

## PATTERNS OF TECHNOLOGICAL INNOVATION IN THE USE OF E-PROCUREMENT IN CONSTRUCTION

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**SUMMARY:** *There is a consensus in the literature that the construction industry is slow in the uptake of electronic procurement when compared with manufacturing and other service industries. However, in the last two decades there is evidence of increasing use of web-based technologies in the execution of construction procurement activities. Despite this development and the expansive research output accompanying it, there is limited understanding of the nature of technological innovations in the use of web-based technologies in executing construction procurement activities. A systematic review of 102 research articles and seminal works from 72 sources published between 1978 and 2013 was used to identify patterns of technological innovation in the use of e-Procurement in execution of the six basic construction procurement activities identified in the International Standard on Construction Procurement (ISO 10845, 2010). Three dominant patterns of technological innovation, namely (i) the identification and adoption of web-based technologies and applications from other sectors (ii) improvement and use of already-known technologies in new areas; and (iii) the conjunction use of new and existing web-based technologies and applications in construction procurement were identified. These patterns of innovation were found to manifest most at the tendering and contract administration stages of construction procurement process; and are influenced by factors, including availability of the technologies, lessons from experience of users in other industries, nature of construction procurement activities, and the need to ensure efficiency in construction procurement process by procurers. The review indicates that although the need to integrate the six procurement activities, participants and different technologies appears to be the impetus for the different patterns of technological innovation in e-procurement use in construction, the inability to integrate the different web-based applications into a single system available to execute construction procurement activities constitutes a barrier to achieving this. Therefore, more attention is required in addressing this challenge.*

**KEYWORDS:** *technological innovation, e-Procurement, construction procurement, web-based technologies, systematic review, ISO 10845*

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## 1. INTRODUCTION

Evidence from the published literature indicates that when compared with manufacturing, transportation, retailing and other service industries the construction sector is generally slow in the uptake of information technologies (IT) mediated innovations such as e-procurement as Aranda-Mena (2004) and Acar *et al.* (2005:713) explained in their respective studies. For instance, whereas Ageshin (2001) revealed that the General Motors Corporation, Ford Motor Company and DaimlerChrysler AG implemented e-procurement in 2000, Eadie *et al.* (2010a) indicated that as at 2010 less than 20% of construction organisations use e-procurement in the UK. Yet another survey by Eadie *et al.* (2010b) also revealed that in the same year, the use of e-procurement lagged behind by 50% in the public and private sectors of the UK construction industry, and that e-procurement was still less used in construction than general e-procurement in Europe. The most common explanation often given for this development is the fragmented and project-based nature of construction activities, conservative nature of the industry, poor investment in construction IT and other related factors as explained by Hardie and Newell (2011) in a study on the factors influencing technical innovation in the construction SMEs in Australia.

Despite this reputation, previous studies (Alarcon *et al.*, 2009; Eadie *et al.*, 2011; Gambatese and Hallowell, 2011; Brewer *et al.* (2013) show that in the last two decades, there has been increasing uptake of e-procurement with a wide of benefits to the construction sector. In an earlier study on the current state of e-commerce technologies applications in the construction supply chain in Sydney, Australia, Zou and Seo (2005) specifically described the transition from paper-based methods to the use of electronic commerce in construction supply chain management as a typical example of IT innovation in construction. Electronic procurement (e-procurement) generally refers to the use of electronic communications and transaction processes to buy supplies and services or conduct tendering for works as defined by Bausa *et al.* (2013:5) in the e-procurement golden book. It involves the use of web-based/supported technologies and applications to procure construction materials, equipment, services and works as explained by Vitkauskaite and Gatautis (2008) in a research on the most internal process of construction SMEs and possibilities to use ICT to optimise the processes in European economies.

The study by Isikdag *et al.* (2011) on the barriers of e-procurement in the Turkish AEC industry and separate reviews by Boddy *et al.*, (2007), Ren *et al.*, (2012), Hosseni *et al.* (2012) help to explain that since the advent of e-procurement following the introduction of the World Wide Web (WWW) aspect of the Internet in the mid-1990s, its uptake in construction has been on the increase. It is however observed that there has been very little attempt in the literature to identify and articulate the various innovative ways in which web-based technologies and applications are used to support the execution of construction procurement activities. This study is therefore aimed at identifying and analysing the patterns of technological innovations in the use of e-procurement to support the execution of construction procurement activities. By patterns of innovation we mean the regular ways of uptake of innovation by adaptors, and this case e-procurement as Wolf (1994) explained in a review on research directions of organizational innovation. To achieve the goal of the study, the following research questions were formulated:

- What patterns of technological innovation in the use of e-procurement in construction can be identified from a systematic review of research literature?
- How do the patterns relate to the construction procurement process? and
- What factors influence the patterns of innovation in e-procurement use in construction?

These research questions were addressed through a systematic review of research literature using Scopus as the main source of literature. In order to streamline the review and analysis to specific construction procurement activities, the International Standard on Construction Procurement (ISO 10845, 2010) was adopted as the framework for breaking down the activities involved in construction procurement into six key components. This helped in the identification of the different web-based technologies used in executing construction procurement activities and their evolutionary trend. By comparing the different web-based technologies and their evolution, it was possible to identify and analyse the predominant patterns of technological innovation in the use of e-procurement in construction.

This paper makes contribution in four main areas. First, it provides an up-to-date review of the existing e-procurement technologies and applications mapped with each of the six basic construction procurement activities identified in ISO 1048 (2010). Second, it identifies the different ways of uptake of e-procurement in construction;

and thus helps to provide vital information to guide firms trying to adopt e-procurement technologies. Third, it also provides information for researchers and practitioners who may wish to keep abreast of the way e-procurement is developing and the current discourse on its use in construction. Last but not the least; the paper also contributes to identifying the factors that can influence the ways of uptake of e-procurement in the construction sector globally.

## **2.0. DEFINITION OF CONCEPTS**

In view of the different conceptions and definitions of construction procurement, innovation, and technological innovations in the literature, it was important to establish operational definitions for the different concepts in the study. This is intended to firstly, help to eliminate ambiguity; and secondly, provide the basis for the review. Therefore, in this section, we present the definitions of construction procurement, innovation, technological innovations, the patterns of technological innovation and factors influencing these as applied in the study.

