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An Appraisal into the Potential Application of Big Data in the Construction Industry

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ABSTRACT

The volume of data generated by the construction industry has increased exponentially following an intense use of modern technologies. The data explosion thus lead towards the big data phenomenon which is envisioned to revolutionize the construction like never before. Like any other technologies, big data is a disruptive paradigm and inevitably will give impact to the construction industry. As the industry is refocusing towards an improved productivity, the appeal to embrace big data is certain given the value it offers. This certainly will benefit construction akin to the manufacturing and the retail industry alike. Nevertheless, a review of the literature suggested a limited coverage on the potential application of big data in construction as compared to other industries. This limits understanding of its potential, where the industry is seemingly unaware thus could not relate and extract its real value. Hence, this study aims to draw insights on the specific areas of construction big data research. The research objectives include: (1) to analyse the current extent of construction big data research; (2) to map out the orientation of the current construction big data research; and (3) to suggest the current directions of construction big data research. The qualitative method through a desk study approach has been carried out to attain the first two objectives. It involved a structured review process which covered articles from the online databases assisted by the Nvivo software. This resulted in the theoretical orientation which was conceptualized as: (1) project management; (2) safety (3) energy management; (4) decision making design framework and (5) resource management. The theoretical orientation discovered from the review process will form the basis to suggest the prospective directions of research on big data in construction. This exploration is substantial as a precursor to a much deeper study on big data. As big data is set to influence the industry, the finding made would be a catalyst for creating an awareness to support the development of big data for the construction industry.

1. Introduction

Big data has been buzzing among many industries around the world on its potential in dissolving most of the industries' common issues and transform them into a smarter way of operating. The advent of big data era is initiated by the data explosion resulted from the presence of advanced technology in today's world. According to Waal-Montgomery (2015) prediction, the world's data volume will rise at approximately 40% per year, and will continue to intensify fifty times from the current volume by the year 2020. The pace in which data is being generated has lead towards data explosion hence big data gain its traction. Basically, big data is often termed based on the 3Vs namely (i) Volume - amount of the data itself, (ii) Velocity – the speed where the data is generated and (iii) Variety – the diversity and complexity of data sources. The construction industry is known to deal with enormous amount of data that reflects the 3Vs and the utilization of these data could be the next frontier for construction industry development.

Peiffer (2016) asserted big data as one of the significant driving factor in configuring the direction which should lead towards improving the industry's efficiency. Though the construction industry is acknowledged as one of the indicator for economic wellbeing, productivity and efficiency are at an all-time low which Harenberg (2017) sorely contended in comparison to when it was in the year 1993. This inefficiency, according to Santiago Castagnino, Christoph Rothballer, and Gerbert (2016) was the result of the slow movement made by the industry in adopting new technologies. This is supported by the MGI's digitization index that put construction sector as the least digitized industry in the world. Santiago Castagnino et al. (2016) added the deliberate changes made by the industry is caused by the insufficient data-driven decision making.

Data is said to be the poster child in enhancing the industry's productivity. This follows as a real-time data exchange could lead to a broadened insight into the industry's operational performance thus making way for a smarter working (Peiffer, 2016). However, albeit of the massive amount of data that is generated in the construction industry, the big data is usually siloed and not being fully utilized for a bigger picture. According to Burger (2017), the inefficiencies of data usage is due to the limited ability in dealing with unstructured data such as free text, images or sensors reading. This is where big data could be the saviour in improving the utilization of data.

According to the Construction Industry Development Board Malaysia (CIDB), reliable and quality big data is currently in demand to align with the board's initiatives under the aspiration of the Construction Industry Transformation Programme (CITP). In conjunction with this, it is essential to identify the level of big data needs for the industry. The current move by CIDB is justified as the most typical error made by organizations was to utilize big data without assessing whether their needs could be satisfied by the use of the technology (Portela, Lima, & Santos, 2016). Likewise, Addo-Tenkorang and Helo (2016), added that there appear to be a limited understanding on the value and the potential of big data for construction. This had resulted in a consequential discouragement in the progress for the adoption of big data in construction industry as compared to other industries.

