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Adoption of Big Data analytics in construction: development of a conceptual model

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Abstract

Purpose – Big Data (BD) is being increasingly used in a variety of industries including construction. Yet, little research exists that has examined the factors which drive BD adoption in construction. The purpose of this paper is to address this gap in knowledge.

Design/methodology/approach – Data collected from literature (55 articles) were analyzed using content analysis techniques. Taking a two-pronged approach, first study presents a systematic perspective of literature on BD in construction. Then underpinned by technology–organization–environment theory and supplemented by literature, a conceptual model of five antecedent factors of BD adoption for use in construction is proposed.

Findings – The results show that BD adoption in construction is driven by a number of factors: first, technological: augmented BD–BIM integration and BD relative advantage; second, organizational: improved design and execution efficiencies, and improved project management capabilities; and third, environmental: augmented availability of BD-related technology for construction. Hypothetical relationships involving these factors are then developed and presented through a new model of BD adoption in construction.

Research limitations/implications – The study proposes a number of adoption factors and then builds a new conceptual model advancing theories on technologies adoption in construction.

Practical implications – Findings will help managers (e.g. chief information officers, IT/IS managers, business and senior managers) to understand the factors that drive adoption of BD in construction and plan their own BD adoption. Results will help policy makers in developing policy guidelines to create sustainable environment for the adoption of BD for enhanced economic, social and environmental benefits.

Originality/value – This paper develops a new model of BD adoption in construction and proposes some new factors of adoption process.

Keywords Sustainability, Technological innovation, BIM, Project management, Asset management, Data analysis

Paper type Research paper

1. Introduction

Big Data (BD) is changing the operational dynamics of businesses by facilitating innovations in products and services; and improvements in productivity, decision making and organizational capabilities. Construction industry is no exception to these changes. In fact, given that the construction industry is plagued by severe inefficiency problems which translate into low productivity, costing global economy an estimated $1.6 trillion a year (Barbosa *et al.*, 2017); adopting a technology like BD seems to be unavoidable.

More so, the above-mentioned problems exclude loss of human lives due to safety and hazardous nature of work. Design optimization, lack of digitalization, project management, workers safety, green-house gas contributions and economization of construction work are some of the other ongoing challenges faced by the construction industry (Li, Xu and Zhang, 2017; Li, Wu, Shen, Wang and Teng, 2017). Resultantly, recent efforts have been directed at achieving efficiencies and reducing impact of construction industry's environmental footprint (Barbosa *et al.*, 2017). Using latest technologies such as BD, data analytics and

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building information modeling (BIM) seems to be a logical way forward to ease some of the pressures faced by the industry (Barbosa *et al.*, 2017).

Ahmed *et al.* (2017) concur and argue that the analytics of BD collected at various stages in the construction cycle will facilitate gaining new insights, thus improving predictions and decision making (e.g. improved design decision making). The common approach used in different construction segments is that alternative designs are generated and imposed during the execution phase. Such practices lead to delays, material wastage and are considered impractical. Inappropriate decisions at the design stage result in an approximately 33 percent of construction waste (Bilal *et al.*, 2015). The use of BD can overcome or minimize such waste and enhance resource efficiencies.

BD of past projects can be mined using appropriate analytics tools to perform text analysis, link analysis and dimensional analysis; which will help achieve BIM efficiencies. Data mining of BD can help in identifying the triggers to safety problems and preventing occupational injuries to workers (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016).

With the increased use of BIM technologies for construction design and execution processes, integrating BD–BIM will yield many benefits such as, improved decision making; enhanced modeling and design efficiencies; identifying the causes of construction failures; detecting damages to the building structures; monitoring the actions of heavy machinery and workers (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016; Motawa, 2017). Using BD for gaining insights on stakeholders' engagement and project planning can result in productive and efficient management of projects (Ekambaram *et al.*, 2018). Marr (2016) highlights one example where a new BD-driven BIM system helped in achieving the savings of \$11m in costs and shortened project completion time by 12 weeks.

The above-discussed advantages and savings seem to be just the tip of the iceberg of the value that the adoption and use of BD can create in improving construction performance and stimulating economic activities.

Despite the potential benefits, little work has been done to examine the DB adoption in construction. The existing work (e.g. Bilal *et al.*, 2015; Raguseo, 2018) offer generic insights. While studies (e.g. Amasyali and El-Gohary, 2018; Bibri, 2018a, b; Chen and Lu, 2017; Ekambaram *et al.*, 2018; Koseleva and Ropaite, 2017; Mawed and Al-Hajj, 2017) have examined the application of BD in many industrial contexts; the in-depth theoretically driven investigations on the BD adoption in construction are clearly lacking.

