BIG DATA ANALYTICS: UNDERSTANDING ITS CAPABILITIES AND POTENTIAL BENEFITS FOR NIGERIA'S CONSTRUCTION INDUSTRY

Jesse Amadosi Emmanuel

Department. of Quantity Surveying, Baze University Abuja.
Corresponding author: jesse.emmanuel@bazeuniversity.edu.ng

Abstract

With rapid development in technology, big data analytics is virtually gaining dominance in many aspect of human endeavours. However, the construction industry is still struggling to understand the opportunities it offers. The digital world has been overwhelmed by an explosion in the magnitude of data, and as never before, the information being captured and recorded in different fields is in a steady increase. While the continuously growing body of academic research on big data analytics has largely advocated a technology-oriented approach, a better understanding of the strategic implications of big data has become even more necessary. To address this gap, this study aims to draw insight into big data analytics capabilities within the construction domain. To achieve this objective, the study examines the historical development of big data analytics, evaluate current big data analytics research and propose potential benefits to the construction industry and built environment. Following inductive content analysis of big data analytics implementation in construction-related studies, the study identifies six big data analytics capabilities in areas of resource and waste optimization: analytical capability for data-driven design, decision support capability, predictive capability, virtual analytic capabilities and Analytic capabilities for Energy Management. This study paves way for the construction industry to understand the big data analytics capabilities and the advantages as they seek to evolve more effective data-driven analytics strategies.

Keywords: Big data analytics; Big data analytics architecture; Construction industry; Big data analytics capabilities; Business value of information technology (IT); Business performance

Introduction

Many factors have been attributed to the poor performance of the construction industry. Similarly, the need to improve performance has so far been advocated for(Egan, 1998; Latham, 1994; Ofori, 2000). Yet, the industry is still characterised by a myriad of issues warring against it. Significant among these factors are technological advancement, and research and development. Chilipunde (2010) noted that in the area of technological advancement, limited skill in construction information technology affects productivity. A recent study by Madanayake & Çidik (2019) reports comprehensively on four broad areas of factors-affecting- productivity in construction. These are people, logistics and operations, information and communication management, and a regulative framework. The researchers also stated that these four categories suggest that the impacts of digitalisation on productivity is enormous. Mbamali & Okotie (2012) however, observed that increase in the application of information technology among indigenous companies and professionals will help increase the performance of construction projects within the country.

The world today is overwhelmed with a steady increase and influx of data. As of 2015, studies show that more data was created within a space of two years than was ever created in the entire history of the human race (Bilal, Oyedele and Akinade, 2016). By some estimates, 2.5 trillion gigabytes are created every day. These data come from social media information, location data, financial information, images etc. given this situation and coupled with the growing concepts of data warehousing, the internet of things, artificial intelligence, robotics and automation which continue to fast track the growth of data. Utilizing such massive data that is being created cannot be handled by adopting the traditional data analysis techniques (Aghimien, Aigbavboa, & Oke, 2019; Ahiaga-dagbui & Smith, 2014).

The construction industry suffers from a structural fragmentation for data integration (Ahmed, Tezel, Aziz, & Sibley, 2017) which explains information technology (IT)-related challenges. At the same time, the industry recognises the imbalance between data capturing and data analytics such as inadequate integration of operations management systems and poor leadership management. These and many other challenges have been found to badly impede efforts to transform IT value to the business value within the construction purview (Ahmed, Tezel, Aziz and Sibley, 2017; Bodenheimer, 2005). Big data can be described as data that grows at a rate so that it surpasses the processing power of conventional database systems and doesn't fit the structures of conventional database architectures. Its characteristics can be defined with 6V's: Volume, Velocity, Variety, Value, Variability, and Veracity (Alaka et al., 2018; Tiwari, Wee, & Daryanto, 2018; Wang & Alexander, 2015; Yang, 2020). Earlier in its development, Big Data was defined in terms of its volume, velocity, and variety (3V's)(Wang, Feng, Chang, & Wu, 2017). These 3V's of Big Data are evident in construction data. Construction data is typically large, heterogeneous, and dynamic; volume stems from progress reports on the design, operation, maintenance and performance, diversity can be ascribed to the different stakeholders involved and the different IT application/format used, the dynamic aspect follow the use of sophisticated IT gadgets like radar systems, sensors, and drones (Aouad, Kagioglou, Cooper, Hinks, & Sexton, 1999; K. K. Han & Golparvar-Fard, 2017). Using this data to achieve a legitimate value proposition is central to optimise construction operations which is arguably the next frontier of innovation in the industry.

Thus, opportunity is availed for construction managers to perform a more comprehensive analysis of their projects to explore the real deficiencies that caused the current productivity issue. Big data analytics, which has been commonly used in many other industries (healthcare, manufacturing, retail, agriculture etc.), could be a promising solution to the above-mentioned problem and assist construction managers in performing a more comprehensive and holistic data exploration in their projects with reasonable cost and time.

Both systematic and technical understanding of big data analytics within construction has been carried out (Alaka et al., 2018; Atuahene, Kanjanabootra, & Gajendran, 2018; Bilal et al., 2016; Chen, Lu, & Liao, 2017; Madanayake & Çidik, 2019; 2018; Moynihan, Chau, Vereen, & Batson, 2017; Omran, 2016). However, construction organizations continue to struggle to gain the benefits from their investments in big data analytics and some of them are yet to fully appreciate or leverage the capabilities like their counterparts from the manufacturing, and health sectors (Oesterreich & Teuteberg, 2016; Omran, Chen, Asce, & Jin, 2014; Omran, 2016). Findings from the McKinsey Global Institute revealed that the construction industry shows disappointing output compared to other sectors (Manyika et al., 2011; McKinsey & Company, 2013). This implies that practitioners within the industry still vaguely understand how big data analytics can support the business decision and improve performance (Madanayake & Çıdık, 2019).

Construction industry data

Big data is known to be related with unstructured data (Suthaharan, 2014). Against this backdrop, however, structured data is also suitable for classification as Big Data as long as the dataset reveal the necessary features (Zikopoulos, Eaton, Deroos, Deutsch, & Lapis, 2012). Data generated and obtained in construction industries are the construction data. This type of data has been broadly classified by (Ismail, Bandi, & Maaz, 2018) as structured data, unstructured data and semi-structured data. Structured data include data that obey define data type, format, and structure. They include those data that can be captured and stored as discrete coded values and analysed in spreadsheets, relational databases and single data table. The variety of construction data is attested to by noting the various formats supported in construction applications which include transaction data (e.g., structured data from realty transactions, stakeholders' profiles)(Ismail et al., 2018; Motawa, 2017; Petruseva, Sherrod, Pancovska, & Petrovski, 2016). Unstructured (without a predefined format) data is generally captured and stored as free text so cannot be stored in rows and columns. Although humans can easily read this data, they are not readable for computers. The common examples of unstructured data are progress notes. The variety of construction data can be revealed by noting the various format supported in construction applications (Bilal et al. 2016)**.** However recent improvements have seen construction firms move into arenas such as real-time, cloud-powered analytics of large and unstructured datasets. Such methods have the potential to redefine the traditionally fraught relationships between the interested parties(Ngo, Hwang, & Zhang, 2020; Wamba et al., 2017; Ahiaga-dagbui & Smith, 2014). Semi-structured data include data that is in the form of structured data but does not qualify the data model. They are organised with minimal structure along with self-describing nature. Example of such data includes data generated from a device such as a sensor for effective monitoring of site activities or data entry interface that may have a grouping of structured data capture and free text (Ambigavathi & Sridharan, 2018).

