tracking of tags attached to objects (Juels, 2006). Wireless sensor networks (WSNs) comprise of autonomous spatially distributed nodes that sense the environment and conduct computations, as well as communicate with other nodes in the network (Yick, Mukherjee & Ghosal, 2008). Cloud computing refers to large-scale, low cost processing unit that is based on Internet Protocol connection for purposes of calculation and storage, whereas ubiquitous computing refers to the idea of computing anywhere and everywhere (Bi, Xu & Wang, 2014). Essentially, the widespread adoption of IoT will be directly linked to the advancement of the underlying supporting technologies.

IoT in the Manufacturing Industry

The growing pressure to adhere to environmental standards, diversification of customer needs and severe competition has forced players in manufacturing to take up digital solutions. The seamless interconnection of physical objects and the internet greatly enhances the various resources and capabilities applied in manufacturing processes. Cloud computing, which is one of the enabling technologies for IoT, provides possibilities for large scale collaborative manufacturing, as well as solutions to complex problems (Tao, Cheng, Zhang & Li, 2014). The new value creation surrounding IoT technologies in manufacturing emerges from operational efficiency, connected ecosystems, human and machine collaboration, and outcome economy (World Economic Forum, 2015). According to Yang, Shen & Wang (2016), some of the applications of IoT in manufacturing include: -

Automation and production efficiency – Real-time data collected from vehicles, materials, equipment and environment can be analyzed and used to automate various processes, leading to highly optimized designs. Actuation is enabled by utilizing intelligent algorithms which are able to use the data collected to make decisions and reduce deviations from original plan.

Energy management – by leveraging IoT technology, continuous measurement of units consumed by various business activities can aid in drawing correlations. A statistical analysis on real time energy consumption can assist the management in making decisions surrounding energy aware driven production.

Proactive maintenance – unscheduled downtimes and unexpected breakdowns can adversely affect delivery timelines, escalating production costs. Sensors attached to equipment can provide early diagnostics prompting replacement. This promotes the idea of predictive maintenance.

Connected supply chain management - all parties along the supply chain connected through IoT enabled systems enable information sharing, leading to better understanding of interdependencies in the production cycle.

IoT in the Construction Industry

Automation in construction is slowly growing over the years, aiding companies to improve on efficiency and acquire value addition. According to Infoholic Research report, IoT use globally in the construction industry will grow at a compounded annual rate of 35.98% during the forecast period of 2017 to 2024 (Infoholic Research, 2019). This is based on three segments, namely; products, applications and regions (Infoholic Research, 2019). The pervasive digitalization will be important in dealing with problems specific to construction such as, inadequate collaboration, fragmentation and insufficient knowledge transfer.

According to Urie (2019) and Mahamadu and Olawale (2019), some of the opportunities presented by IoT in construction include: -

Enabling 'just in time' provision – RFID chips attached to items can give insights in case supply level falls below demand. This informs the management to order more of that item, ensuring just in time provision eliminating inventory related problems.

Tracking tool and equipment – by monitoring equipment on site, it becomes possible to apply preventive maintenance, which proves more cost effective compared to on demand repairs after breakdown. This improves the overall life expectancy of equipment and tools, boosting the salvage value.

Remote usage and activity monitoring – the use of wearables can prove useful in tracking employees presence on-site and also reporting on the worker's current engagement. The alertness of employees can also be tracked, which helps in the avoidance of accidents, especially when fatigue is established.

Power and fuel saving – by attaching sensors to equipment, idle time can be reduced, saving up on costs. Moreover, adjustments of after-hours lighting can help save up on energy costs.

Augmented reality (AR) – the utilization of AR, which combines virtual architectural designs with construction site reality, has the potential of increasing efficiency and accuracy, and reducing human errors, which saves money, time and resources.

Building Information modelling (BIM) - by integrating IoT technology, sensors strategically placed inside buildings can constantly send feedback to the intelligent 3D model, enabling real time updating. The net effect of this integration is increased accuracy as human reliance is kept at a minimum (Mahamadu & Olawale, 2019; Urie, 2019).