We argue that such a situation is counterproductive, which not only hampers the transfer of knowledge to industry but also dilutes the efforts to build academic knowledge in a cohesive manner.

Adding to the predicament, the current estimates on the use of BD for construction show very light to nominal use (Alavi and Gandomi, 2017). As such, there are calls (e.g. Alavi and Gandomi, 2017; Barbosa *et al.*, 2017) for enhanced digitalization of construction industry to improve productivity and efficiencies.

We contend that gaining an understanding of the BD adoption process in construction and the factors that drive it is timely and needed for two reasons (Alavi and Gandomi, 2017). First, such an understanding will facilitate devising strategies and plans to accentuate the adoption and use of BD for achieving much needed construction productivity and efficiency improvements. Second, it will help digitalization of industry. Moreover, it will also help address the calls for identifying factors that drive BD adoption (Raguseo, 2018).

Addressing the above-discussed gap in knowledge and fulfilling calls (e.g. Raguseo, 2018), this study thus investigates the following question:

RQ1. What are the factors that drive adoption of BD for use in construction industry?

The study draws upon technology–organization–environment (TOE) framework to propose new factors and model their relationships to BD adoption in construction, thus uniquely contributing to advancement of academic knowledge in an area with little research.

For the purpose of clarity, BD is defined here as "high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making and process automation" (Gartner, 2018). Whereas, BIM is defined "as a set of interrelating policies, processes and technologies that generate a systematic approach to managing the critical information for building design and project data in digital format throughout the lifecycle of a building" (Wong and Zhou, 2015).

2. Methodology

The study used secondary data involving articles published on BD and construction. The data collection involved search of two key databases, i.e. ScienceDirect and Emerald. The keywords strings such as BD adoption, factors, role and impact on construction industry were used to maximize the search output. Construction industry-related variants such as built environment and buildings were used to enlarge the search yield (Table I). Given the research question of the study, rationale was to use keywords that help find articles on the BD adoption-related issues in construction industry context, as can be seen in Table I.

The fact that the study was able to collect a size-able number of relevant articles shows that the keywords used were appropriate for the study. It also transpired in the search that the research papers examining BD adoption in construction remain limited to none, thus confirming the need for this study.

The data search yielded a sample size of 55 relevant articles. These 55 articles were then reviewed and categorized in broad themes and sub-themes. The review led to a realization that almost all the 55 papers either discussed BD or BIM in construction context, resulting in broad themes, i.e. BD, BIM or BD opportunities and challenges. This initial categorization was further analyzed to consolidate and identify the relevant sub-themes. We reviewed the abstracts, study's objective(s), and findings to develop a more granular understanding. It led to further categorization of articles in sub-themes such as, BD applications in multiple segments (e.g. construction, facility management (FM)), Governance and management, or BIM application in project management.

We explain sub-theme categorization through an example. For instance, the article by Bradley *et al.* (2016) discussed BIM within the infrastructure domain and associated modeling standards, among other issues. Hence the article has been categorized under sub-theme BIM applications in infrastructure (see Table II). The article also discussed the importance of BIM integration with technologies such as BD, which supports this study's conceptualization of the proposed factor "Augmented BD–BIM integration" (Figure 1).

Keywords	Keywords
"Big Data adoption" + "Construction"	"Big Data adoption factors" + "Construction"
"Big Data adoption" + "Built environment"	"Big Data adoption" + "Buildings"
"Role of Big Data" + "Construction industry"	"Big Data" + "Building information modeling"
"Big Data" + "Industrialized construction"	"Big Data applications" + "Construction industry"
"Big Data impacts" + "Construction"	"Big Data adoption" + "Opportunities" + "Construction"
"Big Data" + "Project management"	"Competitive advantage of Big Data" + "Construction"
"Role of predictive analytics" + "Construction industry"	"Relative advantage" + "Big Data" + "construction"