### **2.1. Construction Procurement**

This review is on the different patterns of technological innovation in the use of web-based technologies in construction procurement. Therefore, there was a need to identify the specific aspects of construction procurement activities under focus. From the survey of literature, it was observed that the majority of published works on construction procurement dwell on the different procurement routes/systems, their selection criteria, modus operandi, strength and weaknesses (see for examples Cheung *et al.*, 2001; El Wardani *et al.*, 2006; Laedre *et al.*, 2006; Oyegoke *et al.*, 2009). Other studies (including, Love *et al.*, 1998; Brown *et al.*, 2001; Watermeyer, 2004; Vitkauskaitė and Gatautis, 2008) provide insight into the nature of activities and tasks procurers of construction works, goods and services are engaged in from start to finish of construction procurement processes. Aggregate findings of these studies help to explain that construction procurement is a process that involves several steps and activities people or organizations are engaged in when procuring construction goods, services and works.

ISO 10845 (2010) specifically noted that construction procurement involves three main activities: creating, managing and fulfilling contracts relating to the provision of goods, services, engineering and construction works or disposal, or any combination thereof. These three basic activities involve specific tasks related to the procurement of construction materials, equipment, professional and non-professional services as explained by Grilo and Jardim-Goncalves (2011) in a conceptual paper on BIM-based perspective to electronic procurement in the architectural engineering and construction sector. In this paper, we conceive of construction procurement as encompassing all functional and strategic activities engaged in by procurers in establishing, managing and delivering of construction or engineering projects.

From the various road maps to construction procurement presented by the different authors cited in the previous paragraphs, it was possible to connect them to the six basic construction procurement activities identified by Watermeyer (2004) and ISO 10845 (2010). These activities include:

- i. Establishment of what is to be procured
- ii. Establishment of procurement strategies
- iii. Soliciting for tender offers
- iv. Evaluating tender offers
- v. Awarding of contracts; and
- vi. Administrating contracts to ensure that they comply with requirements.

Although the extent to which each of these activities is executed in a particular construction procurement endeavour is determined by the procurement route / system adopted; these six basic activities represent a generic roadmap for construction procurement process. Therefore, the identification and analysis of the patterns of technological innovation in e-procurement use in construction as presented in this review are based on these six basic construction procurement activities.

### **2.2. Concept of Innovation**

The term “innovation” has been variously defined in the literature. The different definitions as found in the literature reviewed are summarised in Table 1. From the definitions in Table 1 two key inferences can be made. The first one is that innovation means the development and adoption of scientific, technological, financial and commercial

products, strategies or practices by individuals and/or organizations with the intention of improving the existing products, practices, processes or situations. This means that innovations can be technological/technical or administrative as Daft (1978) explained in a study on the role of administrators and technical employees in the process leading to innovation adoption in the U.S. The second is that innovation can manifest as products or services, practices (strategies) or processes and its impact can be measured by the changes it brings when implemented as Sexton and Barrett (2005) explained in a conceptual paper on performance-based building and innovation; and the examples may include patents, technical research papers, introduction of new products or process improvements as Soete (1997:7-8) explained in their book on economics of industrial innovation.

**Table 1: Definitions of Innovation in the Literature**

Authors	Definition of Innovation	Context
Pennings and Harianto (1992)	The adoption of a new idea, process, product or service developed internally or acquired from external environment	Study of the diffusion of technological innovation in commercial banks
Rogers (1995)	Idea, practice, or object that is perceived as new by an individual or other unit of adoption	Book on Diffusion of Innovations
Toole (1998)	Application of technology that is new to an organization and that significantly improves work processes by decreasing the cost, increasing the performance and improving the business process	A study of Home Builders' adoption of technological Innovation
Manley and McFallan (2003)	A process of continual improvement	Survey to investigate innovation adoption behaviour in the construction sector in the Queensland Road industry, Australia
OECD (2005)	The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations	Guidelines for Collecting and Interpreting Innovation Data
Songip <i>et al.</i> (2013)	Something that is new introduced apparently to change the current state for the better	a questionnaire survey of 121 respondents in 340 firms in Malaysia to identify the factors that influenced the diffusion of construction innovations

From the foregoing, it can be inferred that innovation can be said to be the process of conceiving, developing, introducing and adopting new or significantly improved existing products, processes and/or services or situations for the benefit of society. It is also evident from the literature that innovation lends itself to implementation and can result to changes within and outside the adopting unit when implemented. This means that any new idea or technology that is not implementable cannot be described as innovation as Williams *et al.* (2007) explained in the study on adoption patterns of advanced information technologies in the construction industries 152 U.S and 31 Korean firms.

### 2.3. Technological Innovation

From the previous section, it is clear that innovations can be technological or administrative. Nevertheless, the focus of the current review is on technological innovation. The Organization for Economic and Cooperative Development (OECD, 1991) cited in Garcia and Calantone (2002) described technological innovation as an iterative process initiated by the perception of opportunity for a technology-based invention leading to the conception, development, production, commercialization and marketing of inventions. This simply means that technological innovation is the development, adoption and diffusion of products and/or applications resulting from scientific and/or technological discovery and knowledge.

The existing literature (see for examples Daft, 1978; OECD, 2005; Harty, 2005; de Valence, 2010) helps to explain that technological innovations can be in the forms of processes or products; and may include engineering and scientific concepts, new products, processing systems, production processes, physical equipment or tools. This implies that the two key attributes of technological innovation are that it is first a continuous process of initial development and introduction of new or reintroduction of substantially improved products, services, processes or strategies. The second is that technological innovation involves a number of activities, including invention, development of an invention into innovation (e.g. product or service), introduction of an innovation to end-users as well as the adoption and diffusion of an innovation as explained by Garcia and Calantone (2002).