Theories Related to IoT Uptake

Two theories were adopted for this study, namely; Diffusion of Innovation, and Technology Acceptance Model (TAM). The former describes a process by which innovation is communicated through certain channels overtime among the members of a social system. This theory provided insights on accelerating the rate at which IoT spreads to members within the Architecture, Engineering and Construction (AEC) community. The latter posits that individuals' behavioural intention to adopt a new IT is determined by two beliefs, namely; perceived usefulness and perceived ease of use. This was useful in understanding how IoT perceived usefulness and ease of use can be manipulated so as to increase the behavioral intention to apply IoT in construction-related processes.

From the literature reviewed, increased uptake of IoT in the construction industry should enhance the project management performance. Factors that may increase this uptake include: utility; ICT development; training; design/simulation of usage; need assessment; marketing; and firm specific advantages. The influence of these variables on IoT adoption was measured.

Arguably, the low IoT uptake in the construction industry can be attributed to unfamiliarity with the technology, and possible business opportunities. Usage of IoT in construction project is indicated by: stakeholder satisfaction; quick response to inputs; customized activities; worker safety; and assistance to report.

From the theoretical framework, a conceptual framework for the study was formulated, as shown in **Figure 1**. As shown in **Figure 1**, an individual's behavioural intention to adopt IoT will be determined by two beliefs, namely; perceived usefulness and perceived ease of use. The determinants of these two beliefs influencing IoT uptake in construction overtime include: utility; ICT development; training; simulation of usage; needs assessment; marketing; and firm specific advantages. The net effect of IoT adoption is enhanced construction project management marked by: stakeholder satisfaction; quick response to inputs; customized activities; worker safety; and assistance to report.

RESEARCH METHODS

The research design employed in this study is the comparative case study design, whereby a parallel between IoT use in the manufacturing and construction industries is drawn. The study considered two cases. The first case was IoT use in manufacturing industry, with exemplifying instances where the technology has been applied. The second case is IoT use in the construction industry, with exemplifying instances where the technology has been applied. A cross case analysis was then performed to derive patterns, similarities and differences. The analogy was that the construction industry can fast track on IoT uptake by borrowing what is already working in the manufacturing industry.

Qualitative research methods were used in data collection and analysis. The research main aim was to provide insights on how uptake of IoT in construction can be increased by drawing a parallel with its application in the manufacturing industry. Focus group discussions and an observation checklist were applied to gather data. The focus group discussions were carried out in two settings. The first setting focused on manufacturing, and respondents included; industrial automation experts, production engineer, telecommunication engineer, electrical engineer, floor manager and IoT experts. The second setting focused on the construction industry, and respondents included; project managers, BIM experts, contractor, construction finance manager, researchers and IoT experts. On the other hand, the observation checklist was used to guide the researcher on the elements characteristic of IoT solution including: identification; sensing; communication; technologies; computation; services and semantic.

A total of 15 respondents were involved in the three online focus group discussions. The first one involved respondents in the construction industry; the second - the manufacturing industry; and finally an amalgamate of the two industries. A cross