Table I. List of keyword phrases

Themes	Sub-themes	References
BIM	1. BIM application in infrastructure	Bradley *et al.* (2016)
	2. Smart cities and buildings	Yamamura *et al.* (2017)
	3. BIM application in waste management	Akinade *et al.* (2017, 2018), Lu, Webster, Chen, Zhang, and Chen (2017)
	4. BIM applications in sustainability	Lu, Wu, Chang and Li (2017), Wong and Zhou (2015)
	5. BIM applications in construction, project management	Li, Xu and Zhang (2017), Li, Wu, Shen, Wang and Teng (2017), Park *et al.* (2018), Rowlinson (2017), Smith (2016)
	6. BIM adoption	Ahmed and Kassem (2018)
	7. Governance and management	Alreshidi *et al.* (2017)
	8. BIM–BD integration	Aziz *et al.* (2017), Buffat *et al.* (2017), Motawa (2017), Zhong *et al.* (2017)
	9. Building performance	Chien *et al.* (2017), Gerrish *et al.* (2017)
	10. BIM application in facility management	Edirisinghe *et al.* (2017)
BD	1. BD Applications in multiple fields (civil engineering, construction, energy, facilities, real estate; sustainability, urban planning, utilities)	Ahmed *et al.* (2017), Akhavian and Behzadan (2015, 2016), Ang and Seng (2016), Amasyali and El-Gohary (2018), Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha (2016), Cook (2015), Du *et al.* (2014), Koseleva and Ropaite (2017), Mawed and Al-Hajj (2017), Shen *et al.* (2017), Walker (2016)
	2. Smart cities and smart buildings applications	Bibri (2018a, b), Bibri and Krogstie (2017a, b), Hashem *et al.* (2016), Kim (2018), Mehmood *et al.* (2017), Ng *et al.* (2017), Pan *et al.* (2016), Plageras *et al.* (2018)
	3. Project management	Ekambaram *et al.* (2018), Zhang *et al.* (2015)
	4. Construction waste analytics	Bilal, Oyedele, Akinade, Ajayi, Alaka, Owolabi, Qadir, Pasha and Bello (2016), Bilal *et al.* (2017), Chen and Lu (2017), Lu *et al.* (2015), Lu *et al.* (2016)
BD opportunities and challenges	1. Management efficiencies	Deutsch and Leed (2015), Hao *et al.* (2015), Wang and Zhai (2016)
	2. Adoption	Kwon *et al.* (2014), Raguseo (2018)

Table II.
Themes and sub-themes as identified from literature

The categorization of the articles in themes and sub-themes (Table II) helped not only in a systematic structuring and organizing of the literature, but also in underlining and presenting a critical perspective of some of the key issues, triggers and factors that facilitate the adoption of BD in construction.

Once the categorization was finalized, the relevant articles were analyzed using content analysis technique to understand the factors and associated issues that drive adoption of BD in construction.

The entire process of data collection, themes/sub-themes classification, using content analysis and model development is consistent with prior studies (e.g. Edirisinghe *et al.*, 2017; Li, Xu and Zhang, 2017; Li, Wu, Shen, Wang and Teng, 2017) in BD construction context.

Next, we present the review of literature (Section 3) and then based on the issues identified in the review and underpinned by TOE (Section 4), we develop hypotheses and a new model of BD adoption in construction (Section 5).

3. Literature review

3.1 Advantages and challenges of BD adoption in construction

The construction industry is known to be besieged by inefficiency, poor performance of labor and resource utilization problems (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade,