The focus of the current study is on technological product innovation, which according to the OECD (2005:48-49), is the *“implementation or commercialization of a product with improved performance characteristics such as to deliver objectively new or improved services to the consumer”* According to de Valence (2010), in recent times, there has been a great deal of technological product innovations in the construction sector. We find in the literature that technical product innovation in construction can be in the forms of (i) the development and use of new materials (Blackley and Shepard, 1996) (ii) the adoption of information technologies, computer-based electronic services (Gambatese and Hallowell, 2011; Usman and Said, 2012, Brewer et al., 2013) (iii) development and introduction of end products (e.g. design and construction) (iv) adoption of new construction means and methods; and (v) adoption of new construction equipment and others (Gambatese and Hallowell, 2011). In fact, in a position paper on public e-procurement as socio-technical change, Williams and Hardy (2005) specifically identified the adoption of technologies and applications from the electronics and information systems industries into construction as technological product innovation. As they explained, this is because e-procurement involves the use of new technologies to support the execution of construction procurement activities, which often results to socio-technical changes in organizations. It was perhaps on this premise that Gambatese and Hallowell (2011:507) noted that innovation in computer aided design; automation and simulation are on the increase in the construction sector.

## **2.4. Patterns of Technological Innovation**

In a paper that sought to develop a heuristic framework for analysing and explaining different patterns of technological-based innovations, Dolata (2009) identified three basic ways in which technological product innovation can be adopted by organizations. The first is the development and use of new technologies, which are not only used in a sector-specific way but can also be developed mainly within the sector. This may include innovative activities such as developing or using new products; and developing or using new or substantially improved products. The second is the adoption of a new technology developed outside a sector in a way that the technology makes a significant impact on the operation of organizations without changing its functional and constitutional attributes. A typical example is the gradual replacement of Value Added Network (VAN)-supported electronic data interchange (EDI systems) that coordinated companies internal and external procurement functions in the automobile industry by means of Internet-based technologies. The third pattern is the adoption of technologies from outside a sector which may further be developed into new basic technologies and become a major stimulus for far-reaching process of sectoral restructuring. Example of this is the digitization, data compression and Internet, that has come with far-reaching implications for the different industrial sectors such as the entertainment, manufacturing and construction.

In the construction sector, evidence in the literature also indicates that technological innovations follow four generic patterns, namely (i) the application of already known technologies in new areas (ii) the conjunction of various known technologies (iii) the increase in magnitude of the known technology with even more complex configurations; and (iv) dramatic cost reduction of the known technology as explained by Nam and Tatum (1992) in their paper entitled *“Strategies for Technology Push: Lessons from Construction”*. They further explained that although many innovations in construction result from a combination of these four patterns, most common technological innovations in this industry result from the clever adoption and modification of existing technologies used in other areas and the innovative improvement of earlier technologies used in previous projects. This obviously suggests that the different patterns of technical innovation in the construction sector are based on the attributes of the technologies in terms of the degree of flexibility in their applications, and the ease at which they can be manipulated or modified to suit the needs of users.

## 2.5. Factors influencing the Patterns of Technological innovation in construction

Nam and Tatum (1992) also noted that there has been persisted argument in the literature on the factors that influence the patterns of innovation. Hence, Hardie and Newell (2011) opined that in order to discern any pattern of technical innovation in construction, there was a need to identify the potential influencing factors. From the existing literature, two approaches to examining the factors that influence the patterns of technological innovation in construction can be identified. The first is from the lens of the different theoretical frameworks used in studying innovation diffusion and adoption; and the second is from conceptual and empirically based literature.

In the first approach, the technology, organization and environment (TOE) framework and influential theories are very useful tools. For instance, the TOE framework developed in 1990 by Tornatzky and Fleischer identifies technological, organizational and environmental contexts as playing dominant roles in influencing the patterns of technological innovations by organizations (see Oliveira and Martins, 2011). In a theoretical paper on effective benchmarking of innovation adoptions, Azadegun and Teich (2010) explained that technological context deals with features of the existing technologies; and include the current practices, equipment and technologies within and outside the organization. Talking about features of the existing technologies, in his seminal work, diffusion of innovations, Rogers (1995) described the perceived attributes of an innovation (technology) as the key influencing factors determining its diffusion and adoption. He identified the perceived attributes of an innovation to include relative advantage (i.e. perceived cost and benefits); compatibility (the degree to which an innovation is perceived to match the needs, capacity, values, and surrounding social norms of potential adopters); complexity (the degree to which an innovation is perceived as difficult to understand and use (p. 242); trialability (degree to which an innovation may be experimented with on a limited basis” and observability (degree to which the results of an innovation are visible to others (p.243-244). Among these, evidence from diffusion studies however shows that compatibility, relative advantage, and complexity are the three attributes most consistently connected to innovation adoption in general.

Further, Azadegun and Teich (2010) explained that the organizational context is concerned with organizational characteristics such as management structure, organizational size, scope of activities and resource base. In the same vein, Oliveira and Martins (2011) made it clear that the environmental context represents the surrounding environment in which innovation adopters exist and carry out their business activities. This includes the industry characteristics, clients, competitors, government policies, regulatory frameworks and other institutions. Based on the above, a multiple case studies on adoption of 20 new IT by construction contractors in the US by Mitropoulos and Tatum (2000) reveals that the crave for competitive advantage, technological opportunity (technology push force), external requirements from clients, regulators and pressure from other industries were the key factors that accounted for the patterns of IT innovations in construction. This finding was corroborated by Hardie and Newell (2011) who also found that organizational resources (e.g. motivation, finance, time, skill level insurance/risk), clients’ and end-users’ desires (procurement system, client characteristics), project conditions (e.g. supply chain relationships, desire to solve persistent problems), industry networks (e.g. professional and industry associations, research organizations and universities) and regulatory environment (e.g. performance standards, government regulations, industry standards) were among the factors that influenced the technical innovations among construction SMEs in Australia.