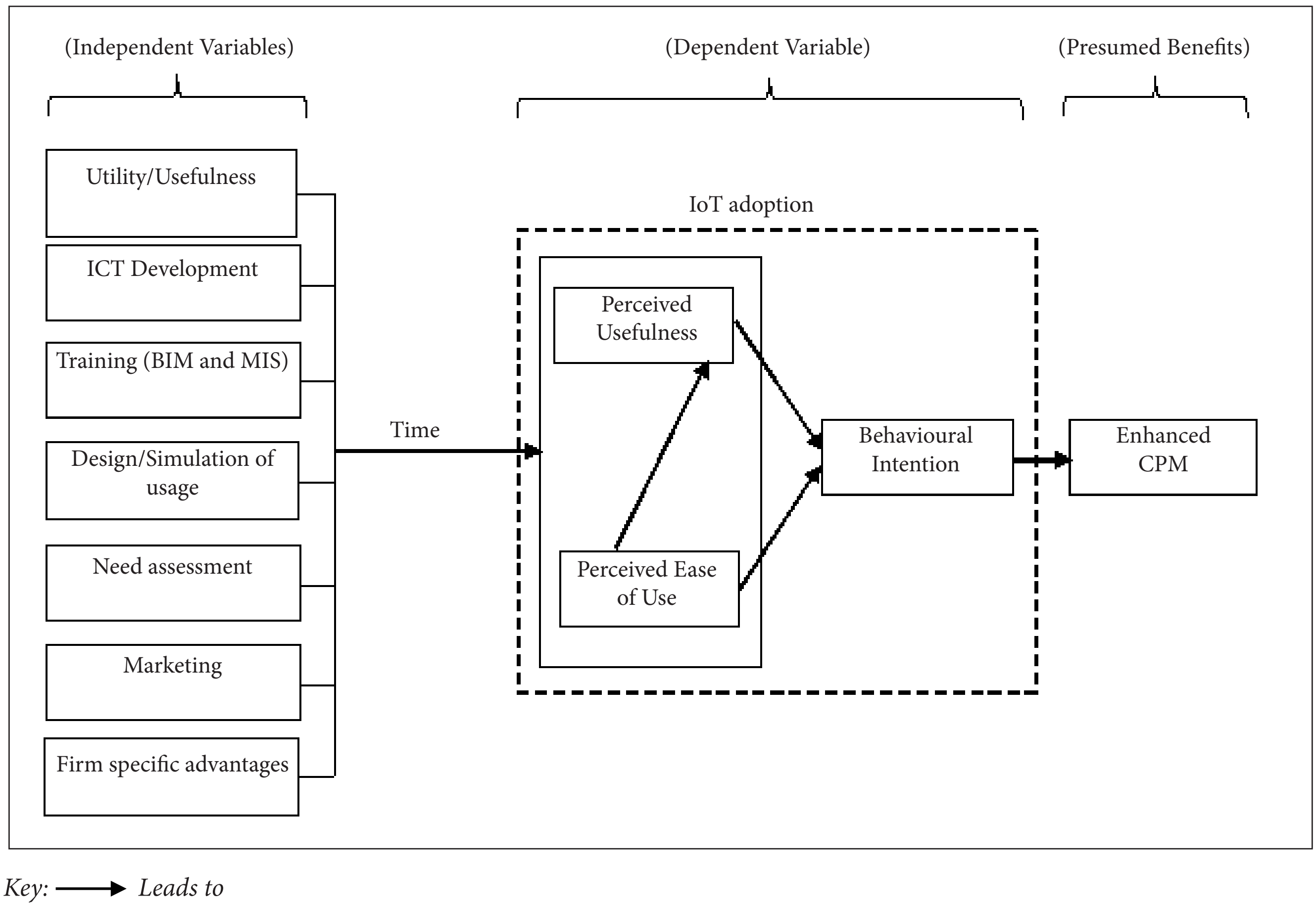


FIGURE 1
Conceptual framework
Source: Author 2019

case analysis was then performed to derive patterns, similarities and differences by querying the data fed into the NVivo program. This was especially useful in drawing out IoT value propositions from the manufacturing industry, which has substantially adopted the technology to make the case for the construction industry.

Thematic analysis was used to make sense of the data collected. Audio data from the focus group discussions was imported into the NVivo program for the coding process. This involved marking of passages in texts in the data using nodes which were then organized into hierarchies for broader (parent) and narrower (child) concepts. Queries were then run to further explore opinions and sentiments. Finally, simple coding reports were generated for representation of research findings.

RESULTS

Extent of IoT Adoption in Kenya

IoT technology has found use in various sectors in Kenya, including; agriculture, building automation, logistics, manufacturing, security, and in smart utility metering (**Figure 2**). The main barrier to IoT entry is the newness of the technology, and this has led to high costs of implementation. The extent to which IoT has been implemented in various sectors varies, with the biggest contenders being the manufacturing industry and smart utility metering. Essentially, the value proposition when it comes to IoT is data, which most businesses leverage to make decisions. The kind of data needed varies greatly among various industries, nonetheless, the goal is always to increase the visibility of an underlying process. Moreover, despite the heterogeneity in the nature of the industries not being a limiting factor, IoT technology has diffused