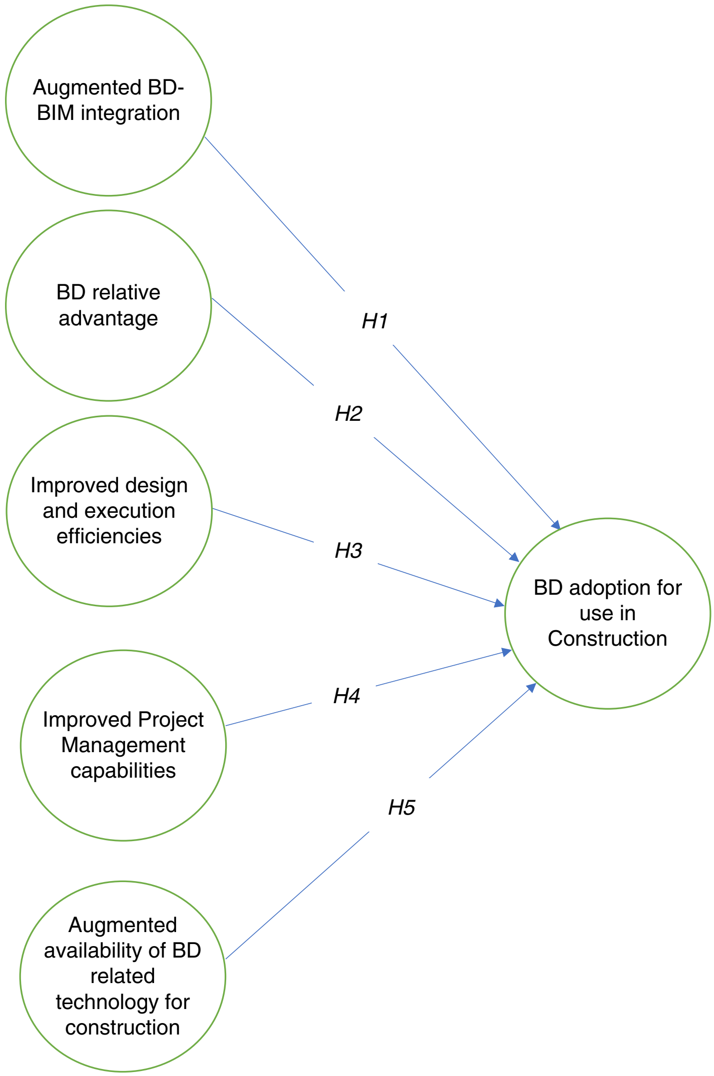

Figure 1.
Model of BD adoption in construction

Owolabi, Alaka and Pasha, 2016). Such a situation has resulted in concentrated efforts to adopt technologies, e.g. BIM, BD and data analytics to improve productivity and enhance efficiencies in planning, design and overall delivery of construction projects (Raguseo, 2018).

BD adoption is considered pivotal to achieving construction efficiencies as it could facilitate data mining and finding new insights such as gaining an understanding of the factors that cause work delays (Kim *et al.*, 2008). Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha (2016) concur suggesting that knowledge discovery in databases is an efficient approach to analyze large construction data sets to identify causes of construction delays, cost overrun and quality controls. BD enables analyzing (e.g. using Multivariate statistical techniques) large data sets to predict total cycle time of construction operation and predict the accuracy of estimation at the early stages of construction projects

(Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016). Mawed and Al-Hajj (2017) found that BD helped improve performance in FM and enabled change in business and the operation models facilitating informed, smarter and quick decisions. BD adoption provides capabilities that can enable an organization to achieve competitive advantage (Kwon *et al.*, 2014).

Despite the benefits, construction industry lags behind in BD adoption (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016). Kwon *et al.* (2014) conducted a survey from a wide variety of industries including construction and found that the adoption of BD is influenced by an organization's capabilities in collecting and maintaining quality data. Raguseo (2018) examined risks and benefits and concluded that the adoption of BD improves productivity and organizational capabilities in skills development and collection of large amounts of data assets. The author argued that privacy and security of data remain the top two risks and recommended conducting further studies to understand the factors and associated issues to BD adoption.

3.1.1 BD adoption across multiple fields. Safety remains one of the priorities in construction sector. Akhavian and Behzadan (2016) used automated sensor data capture technique to understand construction workers' behaviors through activity recognition technology. They used smartphones to capture body movements of workers and simulated the data to understand the workers' productivity and occupational safety on site. The experiment could prove to be a useful starting point to use BD not only for improving the occupational health and workplace safety of workers on site, but also for enhancing overall productivity and efficiencies of other professionals involved in the back-office construction-related work. Big sensor data can also be used for urban planning and management activities including "air pollution monitoring, assistive living, disaster management systems and intelligent transportation" (Ang and Seng, 2016).

BD can help in understanding energy consumption behaviors and achieving efficiencies (Amasyali and El-Gohary, 2018). As such efforts to develop energy consumption prediction models predominantly for commercial and/or educational buildings with a particular interest in overall cooling, heating and lighting energy consumption patterns have been the focus of investigations (Amasyali and El-Gohary, 2018). However, Koseleva and Ropaite (2017) point to the challenges in using energy-related BD for achieving consumption efficiencies and suggest that limited applications are available to process such BD, particularly when several energy-related dimensions are involved.

Building occupancy has direct bearing on the energy consumption efficiencies. Shen *et al.* (2017) examined 50 projects/systems, and reviewed and compared them in "terms of occupancy sensing type, occupancy resolution, accuracy, ground truth data collection method, demonstration scale, data fusion and control strategies." Authors suggest that implicit occupancy sensing can provide capabilities to achieve efficiencies in building energy management "through optimal delivery of building services (including lighting, heating, ventilating and air conditioning) with lower costs compared to traditional explicit sensing approaches."

Mawed and Al-Hajj (2017) examined the data collected from multiple sources and technologies to improve the efficiency of the FM services. Their preliminary findings show that asset owners and service providers in FM are still in early stages of assessing the applications of BD and the benefits and challenges of using BD. Ahmed *et al.* (2017) concur and argue that while BD has a significant role to play in FM, yet firms operating within FM lack an understanding of the value of BD, thus awareness need to be improved. One of the challenges they pointed out was the imbalance between the data capture and data analysis and hence the need for more work to analyze the data. They also identified a number of factors such as data privacy, data security, data heterogeneity and lack of available cases of BD use which could influence its adoption in FM.