In addition, the internal influential model posits that the patterns of innovation are influenced only by internal factors related to what is called “*imitation behaviour*” within the social system. In a study on diffusion of safety innovations in the construction industry, Esmaili and Hallowell (2012:957) made it clear that imitation behaviour is said to exist when innovations occur basically through contacts between members of a social network. What this simply means is that interactions between organizations within the same industrial sector contribute to the patterns of technological innovation emerging from it. In contrast, the external influence model explains that the patterns of innovation are influenced by factors existing outside the adopting organizations (Esmaili and Hallowell, 2012). Such factors may include but not limited to government policies and regulations, mass media, advertisement, consumer demand, and consulting services as Teng *et al.* (2002) explained in their study on information technology innovations- diffusion patterns and its relationship to innovation characteristics. Again, this appears to be consistent with the finding Mitropoulos and Tatum (2000) and Hardie and Newell (2011) as previously highlighted. It also goes to suggest that other industrial sectors who are early adopters of e-procurement and public policy can have influence on the patterns of technological innovation in the construction sector.

There is also the Bass (mixed) model developed in 1969 by Frank Bass. This model posits that the patterns of innovation are influenced by both internal factors among members of a social system and by external factors (see Kale and Ardit, 2005; 2006). In this case, the Bass model appears to be consistent with the TOE framework as it relates to the possible factors influencing the patterns of innovation in the different industries. It can be inferred from the foregoing that a multiplicity of factors can influence the patterns of technological innovation in construction.

### 3. RESEARCH METHOD

This study is part of an on-going research project designed to investigate the use of e-procurement in the South African construction industry. As noted earlier, the research goal is to identify and analyse the patterns of technological innovations in the use of e-procurement in construction through a systematic review of published research literature. In order to achieve this goal and address the research questions of the study, a comprehensive research approach was needed. A systematic review of research literature was considered to be appropriate and was consequently adopted (similar approach was used by Ibrahim, 2013). The choice of this approach was also based on the research questions of the study and the fact that systematic review has been identified as an important scientific research tool that can be used to appraise, summarise, and communicate the results and implications of large quantity of research publications on a subject as Green (2005) explained in a paper on systematic reviews and meta-analysis. In addition, in a paper on integrative review, Whitemore and Gray (2005) pointed out that systematic review combines the advantage of bringing together evidence from multiple empirical studies regarding a specific issue to inform research and practice.

In carrying out this research, the guidance on systematic review was elicited from published works (including Khnan *et al.*, 2003 and Green, 2005). These authors specifically noted that systematic review is a five-step process, including (i) framing of research questions (ii) identifying relevant studies (iii) assessing the quality of studies (iv) summarising the evidence; and (v) interpreting the findings. Following these guidelines, extensive searches and review of peer-reviewed journal articles and conference papers were conducted between July 2013 and March 2014 using Scopus online database as the main source of literature. Scopus was chosen due to its advantages in covering a wider range of journals, and special features in keyword searching and citation analysis as explained by Falagas *et al.* (2008) in a comparative study of the strengths and weaknesses of PubMed, Scopus, Web of Science, and Google Scholar.

In the searches, a combination of the following words was used: *e-commerce Technologies in Construction; e-procurement technologies; and Information Technologies in Construction Procurement*, with published all year to present selected. Both journal articles and conference papers were included in the searches because it is believed that academics and practitioners rely on journals and conference proceedings in the dissemination of research findings and acquisition of information on recent and emerging developments in their different areas of interest. In addition, the choice of the search criteria was based on the need to capture relevant and current evidence-based literature on the subject. In all, 316 items comprising 22 articles for *e-Commerce Technologies in Construction*, 268 articles for *e-Procurement Technologies* and 26 for *Information Technologies in Construction Procurement* were obtained from the searches.

The initial screening of the articles involved the review of both the titles and abstracts of all the 316 articles by the two authors. This was done in order to identify those for which full texts should be sought and most likely to be eligible for inclusion. A total of 236 articles were considered potentially relevant to the subject under investigation. The selection of articles reviewed was based on evaluation criteria developed by the two authors. The first was the degree of relevance of the article to the research questions of the study. Based on this, the articles were rated “1” for low relevance, “2” for medium relevance and “3” for high relevance. Two parameters were used to assess the degree of relevance of the articles included in the reviewed. First was the methodological adequacy of the studies reported in the articles (i.e. appropriate study design); and emphasis was given to case studies, surveys and reviews. The second was the key results of the studies. Articles reporting findings relevant to the research questions were included. Hence, the review covers articles rated “3” that is high relevant by the authors. The second criterion used in evaluating articles included in the review was the date of publication. This was to ensure that information on both the historical development and practical applications of web-based technologies used in construction procurement were captured. However, the majority of articles included in the review are not more than ten years old. Again, this was a

deliberate attempt to ensure that the most recent developments in the use of e-procurement in construction as reported in research literature were captured in the review.

Each selected article was carefully reviewed; and since the data were mainly qualitative in nature, context analysis was used in the data analysis. This involved identification of the different e-procurement technologies and tools used in construction procurement; the trends in their development and applications as reported in the articles reviewed. Given the goal of this review, meta-analysis was neither appropriate nor feasible for data synthesis. This was particularly so for two reasons. First is that the research design and questions of the multiple studies reviewed are not similar or identical to the current study. As Whitmore *et al* (2005:547) explained, systematic reviews often include the statistical methods of meta-analysis if the research design and hypotheses of primary studies are very similar or identical to the current study. The second reason is that evidence from the different studies reviewed could not be combined using statistical methods; meaning that there was no need for meta-analysis. Consequently, the current review did not involve any form of meta-analysis.

#### **4.0. REVIEW FINDINGS**

In this section, we present findings of the review. Starting with the different e-procurement technologies and tools used in construction procurement, followed by trends in their development and applications in construction procurement. The last is the presentation of the patterns of technological innovation in use of these e-procurement technologies in construction as identified in published literature.

##### **4.1. E-Procurement Technologies Used in Construction Procurement**

In order to successfully analyze the patterns of technological innovations in the use of e-procurement in construction, it was important to first of all identify the different e-procurement technologies and applications available to support the execution of the six basic construction procurement activities considered in this study. According to Min and Galle (1999) and Gunasekaran and Ngai (2008), e-procurement or e-commerce technologies are the different packages, tools and/or applications that facilitate electronic communication, information exchange and transactions related to the acquisition of goods and services over the Internet. The different e-procurement technologies and applications available to support the execution of construction procurement activities as published in literature and mapped with the six basic construction procurement activities identified in ISO 10845 (2010) are summarized in Table 2.

