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Key elements of ICT Enhancing Project Delivery in Construction Industry: A Systematic Review approach

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Abstract
The 21st-century economic environment ushered in overarching opportunities with an immense disruptive potential, as a result, of elements of the Fourth (4th) Industrial Revolution (4IR). However, the construction industry is somewhat notoriously resistant to change due to its domineering and adamantine, familiarity with methodical operations. The purpose of this study is to critically assess the key elements of ICT technologies that are enhancing modern construction delivery, and their impact on project design, procurement and construction in relation to the project's cost, time, quality and environmental safety. This study is ongoing research and in order to have a holistic overview of the emerging ICT technologies enhancing modern construction project delivery. Thus, 43 articles were systematically extracted from google scholar, and reviewed and analysed in order to identify key mega and emerging ICT technologies fostering innovative construction projects. Based on the elicited and synthesized articles on emerging ICT technologies shaping and enhancing modern construction projects. The emerging ICT technologies such as 3D printing, the Internet of Things, advanced robotics, artificial intelligence, virtual reality (VR), radio frequency identification (RFID) tags, optical character recognition, 3D scanning laser, building information modelling (BIM), cyber-physical systems (CPS), and Smart procurement applications were identified as the key emerging ICT technologies fostering innovative construction projects across the world. The study concludes 21st-century business has ignited an atmosphere of immense opportunities as well as disruptive change for the construction industry, and as such any construction organisations that lack an innovative and entrepreneurial spirit in making business decisions to adapt to new emerging ICT technologies will grow into an unsustainable business entity.

Keywords: Construction Industry, mega ICT technologies, project delivery.

INTRODUCTION

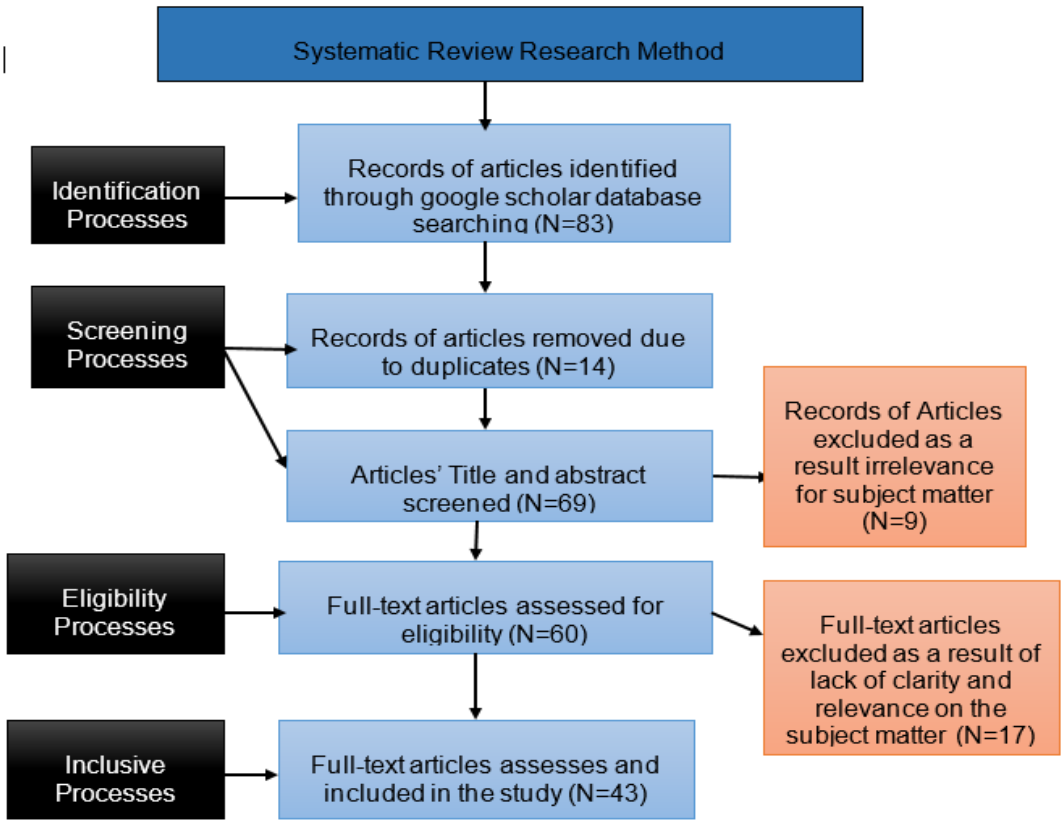
South African construction industry are notoriously resistance to change due to its domineering and adamantine thinking of protecting jobs and familiarity of methodical operations. The resistance to change within the construction industry has contributed to its slow progress of the sector in relation to optimally utilising and benefiting from the emerging and new technologies (Pillay, Ori and Merkofer, 2017). However, the thrust of fourth industrial revolution has evokes the atmosphere of immense opportunities as well as disruptive change for construction industry, most especially in the developing countries (Aghimien, Aigbavboa and Matabane, 2021). The developing countries has a huge infrastructural assets deficit; and the elements of fourth industrial revolution has the potential capability to speedily and effectively bridge the infrastructure gaps in terms of designing, procurement, delivering, operating and maintenance of hard core infrastructure assets (You and Feng, 2020).