Sources of construction data

The construction industry thrives on data and data in any form has inherent value to the success of the industry's performance. One source of big data in BIM is the deployment of 3D laser which can point clouds of a facility to generate as-built BIMs (Gopalakrishnan, Agrawal, & Choudhary, 2017). On Operation and Maintenance, the current system of Internet-connected devices can now gather and transfer data through installed sensors, most modern construction equipment generates data through usage (Côrte-Real, Ruivo & Oliveira, 2020; Mohamed, Najafabadi, Wah, Zaman, & Maskat, 2020). Also, with the steady progression in digitisation, the rate at which logistic information is being created is on the increase. In light of the information investigation and analysis of large data, logistic setup can make certain predictions on the future market and the behaviour of competitors, timely adjust the development strategy and avoid blind asset investment, thus reduce losses (Akter, Wamba, Gunasekaran, Dubey, & Childe, 2016; Aouad et al., 1999). Schedules Information which involve planning, scheduling is an important part of construction management. Construction does not only denote physical activities involving men, materials and machinery but also covers the entire range of activities from conception to realization of construction projects. Therefore, necessitating the effective mix of resources with the construction. Akhavian & Behzadan (2015) examine the possibility of engaging in-built smartphone sensors as data collection and transmission nodes to identify detailed construction equipment activities. Whatever the future will be, the role of big data in supporting organizations (human resources) to deal effectively with changes cannot be overlooked. Harnessing the mutual effect of humans and robots (termed dubbed as "cobotics") is the focus in some industry (Ekambaram, SØrensen, Bull-Berg, & Olsson, 2018; Mbamali & Okotie, 2012). Other big data resources in construction include Cash Flow Information, Reality modelling information, HSE data, Request for information (RFI), Quality control information, Change orders, Weather information, Location data etc.

Proposition for Big Data Analytics Architecture in Construction

To accentuate the aim of this study which is to describe the big data analytics competency profile and its potential benefits for the construction industry, it is vital to understand its architecture, framework, tools and functionalities. The first step taken is to evaluate the best practice of big data analytics architecture within construction. However, owing to the lack of adequate big data analytic architecture in the field, an approach was therefore created based upon the earlier research findings. This was an adaptation of the study carried out by (Wang, Kung & Byrd, 2018). This step was necessary and based on the premise that the healthcare sector is at the frontline of big data analytic researches and have taken more initiative to explore the big data capabilities to turn around organisational practices and create benefit (Yaxing et al., 2017). Hence the conceptual architecture of big data analytics for this study was derived from the work (Wang *et al*. 2018) and (Bilal *et al*., 2016). The big data analytics architecture which comes as the outcome is rooted in the concept of data life cycle framework that starts with data capture proceeds via data transformation, and culminates with data consumption as noted by (Wang et al. 2018) and (Yaxing et al., 2017).

A proposition for best practice big data analytics architecture comprise of five major architectural levels: (1) data layer, (2) data aggregation layer, (3) analytics layer, (4) information exploration layer, and (5) data governance layer. These logical layers make up the big data analytics components that perform specific functions, and will therefore enable construction managers to understand how to transform the industry data from various sources into meaningful information through big data implementations.

Data layer

This layer comprises all the data sources necessary to provide the insights required to support daily operations and solve construction-related problems. The structured data is normally organised in table-based models with rows and columns called relational database management systems (RDBMS). To access and manages entries, a series of standardized commands are used, called structured query language (SQL). Examples of data in this category include transactions that can reside in databases, the same procedure applies to semi-structured data such as the records of monitoring gadgets, and unstructured data such as (non-text) data, such as videos, photos, social media content, and Internet of Things (IoT) sensor data that can exist in many format types. These data when put together from different locations is stored at once into appropriate databases, depending on the content format.

Data aggregation layer

This layer is concerned with handling data from various data sources. This layer essentially absorbs data through a procedure that is similar to that described by (Fayyad, Piatetsky-shapiro, & Smyth, 1996) and (Han, Kamber, & Pei, 2012); this includes data acquisition where data that are related to the task at hand are selected from the database, This step is critical in the implementing big data analytics, because of the widespread of incoming data, a pre-processing would be required to follow. Pre-processing is where noise and inconsistent data are removed; a transformation that involves conversion of the data gathered from their original form to a more appropriate form. In the course of this process, the transformation engine must be able to move, clean, and separate, sort, transform, merge and validate the data available to it (Loyola, 2018).

Analytics layer

This layer is responsible for processing all kinds of data and performing appropriate analyses. In this layer, the data analytic process can be divided into three major components; these include Hadoop MapReduce, Stream computing and in-database: As a constituent of Hadoop, MapReduce is known for breaking down complex data into small units of work that are processed in parallel formats(Loyola, 2018; Wang, Kung & Byrd, 2018). Stream delivers a sound analytic platform for analyzing data in real-time (Zikopoulos et al., 2012). It applies to analytic techniques on data in motion. Stream computing enables real-time analysis, as such, users can track data in motion, respond to unexpected events as they happen and quickly determine the next-best actions. It is an important analytical tool that assists in predicting the likelihood of fraudulent and illegal transactions or deliberate misuse of customer accounts (Mohamed et al., 2020; Wang, Kung & Byrd, 2018). In-database analytic refers to a data mining approach built on an analytic platform that allows data to be processed within a data warehouse. In this manner, the time and effort required to transform data and move it back and forth between a database and an independent application are eliminated. this component offers parallel processing, partitioning, scalability, and optimization tailored toward analytic functionality(Roy, Morales, Fouché, & Möhler, 2019). This analytic component is central to many processes in the fourth industrial revolution as it is also useful for ensuring sustainable construction material selection and improving waste management in the construction industry (Chen et al., 2017; Saggi & Jain, 2018).

Information exploration layer

This layer generates information in the form of visualization reports, real-time information monitoring, and useful business insights obtained from the analytics layer. Playing the role akin to conventional business intelligence platforms, reporting is a critical attribute of big data analytics. This operation allows data to be visualized in a serviceable manner to aid daily operations and help managers to make faster, better decisions. whereas, the most important output for construction may well be its real-time monitoring of construction activities thereby obtaining information such as alerts and proactive notifications for instant tracking and interventions (Akanmu & Anumba, 2015; Jung & Joo, 2011).