Data and the construction industry are indivisible as the industry are dealing with a huge amount of heterogeneous data. This follows as data related to construction industry has been predicted by Bilal, Oyedele, Qadir, et al. (2016) to rise exponentially with the advancement of technologies and the Internet of Things (IoT). According to Addo-Tenkorang and Helo (2016), new opportunities in the form of valuable insights can be developed by excerpting the huge amount of data obtained. Despite, a study that focuses on the potential application of big data particularly in the construction industry has not been comprehensively undertaken (Bilal, Oyedele, Qadir, et al., 2016). This limits understanding of its potential, where the industry is seemingly unaware thus could not relate and extract its real value.

Hence, this study aims to draw insights on the specific areas of construction big data research. The research objectives include: (1) to analyse the current extent of construction big data research; (2) to map out the orientation of the current construction big data research; and (3) to suggest the current directions of construction big data research. As big data is set to influence the industry, the research findings would be a catalyst for creating the much-needed awareness to support the development of big data for the construction industry. This would further lead the industry to gear up in developing their capabilities in harnessing the potential of big data as well as encouraging talent and infrastructure development to engage in the forthcoming wave of big data technology in the construction industry.

2. Literature Review

2.1 An overview of Big Data

The renowned 3Vs characteristics which form the big data concept were established by one of the Gartner analyst named Laney Doug in 2001. Respectively, the Gartner's IT Glossary defined big data as a 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, 2014).

With the arrival of big data, data will no longer be viewed as stagnant whose worth is limited to the accomplishment of its gathering purposes (Viktor & Kenneth, 2013). Whereas, in order to cross the boundary of data collecting purposes, the data need to be handled by means of advanced technologies and human skills as well as data entry base. However, according to Akbar (2017), the current amount of digital information had surpassed the ability of the present tools to process it. This situation is described as "The Industrial Revolution of Data" by Joe Hellerstein, a computer scientist at the University of California in Berkeley and it has affected various public and private sectors (Cukier, 2010).

Definition of big data might varies in different literature, but the domain of the concept is the 3Vs characteristics. Volume is the most important characteristic that represents the extent of big data magnitude. According to C. P. Chen and Zhang (2014) volume is epitomized as the size of the data itself that are generated by the advanced technologies, networks and human interactions especially on the nets (Hammer, Kostroch, & Quiros, 2017). On the other hand, velocity signifies that data is produced at a remarkably high speed which outstrips the conventional systems (Zikopoulos, Parasuraman, Deutsch, Giles, & Corrigan, 2012). Data velocity is regarded as a supplementary to data volume as greater data volume requires the data processing to be winged (Özköse, Arı, & Gencer, 2015). As Gartner (2015) has profoundly predicted, there will be as much as 20.8 billion connected devices by the year 2020 as compared to 6.4 billion as reported in 2016. This shows that the pace of data velocity will continue to speed up following the connected devices' enhanced features for data streaming (Lee, 2017). Last is variety which means the diversity and complexity of data categories and sources (Zikopoulos et al., 2012). According to Özköse et al. (2015), data may be derived from various resources both internally and externally. Similarly, O'Reilly (2014) emphasized in his book that these data come from an assortment of structures and it is often hard to obtain an impeccably, processing-ready data. Such data can be categorized into structured, semi-structured or unstructured data. This classification of data is derived from the existence of the social network, sensors, mobile devices, GPS and other technological appliances (Portela et al., 2016).

2.2 Current Big Data application in other sectors

In recent times, big data has been discussed across various sectors and is considered as a game changer in major industries (Gaitho, 2017). For this reason, many organizations have taken steps to change their plan of action in utilizing the big data value effectively (Akbar, 2017). A survey made by Gartner in 2015 proved that companies have incrementally increased their investment in big data to 75% from 58% recorded by the same survey in 2012. The extensive scope of big data has provided a massive scale of potential and value that can be generated across different sectors such as retail sector, manufacturing as well as the upstream industry.

Retail sector is among the earliest to recognise the potential of big data. This follows from the upsurge of e-commerce during the big data 1.0 era (Laney, 2001). During that time retail businesses leveraged the power of basic internet technologies to establish a strong web presence followed by building their capacity to process a large data which was conducive to their efficiency improvements (Provost & Fawcett, 2013). The potential was further extended in analysing the vast amount of data to support decision to expand businesses, improve cost efficiency and revenue forecasting (Meneer, 2015).