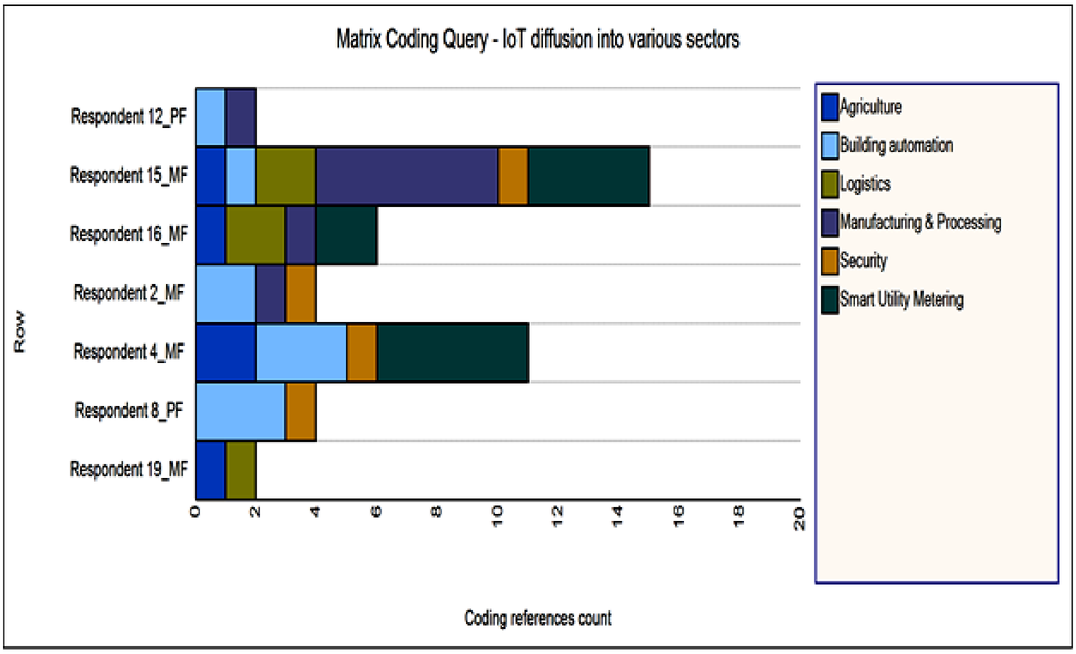


FIGURE 2
The extent to which IoT has diffused into various sectors in Kenya
Source: NVivo Analysis Output 2020

into various sectors in varying extents. Smart utility metering, for example, is one of the sectors taking an early lead.

Comparing the Application of IoT in the Manufacturing and Construction Industries

The juxtaposition of the construction and manufacturing industries, with regard to the adoption of IoT, exposes some overlapping similarities, but with major differences setting them apart. The similarities include: the high end and big enterprise is characteristic of the early adopter category; the need to integrate IoT stems from the need to increase the visibility of the underlying processes; training of end users is paramount, and; predictive maintenance and smart utility metering are the two applications that cut across both industries.

In consideration of the differences, these include: IoT entry point in manufacturing is mainly at the production phase, whereas in construction it is mainly in the living in phase, and thus characterized by consumer end products as shown in **Figure 3**, and; the reliance on in-house expertise to implement and maintain IoT solutions in manufacturing, whereas in construction the expertise is mainly outsourced. This comparative analysis provides the baseline for structuring increased adoption of IoT in construction in following with the success of the technology in manufacturing.

Exploring the Opportunities Presented by IoT in the Construction Industry

The theme 'IoT applicability and opportunities' had by far the most coded references indicative of the untapped potential of IoT solutions. Moreover, a hierarchical analysis of the nature of the sentiments under the same theme revealed that the positives far outweighed the negatives. The attitude held by most of the respondents was optimistic, signaling that the built environment will benefit from the increased connectivity made possible by the IoT technology. As shown in **Figure 4**, the opportunities presented by IoT in construction include: Building Management System (BMS); Building Information Modelling (BIM); smart access; smart utility metering; security; tracking tools and equipment, and; prefabrication technology.