Data governance layer

This layer is composed of master data management (MDM), data life-cycle management, and data security and privacy management. This layer emphasizes how to harness data in the organization. The first component of data governance, master data management, is considered as the processes, governance, policies, standards, and tools for managing data(Ram, Afridi, & Khan, 2019; Siddiqa, Karim, & Gani, 2017). Data is properly standardized, removed, and incorporated to create the immediacy, completeness, accuracy, and availability of master data for supporting data analysis and decision making. The second component, data life-cycle management, is the process of managing business information throughout its lifecycle. This stems from the collection, through the process, storage, use, share, archive, deleting/destroy or reuse(Ram, Zhang, & Koronios, 2016).

In meaningful ways, the construction activities involve rigorous data control mechanisms for information relating to cost, claim, risk, design, safety and so on. Therefore, to prevent security breaches and protect against flagrant use of data. It is imperative to commit to a high-level ethical standard in designing strong compliance conditions that will guarantee that the construction industry preserves value and the enterprise's assets, whether tangible or intangible(Philp, 2018; Ram et al., 2019).

Big Data Analytics Capability

Due to an increasing trend of emerging technology usage, the generation of data in the construction industry is also escalating. Therefore, getting valuable insights from data has taken a prominent position in the minds of academia and industry professionals (Atuahene et al., 2018). In general, big data analytics capability refers to the ability to manage a huge volume of disparate data to allow users to implement data analysis and reaction (Dhoodhat, 2018; Sestino et al., 2020). In proposing a big data analytics capability (BDAC) model for a firm's performance, (Akter et al., 2016; Wamba, Dubey, Gunasekaran, & Akter, 2020)introduce three predominant dimensions, which include, management, infrastructure and personnel capabilities. Similarly, in their effort to develop a capability assessment tool that can measure construction organizations' capability in the implementation of big data and predictive analytics (BDPA), Ngo et al., (2020) considered five factors that impact construction Organizations' capability to adopt BDPA namely Data characteristics, Organization operations, Technology and Software, Technical support and expertise, Organization culture.

Conceptualizing the Potential Benefit of Big Data Analytics

According to Deutsch (2015), the built environment domain is a data-intensive landscape. This indicates that the construction industry hosts a huge volume and a wide variety of data. Extensive analysis on twenty-two papers through content analysis method reveals the potential opportunities of big data in the construction industry centres towards 6 different themes including waste and resource optimization, data-driven design, decision support system, predictive prospects, Visualisation Analytic capabilities and capabilities for energy management.

To properly represent the potential benefits from big data analytics, a multifaceted benefit framework including IT infrastructure benefits, operational benefits, organizational benefits, managerial benefits, and strategic benefits (Shang & Seddon, 2002)is used to classify the statements related to the benefits from the collected 28 big data cases in the construction industry. Shang & Seddon's framework was adopted to classify the potential benefits of big data analytics for three reasons. First, this framework will help us to identify the benefits of big data analytics into proper categories. Second, this framework is suitable as a more generic and systemic model for categorizing the benefits of big data analytics system. Third, this framework also provides a clear guide for assessing and classifying benefits from enterprise systems. This guide also suggests ways how to validate the IS benefit framework through implementation cases, which is helpful for our study.

Research method

To reach the objectives of this study, an exploratory literature review was carried out to gain an understanding of big data analytic (BDA) research and the categorization of BDA capabilities and potential benefits derived from its application. It surveyed 19 influential journals from five distinct sub-division of construction-related research, including 1) automation in construction, 2) Advanced engineering informatics, 3) Journal of business research, 4) applied computing and informatics, 5) energy procedia, and conference papers. These journals were selected based on their sound academic status, impact factor, and relevance to the specific research field. Following this review of big data analytics and its application in the construction industry. We were able to collect a total of 28 big data cases specifically related to the construction industry. Of these number, 26 data analysis techniques from (Manyika et al., 2011) and one each from Bilal & Oyedele, (2020) and Jordan & Mitchell(2015) respectively.

Research approach

The study adopts content analysis to gain insights from the cases collected. Content analysis is a method for extracting various themes and topics from text, and it can be understood as, "an empirically grounded method, exploratory in process, and predictive or inferential in intent." Specifically, this study followed inductive content analysis, because the knowledge about big data implementation in construction is not only fragmented but at an incipient stage (Konanahalli, Oyedele, Marinelli, & Selim, 2018; Raghupathi & Raghupathi, 2012). A three-phase research process for inductive content analysis (i.e., preparation, organizing, and reporting) suggested by Elo & Kyngas (2007) was performed to ensure a better understanding of big data analytics capabilities and benefits within the construction industry domain.

The preparation phase starts with selecting the 'themes'; In this study, the themes from case materials were as described by top practitioners in construction who have put in at least 15 years of working experience with a multinational construction and technology-driven organisations. The second phase is to organize the qualitative data that emerged from phase one through open coding, creating categories and abstraction(Elo & Kyngas, 2007). In the course of open coding, the 113 reports were evaluated and then grouped into preliminary conceptual themes based on their similarities. The purpose is to reduce the number of categories by collapsing those that are similar to broader higher-order generic categories(Dey, 1993).

Featured capability of big data analytics in the construction industry

The next section describes the six generic categories of big data analytics capabilities that were identified from 113 statements in our review of the cases are analytical capability for resource and waste optimisation (coded as part of 27 statements), Analytical capability for data-driven design (23), decision support capability (19), predictive capability (18), Virtual analytic capability (16) and Analytic capabilities for Energy Management (10).

Analytical capability for resource and waste optimization

The upward surge in population and its attendant urbanisation has escalated construction activities globally. This in turn spurs the construction industry to consume the bulk of natural resources and produce massive construction and demolition waste (Hill & Bowen, 1997; Kaatz, Root, Hill, & Bowen, 2006; Nadzri, Osman, Udin, & Salleh, 2012; Ofori, 2000).

The analytical capability has to do with the analytical techniques typically used in a big data analytics system to process data with huge volume (from Terabytes to Exabyte), variety (from text to graph) and velocity (from batch to streaming) via unique data storage, management, analysis, and visualization technologies(Simon, 2014). Barima(2017)noted that the generation and utilisation of massive data are key intrinsic characteristics tied to value delivery within the construction domain. Therefore, the use of big data analytics can reveal better insights for construction value delivery than the traditional method applied in dealing with data and information(Bilal et al., 2016).