Extending the discourse, Aziz *et al.* (2017) proposed that FM can be improved by using data from design and construction stages to plan maintenance schedules. They suggested that the integration of disparate data such as road networks, mobiles and sensors could help decision makers in designing efficient built environment solutions.

BD also plays a core role in infrastructure development and planning, as Pan *et al.* (2016) investigated and confirmed the importance of urban BD for achieving efficiencies in city intelligence.

The growing availability of BD technologies is one of the factors driving adoption of BD in construction (Raguseo, 2018). However, Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha (2016) and Walker (2016) argue that while application of BD and knowledge created by BD has many potential benefits, yet its adoption is still relatively slow. With developments in BIM, Internet of Things (IoT), and cloud computing; the chances are BD uptake will amplify in coming years.

3.2 Factors driving BD adoption in construction

3.2.1 BD–BIM integration and technological capabilities. BIM is an emerging solution which facilitates integration and management of information for the whole building lifecycle (Wong and Zhou, 2015). BD captured throughout the lifecycle can be used for improved BIM output, thus enhancing the effectiveness of BIM. As such, increased interests in using integrated BD–BIM solutions and the growth in availability of integration technologies are driving BD adoption in construction (Aziz *et al.*, 2017).

BIM is used for Green buildings design and development, as it enables addressing sustainability issues during designing processes (Wong and Zhou, 2015). Complemented by BD, BIM is used for performance analyses and simulations. These include energy performance analysis, CO_2 emission analysis, simulation of lighting and also some integrated optimization of building performance. The integration of BD–BIM helps designers at early design phase as it enables gaining an integrated and visualized view of building performance (Lu, Wu, Chang and Li, 2017).

BD–BIM integrated solutions are also used in FM for predicting operational efficiencies, facilitating efficient design and minimizing waste (Bilal *et al.*, 2015). Edirisinghe *et al.* (2017) proposed a BD integrated BIM-enabled FM framework covering elements including planning, value realization, leadership, data capture and integration techniques, and legal and policy context. They argued that framework will offer proactive decision making and response capabilities.

3.2.2 BD's role in improved management. BD adoption is expected to enable changes in stakeholder engagement resulting in productive and efficient management of projects. Rowlinson (2017) highlighted the role of BIM in integrated project delivery (IPD). The author argues that more efforts are needed to integrate BIM into IPD through a process of change management which can be achieved by involving relevant institutional stakeholders including policy makers.

Collection of real time information about stakeholders and different phases of construction and operations enables optimizing the building portfolio and developing sustainable and smart cities (Mawed and Al-Hajj, 2017). Walker (2016) agrees as the author acknowledges that impact of BD on overall construction management and in particular project management is a game changer. The author stressed that the changes in knowledge management and learning due to BD and associated technologies will spur innovations and efficiencies.

Cokins (cited in Mawed and Al-Hajj, 2017) suggested that BD can bring performance improvements in construction in at least six areas, i.e. strategic planning and execution; cost visibility and driver behavior; customer intelligence; forecasting, planning and predictive analytics; enterprise risk management and process improvement. These components align with quality standards, such as six sigma, to reduce or eliminate waste, and streamline processes in order to reduce the cycle times, eventually leading to productivity and efficiency improvements.

Smith (2016) highlighting the challenges argued that "designers not providing full access to the models" and technological incompatibilities are hindering efforts in utilization of BIM and BD in construction.

4. Development of conceptual model of BD adoption

The model developed by this study is informed by TOE framework. TOE has been used widely by prior studies to model adoption of technologies including, e.g. Enterprise 2.0 (Jia *et al.*, 2017). Given its multi-context coverage and inclusiveness, TOE provided a robust theoretical underpinning to conceptualize various factors that drive the adoption of BD in construction, hence adopted by this study.

4.1 Technology–organization–environment framework

TOE posits that a technological innovation process is an ensemble of three inter-connected contexts: technological, organizational and environmental (Tornatzky and Fleischer, 1990).

The "Technological" context is meant to consider technologies within and outside an organizational ecosystem which influences organizations to adopt and use the available latest technologies, and deploy change. An organization considering adopting new technologies will look at the benefits of the technology and how its adoption will enhance efficiencies and add value to its operations (Baker, 2012). As such a host of factors including, but not limited to, relative advantage, higher technological competence, perceived benefits/usefulness, cost efficiencies have been identified by earlier research (Jia *et al.*, 2017).