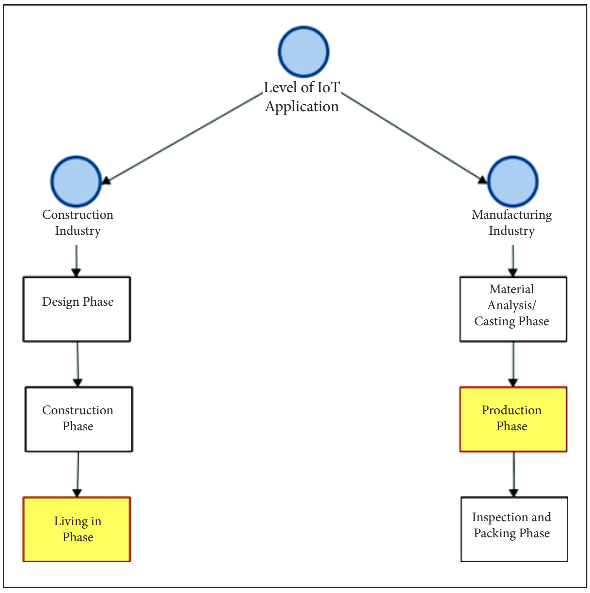


FIGURE 3
Contrasting stages of entry of IoT solutions between the manufacturing and construction industries
Source: Author 2020

The IoT opportunities may be briefly described as follows: -

Tracking tools and equipment – smart sensors integrated into tools and equipment would increase their visibility, enabling easy tracking. In effect, time spent locating these items would then be redirected into performing other critical tasks. Active monitoring of machines and equipment enables predictive maintenance, which mitigates against abrupt breakdowns which can result to project delays that often lead to project costs overrun.

Building management system (BMS) – increased visibility of the mechanical and electrical systems aids in preventive maintenance activities, as well as energy management. Smart monitoring of the building enables better energy management. In case of deviations, it is possible to establish cause and apply corrective measures. Energy savings are also possible through the application of motion sensors where lights can be switched off when the room is unoccupied. Overall, the integration of IoT with BMS enables optimal running of the building systems, which in turn improves the experience of the occupants.

Building Information Modelling (BIM) – smart sensors can take the place of professionals who currently update the 3D model. Real time updating of the 3D model is important in enabling advanced decisions. Moreover, the management is able to leverage the data captured in the 3D model to carry out maintenance activities. It is also possible to draw useful correlations about the effect of building elements on prolonged exposure to certain weather conditions. In addition, since the construction process is ever visible, future projects can be better managed by utilizing the information contained in previous models.

Utility metering – metering of utilities, such as electricity, gas and water, is currently moving towards autonomous data collection. This enables real time collection of consumption rates and usage trends to be used by the customer and the utility company. Through monitoring of water levels in storage tanks, management can also be able to plan beforehand to supplement the supply of water in case of shortages. This results in better relationships between the customer and the utility company.

Security – physical surveillance can be breached with ease. The use of smart cameras integrated with visual recognition algorithms offer improved security standards.

Smart parking – smart sensors detecting availability of parking slots can be used to update a database that can be accessed by car owners looking for parking spaces. Consequently, time and fuel used while looking for parking spaces can be saved, as well as reducing traffic snarl-ups.

Prefabrication technology – IoT can be applied in the three elements of prefabrication; manufacturing, logistics and onsite assembly. The transportation of building modules can be tracked, enabling timely delivery. Structural sensors installed at joints can be useful in monitoring the structural health of the building.

Framework for Boosting Adoption of IoT in Construction Industry in Kenya

Developing an infrastructure of interconnected objects, people, systems and information resources with intelligent services helps to meet the information needs of the construction project and its stakeholders. Based on the diffusion of innovation theory, the new idea (innovation) needs to be communicated through certain channels over time among members of the social system. In developing this framework,