Analytical capability for data driven-design

Data-driven decision-making at the design stage is revealed to bring a revolution for preventing a significant proportion of construction concerns. This ability is beneficial for architects, engineers and all involved in design to better communicate construction designs (Omran, 2016). The construction industry is fraught with many perennial issues ranging from delay, waste, conflict and injury. Being able to minimize waste, avert accident or mitigate their impact is now realizable with capabilities that big data analytic has provided. is core to so many exciting project activities.

The current application of generative design (GD) tools employ sophisticated algorithms to combine design space and generate a wide range of design solutions that meet the given requirements. These designs are presented to designers for evaluation based on their performance. This evaluation enables the designers to go over designs by adjusting design goals and constraints to a design till the design is produced to meet an approved taste. The progression made with this tool has so far been able to facilitate designers, for generating designs based on abstract design requirements. A feat currently achieved in this Autodesk Dreamcatcher—a prototype system to showcase the feasibility of this idea of generating design from abstract requirements (Bilal, et al., 2016b).

Decision Support capability

As the organisation begin to take cognizance of the role of data, decision support systems have become an essential part of an organization's decision making strategy. Many have deployed technology to gain a competitive advantage over others and also to help make better decisions (Akintola, Adetunmbi, & Adeola, 2011). Decision support capability outlines the ability to generate reports about construction activities and processes to guide managers' decisions and actions. In their study, Lin et al., (2016) showed the development of a specialised big BIM data storage and retrieval system for experts and naive BIM users. The intentions are to develop a highly interactive user interface for querying BIM data through mobile devices to maximise its utility and usability.

Finding from the content analysis across research in the related field show that Big Data analytics is capable of tracking the progress of various construction sites using automated tools, processing the real-time streams of these images to measure the daily change and updated the BIM models and construction schedule accordingly. The project managers are presented with an update to date progress on the schedule, which will, in turn, enable them to see whether they are lagging on the project or still follow the schedule.

Predictive capability

According to Shmueli & Koppius (2011), predictive capability involves the ability to design and assess a model whose aim is to generate precise predictions about situations where it’s possible to predict new direction temporally or as a representative sample. Wessler (2013) defines predictive capability as the process of using a set of sophisticated statistical tools to develop models and estimations of what the environment will do in the future. To create predictive capability, organizations have to rely on a predictive analytics platform that incorporates data warehouses, predictive analytics algorithms (e.g., regression analysis, machine learning, and neural networks), and reporting dashboards that provide optimal decisions to users. This platform makes it possible to cross-reference current and historical data to generate context-aware recommendations that enable managers to make predictions.

When employed properly, competency in this area can improve almost every phase of a construction company’s business, including risk forecasting, contractor management, predictive modelling, and safety training. Big data analytics capabilities extend even to improve marketing, machine maintenance, scheduling, and return on construction assets. The right investment strategy combined with technical skills and expertise in predictive analysis can make critical business decisions—decisions that can help cut costs, increase productivity, boost safety, and enhance efficiency (Ngo et al., 2020).

Visualisation Analytic capability

With the rising amount of information and data generated in the construction project life- cycle, what has come to stay in visual analytics. The area of Visual Analytics came into existence to combine automated reasoning and visualisation to solve complex analytical problems. Practitioners in the construction industry are faced with the task of making timely and high-quality decisions based on a large number of data sets [e.g., drawings, schedule and cost data, resource quantity, (3D) image] from various sources. Visualisation techniques hold significant potential to represent these large data sets of construction information in several forms that provide valuable insight into various construction domains(Leite et al., 2016).

The use of visualisation has spread to many construction activities; for example, as a tool to support diverse decision-making tasks; in the design and construction phases focus primarily on scheduling and as-built visualization. Study report that Visualization representation may advance construction communication, collaboration, and coordination in general, but its level of acceptance varies in different construction management tasks.

Analytic capabilities for Energy Management

With the growing emphasis on sustainability, construction processes are fast adopting sustainability principles to encourage environmentally friendly materials. The result which is to reduce pollution and energy use has gained wide acceptability in the construction research domain. Energy management considers the integration of big data analytics in understanding the building energy consumption to increase energy efficiency and add to building performance(Dixon et al., 2017). In the same vein, Koseleva & Ropaite(2017)adds that Big Data analytics provide the opportunity to better monitor, correct, and integrate smart grid technologies and renewable energy. Currently, electronic sensors and enhanced technologies provide data on energy demand, supply, system performance, and operations. This information is essential for the deployment of smart grid technologies, effective operation of demand response programs and the integration of renewable energy. Advances in this ability for energy management is said to be necessary to improve fuel efficiency, reduce emissions and energy consumption.

Potential benefits of big data analytics in the construction industry

Big data is believed to proffer solution to construction and other allied industry. It is seen as a strategic technology that is perceived as a source of competitive advantage for various businesses regardless of their industry. Big data empowers data analysts to make sense of pervasive data sets and transforms them into useful information and new knowledge. The benefits of big data analytics in the construction industry are indeed numerous as this new technology allows high-performance analytics from multiple structures and unstructured data sources.

The outcome from the content analysis indicates that the benefits derived from big data analytics can be categorised into five themes: organizational benefits, IT infrastructure benefits, operational benefits, managerial benefits, and strategic benefits.

Organizational benefits: Information modelling is a virtual process that encourages the integration of all stakeholders in a project for a more accurate and efficient collaboration than traditional processes (Leite et al., 2016). In other words, digital information can be leveraged from each project into business value. This idea in addition to others led to the development of more generic IT solutions especially with the development of Building Information Modelling (BIM). BIM as a process and technology can provide greater consistency of structured data for construction. In doing this, it becomes aware of interoperability problems much more quickly than traditional manual methods. The benefit is also gained through the practices of monitoring and maintaining buildings performance; this is achieved and improved by integrating spoken dialogue system with the knowledge-based BIM systems which enable easier capture and search for solutions to new problems with a more comprehensive retrieval of information (Motawa, 2017). A wide area still exists for the construction industry to capturing multi-mode data into BIM systems using the cloud-based to guide construction teams to utilise the high volume of data generated overbuilding lifecycle and search for the most suitable solutions for maintenance problems.

IT infrastructure benefits: There is a paradigm shift away from BIM to Big BIM data. Equally, the construction industry is witnessing a rapid deployment of technologies that facilitate advanced

programming. For instance, multiple users can simultaneously access cloud services without having to purchase individual licenses. Cloud computing is an Internet computing paradigm in which on-demand access to a shared pool of configurable resources is provided (Bughin, Chui, & Manyika, 2010). A core benefit that has resulted from this is the prevention of unnecessary IT costs and the quick transfer of data among construction professionals. IT infrastructure has also made possible accurate and timely prediction of machine use, workload thereby cutting off possibilities of system redundancy and downtime.
Cloud computing has already fast track the uptake of IT in the construction industry by transforming many domain-specific applications. When Chuang, Lee, & Wu(2011) used cloud computing for BIM design exploration and manipulation, it was to better enhance design systems and process standardization among various construction IT systems. As the implementation of a robust IT infrastructure is already having a meaningful impact on construction processes, it is no doubt guaranteed to bring overwhelming transformation soon.