Organizational context is another element of TOE which involves assessing inwardly the organizational strengths, weaknesses and characteristics. It includes the structure; processes; means of communication; human and physical capabilities; top management involvement and support; size and slack resources among others (Baker, 2012).

Environmental context provides a lens to look into those factors that are related to an organization's business ecosystem and the opportunities and challenges present in the corresponding business environment (Baker, 2012). Researchers have identified a host of factors that either influence or influenced by the environmental context. Some of these factors are competitive pressures, regulations and policies, industrial protocols, marketing opportunities, and value chain dynamics (Jia *et al.*, 2017).

5. The conceptual model

Informed by the literature review (Section 3) and underpinned by TOE, this study proposes five factors that influence the adoption of BD in construction (Table III). These factors and their relationships to adoption are presented in the conceptual model (Figure 1).

5.1 Augmented BD–BIM integration

The developments in BD are accentuating efforts to integrate BD and BIM technologies (Aziz *et al.*, 2017). The integration of BD–BIM facilitates improved cost, time estimates and optimized scheduling (Aziz *et al.*, 2017). Akinade *et al.* (2017) argue that augmented BD–BIM and BIM–IoT integrations are providing value added capabilities to construction organizations.

Yamamura *et al.* (2017) investigated a solution for optimizing energy performance through an integrated geographic information systems (GIS) and BIM. The BD collected from GIS was fed into BIM for modeling, leading to development of an optimal design for energy management and renewable energy utilization. Through their case study they tested

Factors	TOE classification	Factor drawn from the discussion in Literature Review Section(s)	Some reference
1. Augmented BD–BIM integration	Technological	3.2.1, 3.2.2	Aziz *et al.* (2017), Akinade *et al.* (2017)
2. BD relative advantage	Technological	3.1, 3.1.1	Barima (2017), Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha (2016), Raguseo (2018)
3. Improved design and execution efficiencies	Organizational	3.1, 3.1.1, 3.2.2	Motawa (2017), Amasyali and El-Gohary (2018)
4. Improved project management capabilities	Organizational	3.1.1, 3.2.2	Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha (2016), Ekambaram *et al.* (2018)
5. Augmented availability of BD-related technology for construction	Environmental	3.1.1, 3.2.2	Bibri (2018a, b), Plageras *et al.* (2018)

Table III. Factors influencing adoption of BD in construction

the integrated GIS–BIM system for urban planning of Tokyo city and found that the integrated GIS–BIM system provides an appropriate solution for effective energy planning and renewable energy management.

The integration of social media-based BD with BIM is helping in facility planning and management (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016). Similarly, RFID-based BD and BIM integration is used for FM (Meadati *et al.*, 2010). An integrated BD–BIM system that enables capturing building operational knowledge is another development highlighting the growing synergies among two technologies and benefits they offer (Motawa, 2017).

Following the above arguments, we assert that the increased technological integration between BD and BIM are enabling the use of BD in construction to enhance modeling efficiencies and achieve benefits such as improved planning, designing, implementation and control capabilities. Hence the following hypothesis is proposed:

H1. Augmented BD–BIM integration is positively associated with the adoption of BD for use in construction.

5.2 BD relative advantage

The increased use of BD to gain insights for decision making, new product development and achieving operational and strategic capabilities is becoming a source of competitive advantage for the adopting organizations (Raguseo, 2018).

Kwon *et al.* (2014) established that benefits proposition of using BD significantly influence its adoption among organizations including construction organizations. They argued that effective management of data helps develop managerial and operational capabilities which become a source of competitive advantage.

The enormous volume and variety of data generated at various stages in construction projects' lifecycle make BD an important asset for organizations. These data in several forms such as drawings, text, numbers (estimates), videos and photos can be used for improved decision making and efficiencies related to planning, execution and maintenance of construction assets (Barima, 2017). BD adoption can facilitate advanced simulation to improve whole lifecycle performance of built environment products (Wang and Zhai, 2016). Such uses can help organizations become productive and reduce operational risks, gaining competitive advantage in a saturated construction marketplace (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016).

Akinade *et al.* (2017) highlight the value created by BD adoption in construction, such as, in cost savings, speed and efficiencies and informed decision making, just to mention a few. Construction organizations adopting BD gain relative advantage in "end product improvement, design improvements, improved procurement, physical construction processes improvement, construction maintenance processes improvement, enhanced new materials development and boosted technical skills development" (Barima, 2017).

BD enabled data analytics facilitates scenario planning and forecasting (Deutsch and Leed, 2015). Hao *et al.* (2015) echoed the views and argued that BD enables better planning and stakeholder engagement.