From Table 2, it seems evident that the e-procurement technologies and applications available to support execution of the six basic construction procurement activities are in the forms of web-enabled/ supported software packages for the performance of specific procurement tasks (e.g. BIM used in the production of construction documents); network technologies for the exchange of data and information among project participants (e.g. EDI, e-mail, and wireless technologies); web-supported transactional and collaboration applications (e.g. e-marketplaces); web-supported data collection and handling technologies (e.g. GIS,GPS,RFID, Sensor networks); and interactive, integrative and collaboration technologies (e.g. Web 2.0, BIM, ERP, Cloud computing, web-based project management and customized e-procurement software applications). Studies (see for examples Gunasekaran and Ngai, 2008; Underwood and Isikdag, 2011; Grilo and Jardim-Goncalves 2011; Ren *et al.*, 2013) have shown that the common feature of these technologies is that they tend to promote real time interactions and exchange of information and data in the entire construction procurement lifecycle.

**Table 2: e- Procurement Technologies and Applications identified in the Literature**

Construction Procurement Activities	Technologies and Applications	References
<i>Establishment of what is to be procured</i>	Software Applications for selecting professional consultants	Leipold et al (2004)
	Web- supported Computer Aided Design (CAD) based Software Applications e.g. Building Information Modeling (BIM) Technology	Zuo and Seo (2006); Williams et al (2007); Grilo and Jardim-Gonclaves (2011); Ren et al (2012), Vaid (2013); Bynum et al (2013)
	Virtual Reality Technology	Underwood and Isikdag (2011)
<i>Establishment of Procurement Strategies</i>	Web-based Enterprise Resource Planning (ERP)	Gunasekaran and Ngai (2008); Neupan <i>et al</i> (2012)
<i>Soliciting for Tenders</i>	Web-based Project Portals and Web sites	Zuo and Seo (2006); Wong (2007); Tindsley and Stephenson (2008); Heddad, (2013)
	Web.2.0 technology	Klinc et al. (2008); Underwood and Isikdag (2011)
	Cloud Technology	Fathi et al (2012); Grilo and Jardim-Goncalves (2013)
<i>Evaluation of Tenders</i>	Videoconference	Williams et al (2007); Garrido et al (2008)
	Cloud Technology	Fathi et al (2012)
<i>Award of Contract</i>	E-Mail Technology	Zuo and Seo (2006); Garrido et al (2008); Williams et al (2007);
	Wireless Technology	Williams et al (2007);El Ghazali et al.(2012)
<i>Administrating contracts to ensure that they comply with requirements</i>	Radio Frequency Identification (RFID) Technology	Williams et al (2007);El Ghazali et al.(2012); Kim et al.(2013)
	Bar code technology	El-Omari and Moselhi (2011)Williams et al (2007); Ghazali et al.(2012)
	BIM Technology	Grilo and Jardim-Gonclaves (2011); Ren et al (2012), Vaid (2013); Bynum et al (2013); Latiffi <i>et al.</i> , (2013);
	Electronic Data Interchange (EDI)	Gibson and Bell (1990) ;Gunasekaran and Ngai (2008);
	e-Marketplaces	Li et al (2003); Zuo and Seo (2006); Alarcon et al (2009); Grilo and Jardim-Goncalves (2013)
	Wireless Technology e.g. Wi-Fi networks, WLAN, long-haul wireless; cellular modems, satellites communications, page systems	Bowden <i>et al</i> (2006);Williams et al (2007);El Ghazali et al.(2012); Kim et al.(2013)
	Web-Supported Geographic information System (GIS)	Li et al (2003); Williams <i>et al</i> (2007);
	Geographic Positioning System (GPS)	Williams <i>et al</i> (2007); Yassine <i>et al</i> (2012); Nawari (2013); Kim <i>et al.</i> (2013)
	Customized We-based Procurement and Project management software Packages	Zuo and Seo (2006); Farzin and Nezhad(2010)
	Web-Supported Sensor Networks	Underwood and Isikdag (2011)

## 4.2. Trends in the development and use of e-procurement technologies in construction (1970-2013)

The paper on the history of the internet by Campbell-Kelly *et al.* (2013) indicates that research in internet technology began in the 1950s. However, Gibson and Bell (1990) revealed that the migration of construction procurement activities to the internet began in the 70s when CAD system was first used in the production of construction drawings. It was for this reason that 1970 was adopted as the reference year in this review.

The trends in the development of e-procurement technologies in the last four decades is summarised in Table 3. From Table 3 and the account by Hjelt and Bjork (2006) on experiences of electronic data management (EDM) usage in construction projects four phases in the evolution and adoption of e-procurement technologies in construction can be identified. The first phase began in the 1970s and featured the adoption VAN-supported EDI, fax and telephones (see Gibson and Bell, 1990; Gunasekaran and Ngai, 2008) and standalone tools such 2D-CAD system for supporting the execution of specific construction procurement tasks (see also Vaid, 2013; Bynum *et al.*, 2013). That phase was followed by the introduction of 3D-CAD system, and computer supported communication networks for the exchange of procurement information and data. This began in the early 1980s when personal computers were introduced and communication network systems were gaining wider acceptability as Hjelt and Bjork (2006) further explained. Wong (2007) also pointed out that this was the era for the adoption intranet-supported project portals buy construction firms in the UK.