Operational benefits: The benefits of digital monitoring and predictive maintenance extends towards detecting errors on equipment and performing maintenance before they are entirely damaged. It was reported by analytics firm, Kimberlite that approximately $49 million annually were wasted due to an unplanned downtime(Choudhry, Mohammad, Tan, & Ward, 2016). Hence, big data in this respect helped to enhance production and addressed the financial impacts before it eventually occurs (Granberg & He, 2018; Riggins & Wamba, 2015). These challenges however need nothing other than the applications of Big Data technologies in the development of FM systems. Particularly, in the case of predictive maintenance, big data analytics can inform FM managers whenever equipment is likely to break or require an upgrade. Consequently, FM organisations could benefit from lowered operating expenses, higher profit margins 36 and enhanced service availability. The construction industry is positioned to benefit from big data analytic through improving the quality and accuracy of decisions, reductions in injury and hazard related cases, ability to process massive information, cut off the waste of resources and explore more insights embedded in high volume data.

Managerial benefits: The real gains lie in the opportunity to better leverage the vast amount of data and information available(Brock & Khan, 2017), and in understanding which tools and techniques are best for the organization. Big data analytics has been known to play an important role in improving organizational performance by identifying new opportunities, highlighting potential threats, revealing new business insights and enhancing decision making processes among many other benefits(Ram et al., 2016; Xia & Gong, 2014). In general, BDA offer managers the ability not only to gain insights quickly about changing future trends in the construction environment but also provide managers with sound decision-support information for short, mid and long term actions. Finally, as observed by Pries & Dunnigan(2015), a crucial element of managerial benefit of big data analytics is the optimisation of business growth-related decisions.

Strategic benefits: According to Ngo et al., (2020)Big Data Analytics (BDA) entails the application of a series of analytical techniques on large data sets to identify patterns and derive insights for business performance. Globally, this phenomenon is assisting business discover latent knowledge in ways that were once taught impossible traditionally. To keep pace with today’s rapidly changing environment, construction organizations are required to adapt dynamically effectively and efficiently (Lněnička, Máchová, Komárková, & Čermáková, 2017). Strategic management is described as the determination of the long term objectives and goals of an organisation and the implementation of course of action and the allocation of required resources for executing those goals (Bracker, 1980). In other words, strategic management is a process of reinforcing long-range planning and implementing future goal definition and its achievement. Kornyshova & Barrios (2020) and (Lněnička et al., 2017)noted that this concept is currently compelled and under pressure to implement big data analytics as a tool for improving the efficiency of decision-making and monitoring processes. So far, however, organisations that leverage big data analytics' have witnessed much progress in establishing a coherent set of guidelines, principles and governance that provide direction and practical help in the design and development of long term enterprise strategies and visions and created a highly competitive setting for the construction business.

The strategies for success with big data analytics in the Construction Industry

Although the opportunities and benefits brimming from Big Data Analytics to the construction industry are enormous, the full advantage will remain a mirage if certain issues are not dealt with. To build a data-driven organization, Wang, Kung, Wang, & Cegielski(2018) and Atuahene et al., (2018) suggest that practitioners need to identify the strategic and business value of big data analytics, rather than merely concentrating on a technological understanding of its implementation. To secure a successful implementation and propagate advances of big data analytics it is important to take certain concern into consideration

Data security and privacy implementation

Data security is a front line issue that is dominating most discussion for many businesses and organisations. As society tends to become digitalized and activities rely on technology for many processes data security is becoming a priority. Hence the implementation of stringent security measures such as access control, intrusion prevention will be the right direction to go. These issues also require more study within the construction domain so that the appropriate solutions can be adopted in the underlying analytics workflows.

Developing an information-sharing culture

The construction industry has been described as fragmented (Egan, 1998; Latham, 1994; Ofori, 2000) both in its nature and its process; these according to other studies is the bane of steady growth (Miller, Furneaux, Davis, Love, & Donnell, 2009; Ofori, 2007, 2012). Building Information Modelling (BIM) is considered to capture multi-dimensional CAD information systematically for supporting multidisciplinary collaboration among the stakeholders. A major requirement for implementing big data analytics successfully is that the stakeholder within the industry synthesizes all aspect that makes for effective communication and encourages information sharing principles. This is critical for reducing any resistance to new information management systems among professionals. Without an information-sharing culture, data collection and delivery will be limited, with consequent adverse impacts on the effectiveness of the big data analytical and predictive capabilities. To address this issue, construction organisation should engage data providers from the earliest stage of the big data transition process and develop policies that encourage and reward them for collecting data and meeting standards for data delivery. This will significantly improve the quality of data and the accuracy of analysis and prediction.

Equipping personnel with skills to use big data analytics

Technological development is closely linked with technology, software, technical skills and expertise. The essential ingredient to utilize the outputs from big data analytics effectively is to provide managers and employees with requisite competencies, such as critical thinking and the skills of making an appropriate interpretation of the results(Pan & Zhang, 2021). Because incorrect interpretation of the reports generated could lead to serious errors of judgment and questionable decisions. Therefore, it is important that the construction industry must provide analytical training courses in areas such as data mining, machine learning and business intelligence to workers who will play a critical support role in the new information-rich work environment. According to a Study of Leadership from 2005 through 2015 of a Global Study of Innovation Management in Canada, USA, Latin-America, Asia, Pacific, Europe, Middle East and Africa the American Management Association (For, 2006), highlights approaches to help workers develop the big data analytical skills they will need. Invariably, the construction industry can regulate its job selection criteria to engage prospective employees who already have the necessary analytical skills.

Conclusion and recommendation

This study through its analysis of big data analytics cases elicit research direction that is capable of transforming the construction business. It also highlights an understanding of how construction organizations and the industry at large can leverage big data analytics as a means of supporting and transforming IT to gain business value. However, the primary limitation of this study is the data source. One challenge the construction is that its IT adoption usually lags behind other industries. This position is validated by many other studies in this field. Nevertheless, given the growing number of construction organizations adopting big data analytics, many more will be encouraged to implement a reliable means of analyzing data to form strategies and improve business performance. Besides, there already exist best practices that explain that there are practical ways for the adoption of new technologies to digitise and automate the construction process. The findings further complement existing studies that focus on advancing the technical processes of big data analytics by providing a road map for big data analytics potentials in the construction industry.

Moreover, through this comprehensive analysis of the existing application of big data analytics techniques for construction-related discipline, this study extends research streams and acknowledge the fact that the implementation of big data analytics has an overarching potential to improve the capacity to produce more, enhance efficiency, quality and collaboration, their adoption can help to detect fraud, enhance safety, sustainability and therefore improve the unpleasant and long-held impression of the construction industry to change. While noting the thrill and exciting opportunities with big data analytics, it is also worthy to note that the concept does not hold the magic solution, it merely sets the stage. Skilled professionals and domain experts, empowered with sophisticated analytical workflows are therefore required equally necessary to reap the overall benefits.