The above discussion clearly highlights that those construction organizations who adopt BD are expected to gain multiple advantages relative to their competitors in the industry. Thus, we propose:

H2. The relative advantage of using BD is positively associated with the adoption of BD for use in construction.

5.3 Improved design and execution efficiencies

The adoption of BD enables augmented design and execution capabilities (Motawa, 2017). The variety of data collected from the use of constructed infrastructure and facilities help understand the requirements, problems/challenges and advantages in a better way which enhances organizational capabilities in design and execution of construction work (Akinade *et al.*, 2017).

BD in the form of internal data (e.g. temperature, humidity, occupancy, energy consumption) and external data (e.g. weather, traffic, business activities, economy) can enable gaining insights to improve construction work productivity and post construction environment through reduction in air pollution, improved disaster management, and intelligent transportation (Ang and Seng, 2016).

BD can help reduce the negative impact of construction activities on environment by enabling development of efficient consumption models, improving consumption predictive capabilities and construction design processes that maximize natural use of resources and minimize generation of un-recyclable waste (Amasyali and El-Gohary, 2018; Shen *et al.*, 2017).

Construction waste and its treatment also remains one of the thorny issues, resulting in a growing number of studies that have investigated the importance of BD in enabling improved management of construction waste (Bilal *et al.*, 2017; Chen and Lu, 2017). Lu *et al.* (2016) used BD to analyze the construction waste management (CWM) performance and recommended that "the value of environment protection leadership" should be promoted for improved CWM performance.

One of the ways to minimize the negative impact of environmental footprint of construction activities is to use BD for smart city planning and development. Bibri (2018a, b) argued that IoT-driven BD can help in design and development of smart cities. The author argued that state-of-the-art sensor-based BD can be used for planning and design of built environment, waste management, water management and transportation, just to mention a few. This coincided with earlier work by Pan *et al.* (2016) in urban planning context, and Ng *et al.* (2017) who proposed a master data management (MDM) solution that uses IoT BD for smart cities planning.

In light of above arguments, the study hypothesizes:

H3. Improved design and execution efficiencies facilitated by BD are positively associated with the adoption of BD for use in construction.

5.4 Improved project management capabilities

Construction is predominantly project-based activity. A significant amount of data is collected throughout various phases of construction project lifecycle, which become an important source for enhancing project management capabilities (Ekambaram *et al.*, 2018).

Rowlinson (2017) proposed an IPD approach where project-based data collected at various stages in lifecycle can be integrated with BIM for enhanced capabilities. The use of BD induces agility and effectiveness of project management (Zhang *et al.*, 2015). Information generated from planning, design, execution and post construction stages is stored digitally. This information includes cost and schedule estimates, design-related information, construction performance data, variance and issues, risks, quality and procurement data. BD enables understanding these data for enhanced decision making, effective risk management, quality improvements, improved planning, safe and effective construction, and overall improved management (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016).

BD, therefore, can help build project management maturity within organization, as organizations will be able to analyze the past mistakes and become more consistent in their project management-based activities. Such a situation will lead to using project management standards more effectively, and hence we propose:

H4. Improved project management capabilities facilitated by BD are positively associated with the adoption of BD for use in construction.

5.5 Augmented availability of BD-related technology for construction

The increased availability of BD-related technology is one of the driving factors of BD adoption for use in construction (Bibri, 2018a). Off-the-shelf or open source master data management applications are available to analyze BD (Ang and Seng, 2016).

The growth in technologies that serve as BD capture sources is helping adoption too. Availability of technologies, such as, IoT, large scale wireless sensor systems. GIS, RFID and POS (point of sales) are key sources of data collection resulting in increased adoption of BD in construction. Further, open standards for interoperability in the Construction and Urban Planning fields, such as IFC (buildings and infrastructure) and CityGML are also contributing toward favorable view of adopting BD in construction. Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha (2016) provided a comprehensive review of BD applications and the associated technologies.

The development in data storage technology is also leading to the adoption of BD. Distributed data storage file technology such as Hadoop and Tachyon are facilitating the BD developments (Raguseo, 2018). Advancements in Relational database technology such as the development of "Not only SQL" systems, which provide improved traditional data management in numerous ways are also furthering adoption of BD (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016).

Availability of visual analytics software to view the results in graphic/visual formats is also contributing toward BD adoption (Raguseo, 2018). Technologies such as Social–BIM, BIMCloud (to store user interaction with building models' data through IFC, Apache Cassandra, hosted on Amazon EC2) are proposed to be used in construction industry further helps in BD adoption (Bilal, Oyedele, Qadir, Munir, Ajayi, Akinade, Owolabi, Alaka and Pasha, 2016).