**Table 3: Trends in the development and use of e-Procurement Technologies in Construction**

Construction Procurement Activities	1970-1980 Technologies & Applications	1981-1990 Technologies & Applications	1991-2000 Technologies & Applications	2001 -2013 Technologies & Applications
<b>Establishment of what is to be procured</b>	2D-CAD System	3D –CAD tools (e.g ArchiCAD; 3DMax; Form-Z) and quantity take-off (CATO); Intranet; Fax;	E-mail; web-enabled 3D-CAD tools (solid modelling; Revit, Maya) Quantity Takeoff software applications e.g. MasterBill (MB3+) QS Elite WinQS ; Construction E-Marketplaces	Web-based software applications; Wireless and BIM-enabled technology
<b>Establishment of procurement Strategy</b>	Material Requirement planning (MRP)	MRP	Web-based Enterprise Resource Planning (ERP)	Web-based Project Management Software Packages; Extended ERP
<b>Soliciting for Tender offers</b>	Telephone, Fax, Value Added network (VAN) –supported EDI	Intranet-supported project portals; Compact Disk(CD)	Web-based Project portals E-mail technology; Web.1.0; Internet Supported EDI	Web 2.0 tools, social network working (e.g. face book, blog); wireless technology
<b>Evaluation of Tender Offers Received</b>	-	-	-	Web-based Project Management Software packages; Cloud computing; Videoconferencing
<b>Award of Contract</b>	Fax, Telegram	Fax	E-Mail technology; Web 1.0	Web 2.0 tools; wireless technology
<b>Administration of Contract and Confirmation of Compliance with Requirements</b>	Value Added network (VAN) –supported EDI	VAN-supported EDI Fax	e-marketplace; e-mails; Web browsers; Internet supported EDI; Electronic payment ; teleconferencing	GIS; RFID; Wireless, technology, Web-based Project Management Software; BIM; Videoconference

The next phase began in the mid-1990s with the commercialization of the Internet and introduction of the World Wide Web (WWW) (Campbell-Kelly *et al.* 2013). This phase marked a watershed in the movement of construction procurement to the Internet. As explained in the United Nation’s e-procurement Practitioner’s Handbook (UN, 2006)

this period was remarkable for opening the door of opportunities for the adoption of web-based communication and interactive tools and technologies such as e-mail websites/portals, procurement software, e-marketplaces, electronic payment platforms and other applications. Consequently, applications such as e-catalogues (for providing information on materials and products), e-ordering (for requisition, order approval, order receipt and payment for goods and services), e-sourcing (for identification of new suppliers of specific goods or services needed by an organization), e-tendering (used to receive and evaluate bids) and e-informing (for communication and information exchange) became part of the procurement process (see also Tindsley and Stephenson, 2008; Bausa *et al.*, 2013).

The period between 2001 and 2013 has seen the development and adoption of technologies that seek to integrate all construction procurement activities and the different applications used in supporting their execution into one unified and cohesive work process and system. Among the key developments are the use of Web 2.0 technologies, BIM, cloud computing, virtual technology and other integrative and collaboration technologies. Notably, these technologies seek to promote real-time interaction and exchange of information and data among project participants regardless of time and geographical differences as explained by Ibrahim (2013) in a review on the evidence of digital collaboration technologies in major building and infrastructure projects. It is obvious from the preceding paragraphs that in the past four decades or so e-procurement technologies have evolved from standalone tools to web-based integration and collaboration applications. The next paragraphs are devoted to the identification of the patterns of technological innovation in the use of e-procurement in construction.

### **4.3. Patterns of Technological Innovation in the use of e-procurement in construction**

By comparing the data in Table 2 and Table 3, it was possible to identify the patterns of technological innovation in the use of e-procurement in construction in the period under review. From Table 2 it seems evident that a number of e-procurement technologies and applications (e.g. CAD systems, RFID, GIS; e-market places, EDI, ERP, barcode etc.) used in construction procurement today have been successfully used in other industries such as manufacturing, transportation, and retailing before they were integrated into construction procurement. In fact, in a paper titled “Innovation in Construction: a Sociology of Technology Approach”, Harty (2005) argued that the unique nature of construction makes it mandatory that only innovative thinking can help in identifying and adopting technologies that are relevant to it from other industries. It is in line with Harty’s argument, that the adoption of web-based technologies and applications that have been successfully used in other industrial sectors into construction procurement is seen in this review as a typical example of the patterns of technological innovation in e-procurement use in construction.

Also from the data in Table 2, it can be seen that web-based/supported technologies are being used in various ways to support the execution of a wide range of construction procurement activities today. For instance, Campbell-Kelly and Garcia-Swartz’s (2013) account helps to explain that the internet was originally developed in the 1960s to provide data communication infrastructure and information services to replace that provided by telephone and telegraph. However, things have changed today as we find from the different case studies reviewed that internet-based services such as the WWW and e-mail are innovatively being used to support the execution of construction procurement activities. For example, the web has been used as a tool for bringing together geographically dispersed construction procurement participants; and for exchanging of project information (e.g. project requirements, construction drawings, bill of quantities) among them on real time basis; and thus eliminating the barriers usually posed by geographical location and time differences. In addition, the web has also been used as a platform for conducting tendering (e.g. cloud technology), online procurement of materials and equipment and services (construction e-marketplaces), communication and interaction (e-mail, web 2.0); and collaborations (e.g. virtual design and construction, video conferencing, SharePoint etc). Indeed, as shown in Table 2 a wide range of web-supported procurement activities not limited to e-notification/informing/announcement, e-submission, e-tendering, e-evaluation, e-award and e-execution have now become part of the construction procurement process due to the advancements in the Internet technology.

Also there is innovative use of web-supported BIM technology in construction procurement activities as explained by Azhar (2011) in a paper on building information modelling (BIM): trend, benefits, risks and challenges for the AEC industry. The history of CAD systems by Weisberg (2008) makes it clear that CAD systems came into construction as a stand-alone tool for performing architectural and engineering design tasks from the manufacturing industry in the 1970s. Since then, the 2D-CAD systems have been improved, modified and transformed into 3D-

CAD system popularly known today as BIM technology (see Underwood and Isikdag, 2011; Ren *et al.*, 2012). Consequently, the improved capabilities of BIM have made it possible for this technology to be used to perform construction procurement-related functions such as produce construction drawings carry out task likes cost estimating, scheduling, quantity take-offs ( Grilo and Jardim-Goncalves, 2011; Latiffi *et al.*, 2013). In fact, the integration of BIM with the web has given rise to innovative use of BIM to support the performance of construction procurement functions such as administration of contracts, monitoring of progress of work and integration of the activities and works of professional consultants (e.g. architects, engineers, project managers, quantity surveyors), contractors and suppliers in the construction supply chain management as Latiffi *et al.* (2013) explained in a study on building information application in Malaysian construction industry. Similarly, several other already known technologies and tools, including web-supported RFID are also being innovatively used in areas of construction supply chain management such as logistics, tracking and tracing of construction materials, quality control and inventory management among others (see El Ghazali et al 2102). The above paragraphs provide support to the improvement and use of already-known technologies and tools in new areas of construction procurement; and thus making this another pattern of technical innovation in the use of e-procurement in construction.