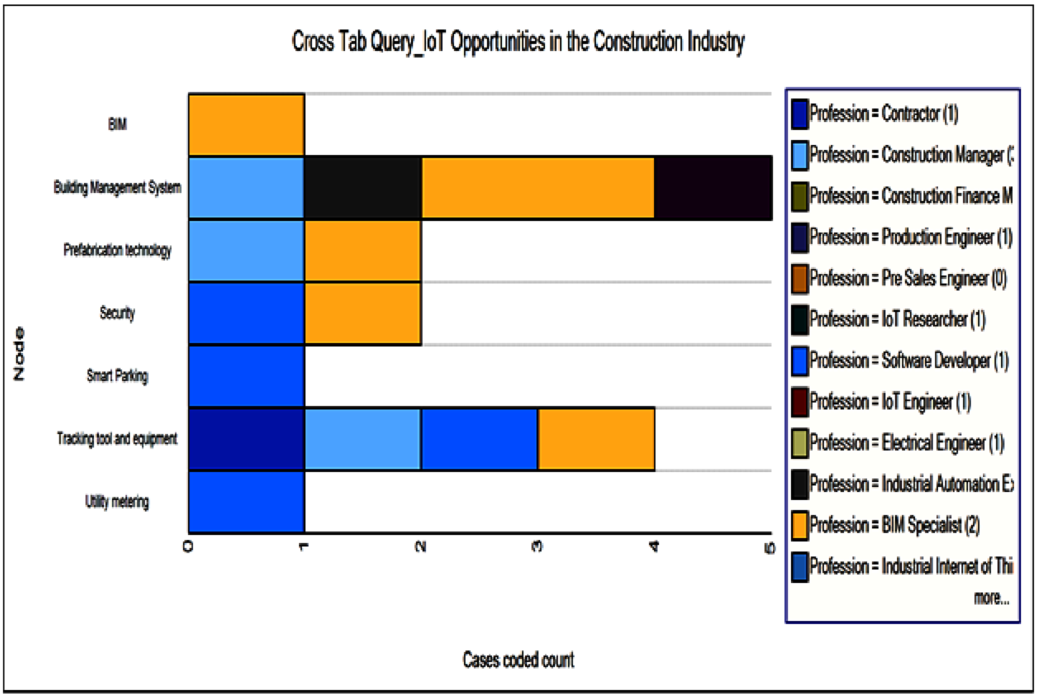


FIGURE 4
Opportunities presented by IoT technology in the construction industry
Source: Field survey 2020

emphasis is placed more on organizations, as opposed to individual members within the Architecture, Engineering & Construction (AEC) community. Based on the findings of this study, increased uptake of IoT into construction is reliant on the interplay between four factors, namely: organization, technology, marketing, and environment.

Firstly, the implementation of IoT requires organizational and behavioural changes. Companies operating in the built environment are rather reactive to new technologies. Bearing this in mind, the required foresight is likely to emerge from dynamic startups, as opposed to large- and medium-size enterprises. For example, some of the areas ancillary to the built environment that have taken the early lead in IoT uptake here in Kenya include smart utility metering. These are all niche markets that largely depend on the business model. IoT as an innovation is never static; it requires constant development of market ready solutions. This poses a challenge, especially when considering the high costs of IoT implementation. However, these prices are likely to come down as IoT modules become cheaper due to economies of scale. Moreover, funding can come from Non-Governmental Organizations (NGOs) and startup investors inclined to technology solutions.

Undoubtedly, diffusion of IoT in other industries is going to have a multiplier effect in the construction industry. Organizations, particularly in the manufacturing industry, are constantly *smartifying* their products. Integration of smart technologies into equipment and machines used in construction is going to have an effect on project management. Active monitoring of these equipment, for example, allows for predictive maintenance. Moreover, manufacturers of building elements can embed smart modules into their products, driving the uptake of IoT in the various phases of construction.

Secondly, from the macro level, IoT implementation is largely dependent on ICT development in the country as a whole. This is in terms of laying out the prerequisite infrastructure, increased network coverages, low tariffs for communication, availability of the expertise needed, and cheap sensors. In construction, existing technologies, such as BIM and BMS, offer open opportunities for IoT integration. The integration of

IoT into BMS increases the visibility of the building systems, enabling better management and efficiency in energy use. Similarly, unification of IoT and BIM allows for real time updating of the 3D model, which consequently enhances project performance. It is for this reason that the inter-operability of the IoT modules with the current systems is important.

For increased IoT uptake, the IT departments of companies in the built environment must extend beyond computers, networks, mobile devices and data centers. Successful implementation of an IoT requires joint effort between the IT, operations, research and development departments. Moreover, with the increased volume of data generated from IoT, proper understanding of the potential use of the data is important to avoid missing out on value capture opportunities. It is for this reason that proper data analytics should be put in place.