References

Aghimien, D., Aigbavboa, C., & Oke, A. (2019). A review of the application of data mining for sustainable construction in Nigeria. *Energy Procedia*, *158*, 3240–3245. https://doi.org/10.1016/j.egypro.2019.01.996

Ahiaga-dagbui, D. D., & Smith, S. D. (2014). Construction Management and Economics Dealing with construction cost overruns using data mining, (December), 37–41. https://doi.org/10.1080/01446193.2014.933854

Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). The future of Big Data in facilities management: opportunities and challenges. *Facilities*, *35*(13–14), 725–745. https://doi.org/10.1108/F-06-2016-0064

Akanmu, A., & Anumba, J. C. (2015). Cyber-physical systems integration of building information models and the physical construction. *Engineering, Construction and Architectural Management*, *22*(1), 91–107.

Akhavian, R., & Behzadan, A. H. (2015). Construction equipment activity recognition for simulation input modeling using mobile sensors and machine learning classifiers. *Advanced Engineering Informatics*, *29*(4), 867–877. https://doi.org/10.1016/j.aei.2015.03.001

Akintola, K. G., Adetunmbi, a O., & Adeola, O. S. (2011). Building data warehousing and data mining from course management systems: A case study of FUTA course management information systems. *International Journal of Database Theory and Application*, *4*(3), 13–24.

Akter, S., Wamba, S. F., Gunasekaran, A., Dubey, R., & Childe, S. J. (2016). How to improve firm performance using big data analytics capability and business strategy alignment? *International Journal of Production Economics*, *182*, 113–131. https://doi.org/10.1016/j.ijpe.2016.08.018

Alaka, H. A., Oyedele, L. O., Owolabi, H. A., Bilal, M., Ajayi, S. O., & Akinade, O. O. (2018). A framework for big data analytics approach to failure prediction of construction firms. *Applied Computing and Informatics*. https://doi.org/10.1016/j.aci.2018.04.003

Ambigavathi, M., & Sridharan, D. (2018). *Big Data Analytics in Healthcare*. *2018 10th International Conference on Advanced Computing, ICoAC 2018*. https://doi.org/10.1109/ICoAC44903.2018.8939061

Aouad, G., Kagioglou, M., Cooper, R., Hinks, J., & Sexton, M. (1999). Technology management of IT in construction: a driver or an enabler? *Logistics Information Management*, *12*(1/2), 130–137. https://doi.org/10.1108/09576059910256583

Atuahene, B. T., Kanjanabootra, S., & Gajendran, T. (2018). Towards an integrated framework of big data capabilities in the construction industry: A systematic literature review. *Proceeding of the 34th Annual ARCOM Conference, ARCOM 2018*, (September), 547–556.

Barima, O. (2017). 'BIG Data' and construction value delivery", Construction Projects: Improvement Strategies, Quality Management and Potential Challenges. In K. Hall (Ed.), *Construction Projects: Improvement Strategies, Quality Management and Potential Challenges* (pp. 113–135). Nova Science Publishers, Inc.

Bilal, M., & Oyedele, L. O. (2020). Guidelines for applied machine learning in construction industry—A case of profit margins estimation. *Advanced Engineering Informatics*, *43*(March 2019), 101013. https://doi.org/10.1016/j.aei.2019.101013

Bilal, M., Oyedele, L. O., Akinade, O. O., Ajayi, S. O., Alaka, H. A., Owolabi, H. A., … Bello, S. A. (2016). Big data architecture for construction waste analytics (CWA): A conceptual framework. *Journal of Building Engineering*, *6*, 144–156.

https://doi.org/10.1016/j.jobe.2016.03.002
Bilal, M., Oyedele, L. O., Qadir, J., Munir, K., Ajayi, S. O., Akinade, O. O., … Pasha, M. (2016). Big Data in the construction industry : A review of present status , opportunities , and future trends. *Advanced Engineering Informatics, 30*(3), 500–521. https://doi.org/10.1016/j.aei.2016.07.001
Bodenheimer, T. (2005). High and Rising Health Care Costs. Part 1: Seeking an Explanation. *American College of Physicians*, *142*(Number 10), 847–854.
Bracker, J. (1980). The historical development of the strategic management concept. *Academy of Management Review*, *5*(2), 219–224.
Brock, V. F., & Khan, H. U. (2017). Are enterprises ready for big data analytics ? A survey-based approach, *25*(2), 256–277.
Bughin, J., Chui, M., & Manyika, J. (2010). Clouds, big Big Data data, and smart assets: Ten tech-enabled business trends to watch. *McKinsey Quarterly*, (4), 26–43.
Chen, X., Lu, W., & Liao, S. (2017). A Framework of Developing a Platform for Construction Waste Management: A Hong Kong Study. *Proceedings of the 20th International Symposium on Advancement of Construction Management and Real Estate*, 1069–1076. https://doi.org/10.1007/978-981-10-0855-9_94
Chilipunde, R. L. (2010). Constraints and challenges faced by small, medium and micro enterprise contractors: A case study of Malawi. *COBRA 2010 - Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors*, (April).
Choudhry, H., Mohammad, A., Tan, K. T., & Ward, R. (2016). The next frontier for digital technologies in oil and gas, (March), 1–3.
Chuang, T. H., Lee, B. C., & Wu, I. C. (2011). Applying cloud computing technology to BIM visualization and manipulation. *Proceedings of the 28th International Symposium on Automation and Robotics in Construction, ISARC 2011*, 144–149. https://doi.org/10.22260/isarc2011/0023
Côrte-Real, N., Ruivo, P., & Oliveira, T. (2020). Leveraging internet of things and big data analytics initiatives in European and American firms: Is data quality a way to extract business value? *Information and Management*, *57*(1), 103141. https://doi.org/10.1016/j.im.2019.01.003
Deutsch, R. (2015). *Data-Driven Design and Construction 25 Strategies for capturing, analyzing, and applying Building data*. John Wiley & Sons, Inc.
Dey, I. (1993). *Qualitative data analysis: A user-friendly guide for social scientists*.
Dhoodhat, Z. (2018). Investigating the Relationship between Big Data Analytics Capabilities Keywords, (November).
Dixon, T., Wetering, J. van de, Sexton, M., Lu, S.-L., Williams, D., Duman, D. U., & Chen, X. (2017). Smart Cities, Big Data and the Built Environment: What's Required?, (March). https://doi.org/10.15396/eres2016_336
Egan, J. (1998). *Rethinking the report of the construction task force*.
Ekambaram, A., SØrensen, A., Bull-Berg, H., & Olsson, N. O. E. (2018). The role of big data and knowledge management in improving projects and project-based organizations. *Procedia Computer Science*, *138*, 851–858. https://doi.org/10.1016/j.procs.2018.10.111
Elo, S., & Kyngas, H. (2007). The qualitative content analysis process, (Cole 1988), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x
Fayyad, U., Piatetsky-shapiro, G., & Smyth, P. (1996). From Data Mining to Knowledge Discovery in, *17*(3), 37–54.