Further, although a closer examination of Table 2 will reveal that e-mail and network technologies appear to be generic applications with the potentials of being used across all the six basic construction procurement activities identified in ISO 1048 (2010), this review and evidence from Ibrahim (2013) indicate that there is yet no single web-based technology or application with the capabilities of supporting the execution of all the six basic construction procurement activities. This means that despite the advances in web technology and software engineering, it has not been possible to integrate all the web-based applications into one system that procurers can use to support the execution of all the activities in the entire construction procurement lifecycle. Consequently, the combination and use of different kinds of already existing applications into technologies of complex configurations have become the norm in construction procurement. A typical example of this is seen in the conjunction use of BIM with web-supported project management software applications and e-marketplaces, which enables project participants to exchange tender information and documents; and facilitates the buying and selling of construction materials and equipment (transactional activities) over the internet as explained by Grilo and Jardim-Gonclaves (2011). In this regard, the conjunction use of the different kinds of know web-based applications to support the execution of construction procurement activities is also seen as another pattern of technological innovation in the use of e-procurement in construction.

## 5. DISCUSSION

Arising from findings of this review as presented in the previous section are three key issues brought forward for discussion in this section. The first issue is related to the patterns of technological innovation identified from the review of literature. The second deals with how the patterns of innovation identified relate to the construction procurement process. The third and last issue is the factors that influence the patterns of innovation identified in the review.

First, from the review, three patterns of technological innovation were identified. These are the adoption of web-based technologies and applications from other sectors into construction procurement; improvement and use of already-known technologies; and conjunction use of different kinds of existing technologies in construction procurement. Generally speaking, this finding appears to be consistent with the first three patterns of technical innovation in construction identified in the study by Nam and Tatum (1992) as previously highlighted. Analysing this finding further, the identification of these patterns of innovation is strengthened by the following evidence in the literature. For the first pattern identified, evidence in the literature shows that the CAD-systems were initially developed and used in the automotive, defence and aerospace industries (Weisberg, 2008), the EDI has its origin in the rail industry in the late 1960s and was later adopted by the automotive, banking, retail and textile industries (Gibson and Bell, 1990), while the origin of barcode and RFID technologies is linked to the retailing and manufacturing sectors (Moselhi and El-Omari, 2007; El Ghazali *et al.*, 2012). Similarly, Alarcon *et al.* (2009) indicated that e-marketplaces were originally designed and used in the manufacturing and retailing businesses, while according to Li *et al* (2003), GIS was predominantly used in urban planning, defence, transportation and other industries. From the above, it seems logical to argue that the use of the aforementioned technologies has been well

established within the different industries before they were identified and found to be useful in the construction procurement. This goes to suggest that these technologies were drafted into construction procurement based on their successful applications in the different industrial sectors. Therefore, going by the evidence in works cited above and the submissions by Harty (2005) and Dolata (2009) as previously discussed, this represents a pattern of technical product innovation in construction.

The reason for this pattern of innovation is not farfetched. The construction sector being a late adopter of e-procurement compared with manufacturing and retailing sectors as previously highlighted has to initially embrace e-procurement by identifying IT applications already used in other industrial sectors and adopting same to suit its need. Indeed, Brewer *et al.* (2013:24), explained that successive industry reviews, including the Egan report of 1998 have suggested the desirability of the construction sector adopting production management strategies such as strategic alliances between trading partners, lean construction, and supply chain integration that have previously proved successful in the manufacturing sector. Following from this, there seems to be a consensus in the literature that the use of web-based applications to support the execution of construction procurement activities is a move towards achieving construction supply chain integration (see Mohamed, 2003; Jaaafar *et al.*, 2007; Vitkauskaitė and Gatautis, 2008). This appears to be in line with one of the recommendations of the Egan report. Hence, several authors (including Zou and Seo 2005; Gambatese and Hallowell, 2011; Usman and Said, 2012; El Ghazali *et al.*, 2012; Brewer *et al.*, 2013) have noted that the adoption of electronic communication systems such as web-based applications into the construction sector is an aspect of technological innovation. This line of thinking is consistent with the view by Kajewski and Weippert (2004) in their study on e-tendering: benefits, challenges and recommendations for practice in which they made it clear that in the adoption of e-procurement, the construction sector was merely following the trends in other industries considered as early adopters.

The second pattern of innovation identified may be explained from the perspective of the need for continuous improvement of the capabilities of the existing technologies to meet the changing needs of the construction industry. This line of thinking is supported by Anumba's (1998) view that two of the reasons for the poor uptake ICT mediated innovations by the construction industry was linked to a mismatch between innovations and industry needs and poor uptake by software developers of new ideas developed in the sector as explained in his paper on industry uptake of construction innovations. What this means is that the improvement and use of the existing e-procurement technologies in new areas is as a result of the limitations of the existing ones in meeting the current demands of the construction procurement processes. In essence, this aspect of technological innovation is borne out of the need to significantly improve the performance of existing products or services for the benefit of the consumer as explained by the OECD, (2005:48-49) as previously highlighted. It involves the adoption, modification and improvement of the existing technologies and using them innovatively in new areas (Nam and Tatum, 1992). A typical example of this is the modification and improvement 2D-CAD systems to BIM with complex configuration resulting in the use of BIM in several construction procurement activities beyond the capabilities of 2D-CAD system (see Azhar, 2011; Jardim-Goncalves, 2011; Latiffi *et al.*, 2013). Another example is the improvement of Web 1.0 to Web.20 technology resulting in a move from internet-enabled delivered content to participation-based internet platforms (e.g. drop box, wikis, blogs, project portals, Skype, SharePoint etc.) that promote both information sharing and collaboration among project participants through as explained by Klinc *et al.*(2008) and Underwood and Isikdag (2011). Arguably, the developments of BIM from the 2D-CAD system and Web 1.0 from Web 2.0 have initiated some kinds of restructuring of construction procurement process with far-reaching implications for business activities in the entire construction sector. Again this pattern appears to be consistent with the third pattern of technological innovation identified in previous studies (see Nam and Tatum,1992 and Dolata, 2009).