Leviakangas, Paik and Moon (2017), acknowledged that most of construction companies had been executing their work for decades and have not been directly involved and investing in the latest technological evolution, resulting in many organisations' disconnection with the emerging and new technologies. These emerging and new technologies has the potential capability to significantly increase the productive level of the entire industry in terms of cost, quality/performance, health and safety, and delivery time (Leviäkangas, Paik and Moon, 2017). In addition, Raphael et al. (2019), claimed that the resistance to new technology, maybe as a result of inadequate capacity, and this issue has caused most construction projects undertaken by local South African building contractors in eThekwini district some element of project delays. Thus, as a result most of the executed projects are often experience delays, cost overruns and non- conformance to quality, and overall poor performance and dissatisfied among various stakeholders (Raphael et al., 2019). It is evident that most of the South African construction companies have fallen behind towards utilisation of the new and emerging

technologies, which makes them lack the competiveness, when compare with their peers from other countries such as China (Pillay, Ori and Merkofer, 2017).
However, there is a perception that other sectors compare to construction sector are more receptive to integrate new and emerging technologies emanating from the fourth industrial revolution in solving their challenges, and as well to increase productivity, such as health and manufacturing sectors (Pillay, Ori and Merkofer, 2017). Park (2016), research findings shown that significant rate of about 45% among the executive directors in various sectors believe that healthcare is the sector that would benefit most from the merging, as the integration of physical, digital, and biological systems as result of fourth industrial revolution will sharp their future services. The manufacturing, automobile, and the banking sector have already tapped into the future by adopting a full digital approach to their everyday business; thereby, contributing to their productivity, accuracy, efficiency and improved customer satisfaction (Osunsanmi et al., 2018). The construction sectors' clients are yearning for the same client's satisfaction their counterparts are receiving from other sectors in terms the services and products, from the construction practitioners, and this has thrust the construction industry to increasingly adopted means to accelerate the strategies towards integrating the fourth industrial revolution technologies in resolving some of the challenges in the sector such as project cost and time overruns, health and safety concerns, clients' dissatisfaction and quality performance concerns (Osunsanmi et al., 2018).Therefore, this monograph undertakes to evaluate and identify the emerging ICT techniques and tools enhancing construction project delivery and performance; and it also proposes a conceptual framework towards integration new ICT technologies in construction project delivery.

RESEARH METHOD FRAMEWORK: SYSTEMATIC REVIEW APPROACH

The paper used secondary data. A literature review on the emerging ICT technologies that are enhancing modern construction project delivery was carried out using scoping research review approach utilising google scholar database. The literature review was carried out in which 41 articles were systematically identified, extracted, reviewed, analysed and synthesized with aim of identifying the key emerging ICT technologies fostering innovative construction project delivery.