For, Q. (2006). *A Study of Leadership from 2005 through 2015 A Global Study of Innovation Management Canada USA-Latin America-Asia-Pacific Europe-Middle East-Africa*. Retrieved from www.amanet.org

Gopalakrishnan, K., Agrawal, A., & Choudhary, A. (2017). Big Data in Building Information Modeling Research: Survey and Exploratory Text Mining. *MOJ Civil Engineering*, *3*(6). https://doi.org/10.15406/mojce.2017.03.00087

Granberg, M., & He, D. (2018). The Future of Big Data Analysis in Facility Management - A Study of Implementation areas.

Han, J., Kamber, M., & Pei, J. (2012). *Data mining Concepts and Techniques*.

Han, K. K., & Golparvar-Fard, M. (2017). Potential of big visual data and building information modeling for construction performance analytics: An exploratory study. *Automation in Construction*, *73*, 184–198. https://doi.org/10.1016/j.autcon.2016.11.004

Hill, R. C., & Bowen, P. a. (1997). Sustainable construction: principles and a framework for attainment. *Construction Management and Economics*, *15*(3), 223–239. https://doi.org/10.1080/014461997372971

Ismail, S. A., Bandi, S., & Maaz, Z. N. (2018). An Appraisal into the Potential Application of Big Data in the Construction Industry. *International Journal of Built Environment and Sustainability*, *5*(2), 145–154. https://doi.org/10.11113/ijbes.v5.n2.274

Jordan, M. I., & Mitchell, T. M. (2015). Machine learning: Trends, perspectives, and prospects. *Science*, *349*(6245), 255–260. https://doi.org/10.1126/science.aaa8415

Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation. *Automation in Construction*, *20*(2), 126–133. https://doi.org/10.1016/j.autcon.2010.09.010

Kaatz, E., Root, D. S., Hill, R. C., & Bowen, P. A. (2006). Fostering sustainability and enhancing quality in construction with building sustainability assessment. In *22nd Annual ARCOM Conference* (pp. 349–359).

Konanahalli, A., Oyedele, L., Marinelli, M., & Selim, G. (2018). Big data : A new revolution in the UK facilities management sector, (June), 58.

Kornyshova, E., & Barrios, J. (2020). Industry 4.0 impact propagation on enterprise architecture models. *Procedia Computer Science*, *176*, 2497–2506. https://doi.org/10.1016/j.procs.2020.09.326

Koseleva, N., & Ropaite, G. (2017). Big Data in Building Energy Efficiency: Understanding of Big Data and Main Challenges. *Procedia Engineering*, *172*, 544–549. https://doi.org/10.1016/j.proeng.2017.02.064

Latham, M. (1994). *Constructing the team: joint review of procurement and contractual arrangements in the UK construction industry*.

Leite, F., Cho, Y., Behzadan, A. H., Lee, S., Choe, S., Fang, Y., … Hwang, S. (2016). Visualization, Information Modeling, and Simulation: Grand Challenges in the Construction Industry. *Journal of Computing in Civil Engineering*, *30*(6), 1–16. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000604

Lin, J. R., Hu, Z. Z., Zhang, J. P., & Yu, F. Q. (2016). A Natural-Language-Based Approach to Intelligent Data Retrieval and Representation for Cloud BIM. *Computer-Aided Civil and Infrastructure Engineering*, *31*(1), 18–33. https://doi.org/10.1111/mice.12151

Lněnička, M., Máchová, R., Komárková, J., & Čermáková, I. (2017). Components of big data analytics for strategic management of enterprise architecture. *SMSIS 2017 - Proceedings of the 12th International Conference on Strategic Management and Its Support by Information*

Systems 2017, (July), 398–406.
Loyola, M. (2018). Big data in building design: A review big data in building design : a review. *Journal of Information Technology in Construction - ISSN 1874-4753*, *23*(January), 259–284.
Madanayake, U., & Çıdık, M. S. (2019). The potential of digital technology to improve construction productivity. In C. J. Gorse, C and Neilson (Ed.), *35th Annual ARCOM Conference* (pp. 416–425). Leeds, UK.
Madanayake, U. H., & Egbu, C. (2018). Critical analysis for big data studies in construction: significant gaps in knowledge.
Manyika, J., Chui Brown, M., B. J., B., Dobbs, R., Roxburgh, C., & Hung Byers, A. (2011). Big data: The next frontier for innovation, competition and productivity. *McKinsey Global Institute*, (May), 156. Retrieved from https://bigdatawg.nist.gov/pdf/MGI_big_data_full_report.pdf
Mbamali, I., & Okotie, A. (2012). An Assessment of the Threats and Opportunities of Globalization on Building Practice in Nigeria. *American International Journal of Contemporary Research*, *2*(4), 143–150.
McKinsey & Company. (2013). The "big data" revolution in healthcare: accelerating value and innovation. *McKinsey Global Institute*, (January), 1–22. Retrieved from http://www.images-et-reseaux.com/sites/default/files/medias/blog/2013/12/mckinsey_131204_-_the_big_data_revolution_in_healthcare.pdf
Miller, G., Furneaux, C., Davis, P., Love, P., & Donnell, A. O. (2009). Built Environment Procurement Practice : Impediments to Innovation and Opportunities for Changes, (May).
Mohamed, A., Najafabadi, M. K., Wah, Y. B., Zaman, E. A. K., & Maskat, R. (2020). *The state of the art and taxonomy of big data analytics: view from new big data framework*. *Artificial Intelligence Review* (Vol. 53). Springer Netherlands. https://doi.org/10.1007/s10462-019-09685-9
Motawa, I. (2017). Spoken dialogue BIM systems – an application of big data in construction. *Facilities*, *35*(13–14), 787–800. https://doi.org/10.1108/F-01-2016-0001
Moynihan, G. P., Chau, A., Vereen, S., & Batson, R. G. (2017). Application of big data in university construction projects. *67th Annual Conference and Expo of the Institute of Industrial Engineers 2017*, 85–90.
Nadzri, W., Osman, B., Udin, Z. M., & Salleh, D. (2012). Adoption Level of Sustainable Construction Practices : A Study on Malaysia ' s Construction Stakeholders, *2012*. https://doi.org/10.5171/2012.270273
Ngo, J., Hwang, B. G., & Zhang, C. (2020). Factor-based big data and predictive analytics capability assessment tool for the construction industry. *Automation in Construction*, *110*(November 2019), 103042. https://doi.org/10.1016/j.autcon.2019.103042
Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121–139. https://doi.org/10.1016/j.compind.2016.09.006
Ofori, G. (2000). Greening the construction supply chain in Singapore, *6*(April), 195–206.
Ofori, G. (2007). Construction in Developing Countries. *Construction Management and Economics*, *25*(1), 1–6. https://doi.org/10.1080/01446190601114134
Ofori, G. (2012). Developing the Construction Industry in Ghana : the case for a central agency, (March), 1–19.
Omran, B. A. (2016). Application of Data Mining and Big Data Analytics in the Construction