Moreover, the construction industry, in comparison with the manufacturing industry heavily relies on outsourced expertise, which discourages proactivity in implementing IoT solutions. Colleges and training institutions should expand the project management curriculum to include emerging technologies and how they are going to shape the built environment of the future. The Internet provides an alternative by providing access to information without the institutional barrier. EDX, for example, provides access to over 2000 free online courses from 140 leading institutions. Local companies, such as Gearbox which focuses on hardware prototyping, allows the engineers (builders) to link up with the entrepreneurs (sellers), which accelerates IoT implementation.

Thirdly, marketing of the technology is critical in reaching the mass audience, especially members within the AEC community. Online forums, such as Africa Proptech, enable leading brand investors and developers engaged in the property technology space to meet. Such forums provide platforms for ideas on emerging technologies, such as IoT, to be conveyed. Furthermore, social media platforms, such as Twitter and LinkedIn, have a wide reach, proving appropriate for communicating about the technology. The professional bodies in Kenya, such as The Association of Construction Managers of Kenya (ACMK) and the Architectural Association of Kenya (AAK), are also well poised to promote the technology to their members through various communication outlets.

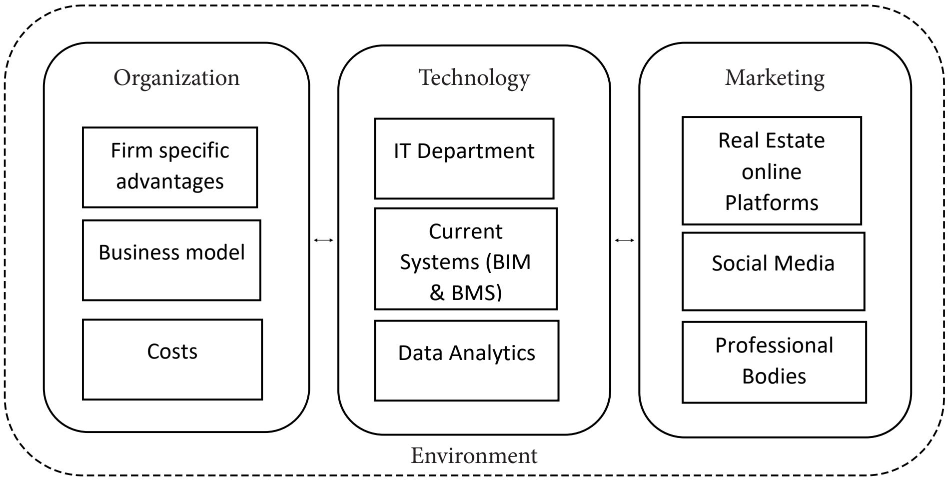
Finally, IoT requires an enabling environment, especially with regards to regulation. The Kenyan Government can stimulate an exploration of innovative alternatives to current practice by inflicting operational constraints and costs on industry, but can also codify certain existing practices, raising significant barriers to innovation. As highlighted, high costs of implementation is a major challenge facing IoT implementation. The government can incentivize IoT adoption by subsidizing approval costs for smartified construction projects that save on energy use and promote sustainability. Furthermore, the government can lower communication tariffs, in turn lowering the costs of rolling out the IoT solutions.

Figure 5 shows is a schematic model of the process and institutional setup that can enhance the uptake of IoT in the Kenyan construction industry.

DISCUSSION

In this study, it is evident that most IoT solutions in construction have been adopted in the living in phase, such as smart utility metering and smart access. Nonetheless, there are more open untapped opportunities. According to Gromov (2015), there were promising IoT application areas for construction companies adopting the product-oriented model, as well as the service-oriented model. These included; better processes, more safety and savings during the building phase, faster sales during handover, and new businesses in the after initial sales phase (Gromov, 2015).

The type of building methodology has an influence in promoting the application of IoT technology. In this study, practitioners in the built environment placed emphasis on prefabrication technology being a proponent of the IoT uptake. Similarly, Zhong et al. (2017), found that an IoT enabled system works collaboratively in easing operations within the three elements of prefabrication, that is, manufacturing, logistics and onsite assembly. Furthermore, the unification of IoT with BIM allows for leveraging real



Key: ⟷ *Communication*

FIGURE 5
Internet of Things adoption framework in the construction industry
Source: Author 2020

time data to make advanced decisions. The net effect is increased visibility, as well as traceability, that enables different end users to monitor the project status and cost implications in real time (Zhong et al., 2017).