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THEORETICAL BACKGROUND REVIEW AND ANALYSIS

Brief Historical Background of Industrial Revolutions Phenomenon

According to Posada et al. (2015), the world have witnessed three major industrial revolutions and the so-called Fourth Industrial Revolution (4IR). Based on historical account, the first industrial revolution relates to mechanization, which lead to improved efficiency from handcraft process, the second industrial revolution saw the advent of electricity and mass production, and whilst the third industrial revolution fostered the optimal utilisation of electronics and information and communication technology. The fourth industrial revolution is a fusion of all current and emerging technologies (Chung and Kim, 2016). The fourth industrial revolution confluence of technologies ranging from a variety of digital technologies e.g. 3D printing, Internet of Things, advanced robotics, artificial intelligence etc. These technologies have the potential to revolutionise operations and supply chain management within construction industry (Dallasega, Rauch and Linder 2018; Koh, Orzes and Jia 2019). Industry 4.0 is an emerging concept deriving from technological advancement and disruptive developments in the industrial sector worldwide in the past few years (Dallasega, Rauch and Linder, 2018; Koh, Orzes and Jia, 2019). A research conducted by the Economist Intelligence (2016) ,across various sectors of economy among 622 business executive and leaders on the anticipated megatrends such as fourth industrial revolution in areas of healthcare, education, finance, infrastructure, and energy. The findings indicated significant number of business executives and leader, i.e. 45% of 622 believe that healthcare sector would benefit significantly through the merging of physical, digital, and biological systems.

Understanding the Concept of Fourth Industrial Revolution

Buhr (2015) claims that fourth industrial revolution would seamlessly integrate human factors in the centre of production with the demands of high-level skilled workforce in order to ensure an effective management of complex projects especially in the construction industry. This process would foster continuous improvement of production and dynamic working routines within various industries, such as construction industry and its site working environment (Buhr, 2015). Oesterreich and Teuteberg (2016) acknowledge that there is huge potential, advantages and benefits embedded in the fourth industrial revolution with the emerging and innovative technologies. However many of companies within the construction industry are adamant to effectively transform and manage the integration of these innovative and emerging technologies that would ensure their competitiveness as with their counterparts in the automotive or mechanical engineering related sectors ((Oesterreich and Teuteberg, 2016).Gower (2018:) cited Gustav Rohde (2018), which claims that if African businesses such as construction companies do not adapt to the fourth industrial revolution, they may risk to become obsolete, isolated and unable to compete in both local and global market environment. Therefore, the Fourth industrial revolution phenomenon should be undertaken as an opportunity for African society and businesses to play a much more constructive role in embracing the digital age (Gower, 2018).

According to Gower (2018), South African industrial has championed some pockets of excellence in areas of significant innovation through digital technology. However, Jarbandhan in his research found that industry players in South Africa are underprepared for the Fourth Industrial Revolution (Jarbandhan, 2017). Sutherland (2020), in his research stated that South Africa is not an obvious location for Fourth Industrial Revolution, given its economy is still rooted in farming, mining and the informal sector, and burdened with high levels of unemployment, while the vast majority of its citizens lack advanced and, often, basic skills. Thus, the combinations of technologies the (Fourth Industrial

Revolution) is forcing companies to re-examine the way they do business. The bottom line, however, is the same: business leaders and senior executives need to understand their changing environment, challenge the assumptions of their operating teams, and relentlessly and continuously innovate (Schwab, 2017).

The Understanding the Basic Concept of Smart Construction

In construction industry, the labour costs are high and manual operations are prone to errors, health and safety (H&S) and inaccuracies. The application of automated solutions that based on robots and robotic arms would reduce the labour crisis and challenges on construction sites, which essentially means that safety on sites can be improved (LI, 2017). According to Iacovidou, Purnell and Lim (2018), the last decades, a number of advanced "smart" technologies have emerged including radio frequency identification (RFID) tags, optical character recognition, 3D scanning laser, building information modelling (BIM), etc. , and these technological elements has becoming important tools in the construction sector. Thus, the smart technologies leverage the industry 4.0 dimensions and foster the interconnectivity, which provide intelligence to the new construction system, and enable construction site participants to track and monitor the site activities (Frank, Dalenogare and Ayala, 2019). These technologies according to Osunsanmi et al. (2018), are the roadmap for the implementation of construction industry 4.0 concepts in the South African construction industry.