For the third pattern of innovation, copious evidence in the literature also indicates that there is not yet any single e-procurement technology with the capabilities of either supporting the execution of all tasks in the six basic construction procurement activities or integrating all the applications used into one single system (see Ibrahim, 2013; Grilo and Jardim-Goncalves, 2013). One of the consequences of this is the conjunction use of the different kinds of already existing technologies and applications. This finding provides support to the second pattern of technical innovation as identified by Nam and Tatum (1992). Table 2 shows that this pattern is very common at the tendering and contract administration stages of construction procurement, where there is conjunction use of BIM, cloud technology, communication networks and construction e-marketplaces. Although this third pattern of technical innovation seeks to achieve full integration of the all the activities and collaboration among the diversified groups of

participants across the entire construction procurement lifecycle, Ibrahim (2013) and Grilo and Jardim-Gonclaves (2013) noted that this was yet to be achieved due to the perennial problem of interoperability of the different e-procurement systems and applications.

Second, on how the patterns of technological innovation identified in the review relate to the nature of construction procurement process as outline in ISO 10845 (2010), it is noted that across the entire construction procurement lifecycle, the three patterns of innovation manifest at varying degrees depending on the procurement activity. For instance, it is evident from Table 2 that at the contract administration stage, the use of a number of technologies from other industries (e.g GIS; GPS; e-marketplaces); application of the existing technologies in new areas ( for example the use of BIM in tracking of the progress of work in real time) as explained by Latiffi *et al.*, (2013); and a combination of different kinds of technologies for the purpose of communication, collaboration and integration (e.g. integration of web-supported BIM and project management software applications and e-mail technologies) can easily be seen. Indeed, from the data in Table 2, it seems evident that the patterns of innovation identified in this review manifest more at contract administration and tendering stages than at the establishment of what is to be procured and procurement strategy stages. This goes to suggest that in practice, there is more innovative use of web-based technologies in conducting tendering and administration of contracts than in the other aspects of construction procurement activities. This is understandable going by the number of tasks and functions involved at tendering and contract administration stages; and the fact that most of the tasks require the exchange of project information, interactions and collaborations among different firms. This is in contrast to the tasks involved in the establishment of what is to be procured and procurement strategy both of which involve activities and functions that mainly involve intra-firm communication, interactions, collaboration and exchange of project data and information.

Third, on the factors that influence the patterns of technological innovation identified in this study, evidence from this review seems to support the view that attributes of the e-procurement technologies such as their relative advantage over paper-based tools, compatibility and complexity as proposed by Rogers (1995) are among the factors that influence the pattern of uptake of e-procurement in construction. This is because one of the reasons why firms adopt e-procurement is the perceived advantage it has over paper-based methods in costs and time savings, and in enhancing organizational productivity and level of competitiveness as previous studies have reported (see for examples Aranda-Mena, 2004; Bowden *et al.*, 2006; Alarcon *et al.*, 2009; Eadie *et al.*, 2011; Gambatese and Hallowell, 2011; Brewer *et al.*, 2013). It can also be explained that the degree of compatibility of e-procurement process with the existing workflow as well as the ease at which e-procurement technologies can be used in firms may also help to explain the patterns of innovation identified in the review. In addition, the project-based nature of construction industry and fragmented nature of construction procurement activities as previously discussed can also be considered as another key factor. Further, the environment in which AEC firms operates (e.g. the availability of e-procurement technologies, influence of clients and early adopters of e-procurement in other industries) is yet another factor with significant influence on the pattern of innovation identified in this review. The above assertions are based on the following arguments. First is that firms can only make innovative use of technologies that are available; meaning that the availability of and accessibility to the different e-procurement technologies (i.e. technology push factor) account for the different ways of their uptake by AEC firms. The second is that in the AEC industry, clients are usually the procurers of goods, services and works; hence, they play a significant role in the choice of and the extent of use of e-procurement technologies in their procurement endeavours. The last is that the lessons from other industries outside the construction sectors considered as early adopters of e-procurement cannot be ruled out as a factor influencing the ways firms are adopting e-procurement in construction today. In all, it seems evident that the theories, including, Rogers' innovation diffusion theory, TOE framework and influential models discussed in this review can in one way or the other be applied to explain the patterns of technological innovation in the use of e-procurement in construction.

## 6. CONCLUSIONS

This systematic review of evidence-based literature has identified and analysed the patterns of technological innovation in the use of e-procurement in construction. Three patterns of technological innovation were identified and linked to the nature of construction procurement process. The factors, which influenced the patterns of innovations, were also identified. Based on finding of the review, the following conclusions can be made.

First is that the three patterns of technological product innovation in the use of e-procurement in construction identified in this review clearly show the regular ways e-procurement uptake occurs among procurers of construction goods, services and work globally. This indicates that although within current practice there are different levels of uptake of e-procurement, the ultimate goal of the different patterns of innovation identified is to achieve a full integration of the six procurement activities, participants and the different technologies used into a unified system. The implication of this is that the industry is gradually moving towards fully computer-based virtual procurement method characterised by a high degree of integration and collaboration across the entire construction procurement lifecycle. Therefore, future research is needed on ways to achieving this.

The second conclusion is that the patterns of innovation identified are linked to the nature of the construction procurement activities. Nevertheless, it does appear that the innovative use of e-procurement technologies manifest more at tendering and administration of contract stages than in the other stages of construction procurement process. This implies that there are more innovative uses of web-based technologies and applications in conducting tendering and administering contracts than in establishing what is to be procured and procurement strategy as well as the award of contract.

The third and last conclusion is that the patterns of technological innovation emerging from the use of e-procurement in construction are mainly influenced by the availability of e-procurement technologies and their attributes; lessons from the experiences of early adopters of e-procurement in other industries; nature of construction procurement process as well as the influence of construction clients. The implication of this is that these are among the key factors that can be manipulated to bring a change in the uptake of e-procurement in the construction industry globally.

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