Plageras *et al.* (2018) propose use of IoT-based BD applications for smart buildings. MDM is another BD-based application used in infrastructure and smart cities planning and development (Ng *et al.*, 2017). The above discussion highlights the vast opportunities involving availability of BD-related technology for construction (Barima, 2017). Hence, we propose:

H5. Augmented availability of BD-related technology for construction is positively associated with the adoption of BD for use in construction.

6. Conclusions

BD and associated technologies are being increasingly adopted for achieving efficiencies and improved productivity. Yet, little work has been done to examine the factors that drive BD adoption for use in construction. Taking a two-fold approach, the study first presents a structured review of literature. Then, underpinned by TOE theory, the study proposes five new factors and builds a corresponding model explaining the relationship of these factors to BD adoption for use in construction.

We argue that BD adoption is influenced by increased technological synergies between BD and BIM. These synergies facilitate BD–BIM integration allowing feeding BD into BIM and leveraging this connectivity for design and development efficiencies.

Organizations that adopt BD are expected to enjoy relative advantage compared to the competitors due to improved capabilities in gaining new insights from BD. Technological superiority achieved by adopting BD provides added value and help construction organizations remain comparatively sustainable in highly intense construction market.

The findings also suggest that achieving technological sophistication is not the only reason to adopt BD, but capacity development in project management and resource management are also some of the factors weighing in the favorable adoption decision.

With the increased use of BD across various business sectors, the technological competence is also growing. These fast-paced technological developments and availability of technologies facilitating capture, storage and processing of BD is building confidence among the potential adopter in construction organizations to adopt BD.

6.1 Implications for theory and practice

The study makes several theoretical and managerial contributions. First, the study proposes a set of five antecedent factors explaining the adoption of BD in construction encapsulating technology, organization and environment context.

Second, underpinned by TOE theory, the study develops hypotheses and a corresponding conceptual model. The newly developed model contributes toward extending application of TOE (particularly for the adoption stage of innovation process) to new form of BD technological innovation.

It is pertinent to note that the growing trends in the use of BD warrant upgrading innovation theories and making them more inclusive with factors related to technologies such as BD. The current theories on technological innovation process may not be fittingly applicable to BD given novel technology. Therefore, we believe that the proposed model contributes significantly toward extending current knowledge on innovation process and development of new academic insights and thoughts.

Third, by taking a theory-driven approach to examine BD adoption in construction, the study contributes to an area where theoretically informed existing research is scarce.

Fourth, through a systematic literature review, the study has categorized a large body of literature on BD in construction in various themes/sub-themes which will serve as a platform for future research work and development of knowledge in a cohesive manner.

Finally, fulfilling the calls, the study builds knowledge that will help in efforts toward digitalization of construction industry.

Managerially, findings will help chief information officers, IT/IS managers, business development managers and senior executives in construction organizations to understand the factors that drive the adoption of BD and evaluate their organizational environment for adoption considerations. The knowledge developed in the study can also be used for business case development for adopting BD, making informed investment decisions and strategies for realizing expected returns once BD is adopted.

Findings will help policy makers in devising policy guidelines and regulations for uptake of BD in construction. Given that the construction work produces long-term environmental impacts and BD adoption can help mitigate some of the negative impacts, policy makers can form policies to help organizations adopt BD and minimize the negative impact on environment.

6.2 Limitations and future directions

The study opens up new avenues of scholarly investigations. First, further studies can identify more antecedent factors of BD adoption in construction, which will extend the findings presented here. Factors such as availability of BIM (software tools), GIS and sensors (as RFIDs) as enabling tools driving BD adoption, and BD being as an enabler of Lean and Green Building design, construction activities could be tested.

Second, future work can consider articles focused on manufacturing as industrialized construction, pre-fabrication and modularization also plays a big role in diving BD adoption.

Third, more work can look into the differences and similarities in factors driving adoption across different types of construction environments, e.g. traditional vs sustainable or green building construction.

Fourth further studies can actually collect the data for the factors identified in this study and examine the causal relationships presented in the model. Finally, more work is needed to identify the item measures for the constructs shown in the model of the study.

The study has some limitation too. The model proposed in the study is based on secondary literature-based data, and primary data can be collected to examine the hypothetical relationships. The generalization of findings therefore needs to be done with lot of caution. Second, like other qualitative content analyses-based studies, findings are based on subjective understanding and a longitudinal or cross-sectional study may be done to extend this work. Finally, BD research is still in its infancy, so the work presented here is of fundamental knowledge building type which necessitates further studies to advance knowledge in this area.

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