Basic Concept of Cyber-Physical Systems and Internet of Things (IoT) in Construction Sector

Yuan, Anumba and Parfitt (2015) claim that the initial attempts of Cyber-Physical Systems (CPS) applications in the various sectors such as transport, healthcare, and manufacturing industries have given raise the recognition and importance of CPS to the construction industry. The CPS applicability and potential benefits have been explored in various areas of the construction industry, including project delivery process (Yuan, Anumba and Parfitt, 2015). Based on these investigations, CPS has been identified to have a considerable potential in the construction industry, particularly in addressing those problems that require bidirectional coordination between physical systems and their virtual representations.

According to Bughin, Chui and Manyika (2015), usage of the IoT technologies on construction sites, mines, and oil and gas extraction sites has enhanced the operations in monitoring the soundness of machinery, and improvement of health and safety issues. The IoT is rapidly developing to become the major technological trend that could offer sustainable benefits to the construction sites management, safety and productivity. These competitive and sustainable benefits include lower costs, safer employees on site, optimal production outputs, and smarter designs process (Bughin, Chui and Manyika, 2015). Some examples of IoT implementation in the construction industry is the combined sensors on physical objects such as vehicles, robotics, and building components which are capable of connecting to the internet (Oesterreich and Teuteberg, 2016). Machineries such as cranes, dozers, loaders that are equipped with sensors will transfer performance data via the internet to engineer to be analyzed. According to received data, engineers can predict the upcoming failures in vehicles and fix them beforehand (Oesterreich and Teuteberg, 2016).

General Overview of Smart procurement Approach within Construction Industry

According to Sobhani et al. (2014) procurement in sustainable building construction has over the years changed to a strategy for cutting production cost, improving building quality and enhancing procurement efficiency. According to Watermeyer (2012) procurement is a key process in the delivery and maintenance of construction project works to the client's needs and satisfactions. Emuze, Smallwood and Shakantu (2011) emphasize that the perfect goal of the project manager is to make decisions on enhancing productivity and value for money at the materials procurement phase effectively; as well as to meet the goals and objectives of the project. As a result, the materials procurement strategy implemented by the project manager is likely to have a great effect on the cost, quality, time and sustainability of a building (Emuze, Smallwood and Shakantu, 2011). The e-procurement approach would led to substantial time and money savings, increase customers' satisfaction, and improved internal and external communication and collaboration (Klinc, Dolenc and Turk, 2008). In addition, Luzzini et al. (2015) claim that the adoption of the e-procurement in the execution of construction materials procurement activities would improves the system of communication among project stakeholders. The e-procurement has the functional capability to promote accurate, effective and timely exchange of materials information among the different procurement participants and stakeholders within construction sector (Luzzini et al., 2015). The ripple of effect towards the adoption of the electronic procurement system reflects on better management of materials information overtime during construction phases.

It is obvious that current manual and paper-based way of tracking construction resources and components would be ineffective and inefficient for the 21st century business environment (Ergen and Akinci, 2007). Thus, there is a need for an automated resource tracking system in the construction production, that have the functional capacity to optimally perform in dynamic and harsh environments has observed in construction industry (Ergen and Akinci, 2007). However, another challenging characteristics of construction industry is that there are many unique materials /components that need to be uniquely tracked, which requires strategic handling and installation techniques. The workers that are handling those construction materials/ components at site normally search for the paper-based documents in order to obtain vital instructions for handling and installation. This results in time-consuming manual methods of searching in order to identify the related construction materials/ component information. Thus, the various automated identification technologies, such as barcodes, two dimensional barcodes, RFID, optical character recognition, and contact memories are available for tracking resources and related information in construction planning, monitoring, controlling and maintenance (Wang et al., 2013). The Radio Frequency Identification (RFID) technology make it an attractive technology that has potential to address the challenges associated with tracking resources on construction sites. Radio Frequency Identification (RFID) technology has been widely applied in various areas such as retail, electronic transaction, logistic and supply chain management, scientific research, security, etc (Lu, Huang and Li 2011). According to Jaselskis and El-Misalami (2003) the utilization of RFID technology in construction industry can enhance operation of construction project.