Manufacturing is another leading sector that has moved towards big data exploration in enhancing their product quality, and at the same time reducing the operational costs (Oracle, 2015). External data especially from social networks and suppliers' data combined with data from sensors and machines has given valuable insights to the existing information. In this respect, big data was utilized to analyse varieties in enhancing the efficiency of manufacturing and the operational process by providing the bird's eye view of the processes which led to a better decision making. Apart from that, big data technologies also assist in improving the product quality and reducing the overall cost through production and quality data analysis along with customers' returning data, capacity consumption as well as machinery efficiency (Oracle, 2015).

The oil and gas industry has also gained a lot from big data. According to B. Mathew (2016), in the current situation, data collected particularly in the operational process is used mainly for detection and control purposes. Big data's advanced analytics assisted in the decision making where big data insights were used to plan for predictive maintenance. In this case, it was reported that the technology has managed to bring the maintenance cost down to about 13% (Choudhry, Mohammad, Tan, & Ward, 2016). 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 an approximately $49 million annually were wasted due to an unplanned downtime (Choudhry et al., 2016). Hence, big data in this respect helped to enhance production and addressed the financial impacts before it eventually occurs.

2.3 Big Data and the Construction Industry

Construction is one of the major industry that is responsible towards a country development. The construction works to be carried out in a project is dynamic (Wood, 2016) and involve a high volume of data exchange from various stakeholders to be gathered and processed (Shrestha, 2013). Shrestha (2013) added that data is generated throughout the various phases of construction projects from planning phase to completion. As shown in Table 1, the stream of data includes design and financial data, sensors and equipment data, photos and videos and others. This data is often large in volume, highly diverse in format and dynamic. The multi faceted data reflects the multitude characteristics of data streaming from construction activities thus sits in comformity with the 3V's concept of big data.

Table 1 *Big Data context in Construction Industry*

Characteristics	Contributors	Examples
Volume	Large volume of data from different sources	Design data, cost data, financial data, contractual data, Enterprise Resource Planning (ERP) system, etc
Variety	Diversity in the content format	DWG (drawing), DXF (drawing exchange format), DGN (design), RVT (revit), ifcXML, ifcOWL, DOC/XLS/PPT (Microsoft format), RM/MPG (videos), JPEG (images)
Velocity	Dynamic nature of data sources	Sensors, RFIDs, Building Management System (BMS)

Source : Aouad, Kagioglou, Cooper, Hinks, and Sexton (1999); Bilal, Oyedele, Qadir, et al. (2016)

Further, Table 1 shows that the advancement of construction processes through the widespread utilization of these data shall be the next frontier of construction industry innovation and productivity. This is supported by Harenberg (2017) who mentioned real-time data processing as the future booster of productivity in construction.

2.4 Triggering Constituents of Big Data in the Construction Industry

The digitalized revolution has impacted the construction industry rather significantly as the industry is dealing with heterogeneous amount of data (Bilal, Oyedele, Qadir, et al., 2016). These triggering contituents to big data are identified and discussed as the following:

2.4.1 Building Information Modelling (BIM)

BIM is anticipated to capture the multi-dimensional CAD data to deliberately support the multidisciplinary and coordinated working environment among the stakeholders involved in a project (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). As BIM involves with capturing the additional layers of information throughout the entire building lifecycle, BIM is perceived to transform the construction industry across various perspectives (Azhar, 2011). Though data volume has been the characteristic of BIM, yet Humphreys (2016) argued that this data are not precisely big data. This follows as the huge files of BIM with the combination of the numerous models is still promptly prepared only to be processed by BIM applications. Likewise, the arrival of built-in devices and sensors has increased the amount of data generated where it eventually leads to the wellsprings of Big BIM Data (Bilal, Oyedele, Qadir, et al., 2016). Thus, this triggers the construction industry to penetrate the big data era.

2.4.2 Cloud Computing

Cloud computing is an internet computing trend which on request, give access to the merge of configurable resources (Bughin, Chui, & Manyika, 2010). The main purpose is to provide multiple users with access to data storage and computation without each having to resort for an individual license. The acceleration of cloud computing technology has contributed to the evolution of big data (Qubole, 2017). As cloud computing is supporting the coordination of errands in the BIM-based application, it has been broadly applied in the construction industry and big data performance in this revolution is astounding (Bilal, Oyedele, Qadir, et al., 2016). In addition, cloud computing and big data are said to be an ideal combo that contributes to the cost efficiency and extensible infrastructure in supporting Big Data and Business Analytics (Ferkoun, 2014).