Industry. *PhD Dissertation*, *147*, 178.
Omran, B. A., Chen, Q., Asce, A. M., & Jin, R. (2014). Comparison of Data Mining Techniques for Predicting Compressive Strength of Environmentally Friendly Concrete, 1–13. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000596.
Pan, Y., & Zhang, L. (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. *Automation in Construction*, *122*(October 2020), 103517. https://doi.org/10.1016/j.autcon.2020.103517
Petruseva, S., Sherrod, P., Pancovska, V. Z., & Petrovski, A. (2016). Predicting Bidding Price in Construction using Support Vector Machine. *Tem Journal*, *5*(2), 143–151. https://doi.org/10.18421/TEM52-04
Philp, D. (2018). The role of security in the construction industry. *The Chartered Institute of Building*.
Pries, K. H., & Dunnigan, R. (2015). *Big Data Analytics: A Practical Guide for Managers*. Taylor & Francis Group.
Raghupathi, W., & Raghupathi, V. (2012). Big data analytics in healthcare: promise and potential. *Communications of the ACM*, *55*(10), 11. https://doi.org/10.1145/2347736.2347741
Ram, J., Afridi, N. K., & Khan, K. A. (2019). model Adoption of Big Data analytics in construction : development of a conceptual model construction. https://doi.org/10.1108/BEPAM-05-2018-0077
Ram, J., Zhang, C., & Koronios, A. (2016). The implications of Big Data analytics on Business Intelligence : A qualitative study in China. *Procedia - Procedia Computer Science*, *87*, 221–226. https://doi.org/10.1016/j.procs.2016.05.152
Riggins, F. J., & Wamba, S. F. (2015). Research directions on the adoption, usage, and impact of the internet of things through the use of big data analytics. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2015-March*, 1531–1540. https://doi.org/10.1109/HICSS.2015.186
Roy, A., Morales, R. R., Fouché, E., & Möhler, G. (2019). In-database geospatial analytics using python. *Proceedings of the 2nd ACM SIGSPATIAL International Workshop on Advances in Resilient and Intelligent Cities, ARIC 2019*, 17–24. https://doi.org/10.1145/3356395.3365598
Saggi, M. K., & Jain, S. (2018). A survey towards an integration of big data analytics to big insights for value-creation. *Information Processing and Management*, *54*(5), 758–790. https://doi.org/10.1016/j.ipm.2018.01.010
Sestino, A., Prete, M. I., Piper, L., & Guido, G. (2020). Internet of Things and Big Data as enablers for business digitalization strategies. *Technovation*, *98*(August), 102173. https://doi.org/10.1016/j.technovation.2020.102173
Shang, S., & Seddon, P. B. (2002). Assessing and managing the benefits of enterprise systems: the business manager's perspective. *Information Systems Journal*, *12*, 271–299.
Shmueli, G., & Koppius, O. R. (2011). Predictive Analytics in Information Systems Research1, *35*(3), 553–572.
Siddiqa, A., Karim, A., & Gani, A. (2017). Big data storage technologies: a survey. *Frontiers of Information Technology & Electronic Engineering*, *18*(8), 1040–1070. https://doi.org/10.1631/fitee.1500441
Simon, P. (2014). *The visual organization: data visualization, big Data, and the quest for better decisions*. John Wiley & Sons, Inc., Hoboken, New Jersey.
Suthaharan, S. (2014). Big data classification: Problems and challenges in network intrusion prediction with machine learning. *Performance Evaluation Review*, *41*(4), 70–73.

https://doi.org/10.1145/2627534.2627557
Tiwari, S., Wee, H. M., & Daryanto, Y. (2018). Big data analytics in supply chain management between 2010 and 2016: Insights to industries. *Computers and Industrial Engineering*, *115*, 319–330. https://doi.org/10.1016/j.cie.2017.11.017
Wamba, S. F., Dubey, R., Gunasekaran, A., & Akter, S. (2020). The performance effects of big data analytics and supply chain ambidexterity: The moderating effect of environmental dynamism. *International Journal of Production Economics*, *222*. https://doi.org/10.1016/j.ijpe.2019.09.019
Wamba, S. F., Gunasekaran, A., Akter, S., Ren, S. J. fan, Dubey, R., & Childe, S. J. (2017). Big data analytics and firm performance: Effects of dynamic capabilities. *Journal of Business Research*, *70*, 356–365. https://doi.org/10.1016/j.jbusres.2016.08.009
Wang, Kung, L. &, & Byrd, T. (2018). Big data analytics: Understanding its capabilities and potential benefits for healthcare organizations. *Technological Forecasting and Social Change*, *126*, 3–13. https://doi.org/10.1016/j.techfore.2015.12.019
Wang, L., & Alexander, C. A. (2015). Big Data in Medical Applications and Health Care. *American Medical Journal*, *6*(1), 1–8. https://doi.org/10.3844/amjsp.2015.1.8
Wang, Y., Kung, L. A., Wang, W. Y. C., & Cegielski, C. G. (2018). An integrated big data analytics-enabled transformation model: Application to health care. *Information and Management*, *55*(1), 64–79. https://doi.org/10.1016/j.im.2017.04.001
Wessler, M. (2013). *Big Data Analytics for Dummies*. John Wiley & Sons, Inc. Hoboken, New Jersey.
Xia, B. S., & Gong, P. (2014). Review of business intelligence through data analysis. *Benchmarking*, *21*(2), 300–311. https://doi.org/10.1108/BIJ-08-2012-0050
Yang, K. (2020). The construction of sports culture industry growth forecast model based on big data. *Personal and Ubiquitous Computing*, *24*(1), 5–17. https://doi.org/10.1007/s00779-019-01242-z
Yaxing, W., Feng, L., Chang, H., & Wu, M. (2017). Research on the impact of big data on logistics. *MATEC Web of Conferences*, *100*, 1–5. https://doi.org/10.1051/matecconf/201710002015
Zikopoulos, P., Eaton, C., Deroos, D., Deutsch, T., & Lapis, G. (2012). *What Is Big Data? Hint: You're a Part of It Every Day*. *Understanding Big Data: Analytics for Enterprise Class Hadoop and Streaming Data*.