Brief Overview of Building Information Model in Planning & Procurement of Construction Project

According to Ren, Sha and Hassan (2007), the dynamic characteristics of the construction industry in relation to its operational planning and management of resource within a construction site are incredibly vital in improving the project in both time and cost efficiency. Time efficiency and waste elimination within construction production would have great leverages in the construction industry's competitiveness through utilisation of Building Information Modelling (Ren, Sha and Hassan, 2007). Building Information Modeling (BIM) is one of the tool that is being used more frequently in modern construction projects (Eastman et al., 2011).Building Information Modeling addresses integration and effective information management problems throughout the entire life cycle of a facility (Meadati, Irizarry and Akhnoukh, 2010). The implementation of BIM in planning and procuring construction project would benefits all phases of the facility's life cycle (Meadati, Irizarry and Akhnoukh, 2010)

Understanding the Concept of Construction 3D Printing: Emerging Construction Technologies

The 3D technology can bring significant benefits to the construction industry, in terms of increased customization, reduced construction time, reduced manpower and construction cost (Wu, Wang and Wang, 2016). According to Momin, Patil and Nale (2015) construction industry is labour-intensive and is conducted in dangerous situations and therefore the importance of construction robotics has grown rapidly. Today's construction projects are characterizing by short design and build period, increased demands of quality and low cost. These problems can be approached by a flexible automation using robots- based computer that assist in planning, engineering and construction management of infrastructure projects. Especially in high labour cost countries, automated and robotized construction technologies can compensate increasing demand on construction projects (Yaghoubi, 2013). In addition, the Virtual Reality (VR) offers an opportunity as it has potential to improve construction site activities as well to assist significantly in the construction planning stage. In addition, virtual reality has the capacity to enhance the scheduling usage of site space , logistics, and initial layout prior to project work commencement (Heesom and Mahdjoubi, 2002). Thus, with the VR, the issues of conflicts between material positions can be detected, and resolved seamlessly with regards project schedule (Heesom and Mahdjoubi, 2002).

RESULTS AND DISCUSSIONS

The emerging ICT technologies as key drivers for changes that are enhancing modern construction project planning, delivery and performance are discussed as follows:

Key driver 1: Usage of Robotic Tool

Li (2017) proposed the use of robotic in construction industry would significantly alleviate the problem such as the high labour costs due to manual operations which are prone to errors, health and safety (H&S) and inaccuracies. He further stated that the application of automated solutions that based on robots and robotic arms would reduce the labour crisis and challenges on construction sites, which essentially means that safety on sites can be improved and holistic project performance (LI, 2017).

The construction industry is one of the main source of job creation in the South Africa, and has remains a vital player and stimulus to the entire economy. The South African construction industry is deemed crucial based on its operations are still mostly labour-intensive within the emerging economics (Ogwueleka and Maritz 2014: 6). The construction industry also plays a significant role, with ripple effects in supporting other economic sectors through provision of building and engineering infrastructure assets (Ogwueleka and Maritz, 2014). and thus, slow adoption of the emerging technologies within the construction industry makes it prone to low productive and cost overruns due to rudimentary style of construction planning and delivery(Castro-Lacouture, 2009).Therefore, the following hypothesis H1 was formulated:
H1: The usage of robotic tool and techniques will significantly enhance modern construction project delivery in South African construction.

Key driver 2: The Internet of Things and E-procurement
Bughin, Chui and Manyika (2015), claim that the usage of the IoT technologies on construction sites enhanced the operations in monitoring the soundness of machinery, and improvement of health and safety issues. Luzzini et al. (2015) the e-procurement has the functional capability to promote accurate, effective and timely exchange of materials information among the different procurement participants and stakeholders within construction sector. The ripple of effect towards the adoption of the electronic procurement system reflects on better management of materials information overtime during construction phases.Therefore, the following hypothesis H2 was formulated:
H2: The adoption of internet of things and e-procurement within the South African construction industry would significantly promote and foster effective site management and collaborative effort among project team.