In this study, the need to increase the visibility of underlying processes is the primary driver for the adoption of IoT technology, in both the manufacturing and construction industries. Advanced decisions can be made, especially concerning efficiency and productivity, once real time data is made available. This is in line with the observations made by Batrawi & Percudani (2017), who put forward the notion that IoT is poised to enhance all the characteristics of a project as a result of the availability of data gathered that allows for transparency, as well as increased data sharing in the created ecosystem.

CONCLUSION

The first objective of this study was to describe the extent to which IoT has been adopted in Kenya. Based on the presented results, it is clear that Kenya has an active IoT footprint implemented in sectors such as agriculture, logistics, security, manufacturing and smart utility metering. The major challenge facing IoT adoption remains to be the high cost of implementation, mainly due to its newness. The extent to which IoT has penetrated into various sectors is commendable; the manufacturing and smart utility metering being the predominant ones.

The second objective was to compare the application of IoT in manufacturing and construction industries. In consideration of the similarities, it was evident that the high-end business and big enterprises make up the early adopter category as they can afford to take the high financial risks. Both industries also have an intrinsic need to increase the visibility of underlying processes, which drives the uptake of IoT. Moreover, training of the end users is paramount. Both industries leverage IoT for predictive maintenance and smart utility metering. In regard to the differences, IoT in manufacturing is mainly during the production phase, as opposed to construction, where it is mainly in the living in phase. Also, manufacturing relies on in-house expertise to implement and maintain IoT solutions, whereas in construction, the expertise is mainly outsourced.

The third objective was to explore the opportunities that IoT presents in the construction industry. These include: BMS; BIM; smart access; smart utility metering, security; tracking tools equipment; and prefabrication technology. The uptake of IoT in construction in certain aspects of the built environment, such as utility metering and smart access, take the early lead. Success in these areas will be the impetus for future applications.

The fourth and final objective was to develop a framework for boosting adoption of IoT in construction to enhance project management in Kenya. The major players who are going to play a critical role in increasing the uptake of IoT in construction include: startups, private sector, government, NGOs, research institutions, training centres, online communities, manufacturers, and professional bodies in the AEC community. The main roles to be performed by these players include: need assessment, training, financing, designing/ simulation, marketing, and regulating. In line with diffusion of innovation theory, the interplay between these various players is important in assessment of need, providing proof of concept, prototyping and developing the final design. Mitigation against the high cost of implementation is critical in driving the increased uptake of the IoT technology in the built environment.

RECOMMENDATIONS

The establishment of an IoT forum within the AEC community aimed at exchanging the best practices, as well as exploring partnerships that can leverage individual strength of the parties. Such a platform would make the addressing of specific problems, such as long shipping periods of IoT devices, clearance delays, poor quality of locally available components and high communication tariffs imposed by the government; possible.

Evidently, the implementation of IoT solutions in construction is a very onerous engineering process that demands technical skills, as well as knowledge of the best practices in construction. Boot camps aimed at equipping students with knowledge on IoT should be introduced in colleges, vocational centres and universities to revamp IoT training. Additionally, students majoring in construction professions can collaborate with computer science students to capitalize on individual expertise, leading to more IoT solutions.

Funding to IoT projects should be increased to mitigate against the high cost of implementation. Through donor funds to research institutions and startups in the IoT space, it is possible to fast track prototyping of IoT solutions for use in the construction industry. Increased grant funded IoT projects in construction will allow for predictive analytics, and the development of innovations.

Media outlets, such as newspapers, television, radio, Twitter, Facebook and LinkedIn, should be used to promote IoT. Increasing the awareness of the technology is important in deriving the desired effect of increasing the uptake of IoT technology.

Cross-collaboration between various organizations in the project-oriented environment should be enhanced. The current practice involves a single entity developing end-to-end products, starting with the need assessment, to the final designs. Having cross-collaboration between research institutions, startups, and private sector enables each party to bring in specific expertise needed for the successful development of IoT solutions.

Finally, the consideration of the project lifecycle to include the longest phase in the construction process which is the living in phase.

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