Key driver 3: Cyber-physical systems (CPS) and Radio frequency identification (RFID)
According to Yuan, Anumba and Parfitt (2015) CPS has shown potential benefits to the built environment through its successful application in structural health monitoring and facility management. Therefore, CPS offers an opportunity to address the current problems and safety issues associated with temporary structures, including temporary performance stages and scaffolding. To be specific, a CPS for temporary structures monitoring enables remote control, “on physical component instructions”, and real-time interaction between temporary structures and their virtual representations. The Radio Frequency Identification (RFID) technology make it an attractive technology that has potential to address the challenges associated with tracking resources on construction sites. According to Jaselskis and El-Misalami (2003) the utilization of RFID technology in construction industry can enhance operation of construction project.Therefore, the following hypothesis H3 was formulated:
H3: The radio frequency identification and cyber-physical systems as one of the emerging ICT technologies has potential to positively influence construction team interaction and material management and operation on site.

Key driver 4: Building information modelling (BIM)
According to Meadati, Irizarry and Akhnoukh (2010) the implementation of BIM in planning and procuring construction project would benefits all phases of the facility’s life cycle. BIM technology provides users with accurate and consistent building/project data and information, accommodating the functions needed to model the building and provides a virtual view of it (Fernandes, 2013). BIM is a collaborative approach to construction that involves integrating the various disciplines to work on a structure in a virtual and visual environment (Lu, Zhang and Rowlinson, 2013). The BIM process involves a high level of transactions on data, information and knowledge. A successful BIM project highly relies on effective collaboration among project participants including owners (Lu, Zhang and Rowlinson, 2013).Therefore, the following hypothesis H4 was formulated:
H4: Adoption of Building Information Modelling (BIM) will significantly enhance project collaboration among key project team/stakeholders as well as improve the South African construction industry overall project delivery and performance.

Key driver 5: 3D printing and Virtual Reality (VR)
Wu, Wang and Wang (2016) state that the 3D technology can bring significant benefits to the construction industry, in terms of increased customization, reduced construction time, reduced manpower and construction cost. Heesom and Mahdjoubi (2002) explain that virtual reality offers an opportunity as it has potential to improve construction site activities as well to assist significantly in the construction planning stage. In addition, virtual reality has the capacity to enhance the scheduling usage

of site space, logistics, and initial layout prior to project work commencement.Therefore, the following hypothesis H5 was formulated:

H5: 3D printing and virtual reality (VR) has a huge potentiality to significantly enhance modern construction project delivery and performance in South African construction industry.

CONCLUSIONS AND RECOMMENDATION

The 21st century economic environment ushered in overarching opportunities with an immense disruptive potential, as a result, of elements of the Fourth (4th) Industrial Revolution (4IR). The emerging technologies such as artificial intelligence/robotic tools, the Internet of Things (IoT), cloud computing, social media, data science, 3D printing, connected wearable devices, quantum computing, robotics, and genetics are the key drivers for change and forces for emerging modern construction. These transformative technologies will significantly influence entire supply value chain within the Built environment sector. However, as analysed in the study, despite the emerging ICT technologies and its potential to significantly improve construction project delivery and performance, activities within the construction industry globally are characterized with mostly traditional approaches and little implementation of integration of emerging ICT technologies. In addition, the 21st-century business environment has ignited an atmosphere of immense opportunities as well as disruptive change for the construction industry, and as such any construction organisations that lack an innovative and entrepreneurial spirit in making business decisions to adapt to new emerging ICT technologies will grow into unsustainable business entity. Thus, adoption of emerging ICT technologies would significantly enhance modern construction project delivery and holistic performance of the industry which will in turn reduce the incessant records of production of low quality infrastructure, cost and time overrun. Thus, this paper proposes the adoption of emerging ICT technologies by construction industry organisation in order to improve the overall performance project delivery within South Africa. Finally, construction sector professionals should adopt a proactive thinking approach to their daily construction activities.

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