2.4.3 Internet of Things (IoT)

The Internet of Things (IoT) has been the main pillar that triggers the big data 3.0 era. Basically, IoT is a system of Internet-connected devices that gather and transfer data through installed sensors (Meola, 2016). IoT application frequently conveyed a substantial number of sensors devices for data accumulation. As the industry presents boundless big data utilization cases for IoT, big data is inalienably the subject of intrigue (Bilal, Oyedele, Qadir, et al., 2016). Among the prominent areas of IoT applications includes logistics, transport, asset recording, intelligent homes and buildings, energy and agriculture. Bilal, Oyedele, Qadir, et al. (2016) claimed that IoT and big data are interdependent trends where a huge amount of data is created, accessed and analysed in real-time in construction applications. Additionally, Pal (2015) suggested that during the selection of big data processing technology, huge flood of information produced by IoT triggers big data on a reciprocal basis following the selection of big data processing technology.

2.4.4 Smart Buildings

Smart Building technology assimilates the contemporary technologies with existing building systems to attract the economical trade-off between comfort maximization and energy reduction (Khan & Hornbæk, 2011). Often, these systems will produce an enormous volume of data and the greater part of this information often stay undiscovered and eventually disposed of. According to Bilal, Oyedele, Qadir, et al. (2016), this data needs to be interpreted to truly reflect smart buildings hence gives big data analytics a significant role to play. The information and communication technology (ICT)-based integration and development systems, particularly Internet of Things is an important catalyst for various applications, both industry and the general population in realizing the smart buildings (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014). In this sense, Moreno et al. (2016) opined that big data and IoT are an impeccable combination in enhancing energy efficiency for Smart Buildings.

2.4.5 Augmented Reality (AR)

Augmented Reality is a technology that coordinates virtual object images into real-world images. These images can be taken from the camera or, by using a live view, the audience can be added directly to the world (Reiners, Stricker, Klinker, & Müller, 1998). According to Jiao, Zhang, Li, Wang, and Yang (2013) AR comes from 'Virtual Reality' (VR) and provides a half-depth environment that highlights the exact alignment between actual scenes and virtual world images in real time. It is also broadly recognized as an assuring technology to improve human viewpoint. Additionally, the means to enhance prevailing big data visualization techniques is correlated with AR and VR where it is relevant for human limited perception capabilities (Olshannikova, Ometov, Koucheryavy, & Olsson, 2015). Consequently, AR and big data are certainly unavoidable where the complexity related with big data in construction is tremendous and must be overcome by advanced visualization methods, specifically AR and VR (Bilal, Oyedele, Qadir, et al., 2016).

2.4.6 Social Networking Services

Social media is one of the exciting trends that could assist the construction industry to improve the communication among project teams (Jiao, Wang, et al., 2013). Yet, one of the main challenge is to accede the value and exploring ways of analysing it (H. Chen, Chiang, & Storey, 2012). This follows from the enormous volume of heterogeneous data produced by the social networks. Hence, to properly analyse data from social media, the analytical techniques of data analysis need to be modified and incorporated into the new enormous data for enormous information processing (Bello-Orgaz, Jung, & Camacho, 2016). In relation to this, big data can be utilized in developing appealing domain applications through the high volume, velocity, and variety of social network data to improve stakeholders' productivity.

2.5 Current Big Data research in the Construction Industry

Big data has begun to set foot in the construction industry in sync with other sectors that have long benefited from big data. In this regard, the construction industry could exploit big data in the same manner as anticipated by the other sectors or industries. As discussed earlier, this includes enhancing efficiency, decision making, and sensors monitoring. Bilal, Oyedele, Qadir, et al. (2016) maintained that the outlook on the applicability of big data in construction could be magnified as the triggering contituents discussed in section 2.4 advanced. Thus, the surge of these contituents and trends could be the factors to propel the construction industry to the next level of data driven initiatives.

The current big data research or application excerpted from various literature is summarized in Table 2 with the important concepts identified from the review process are aggregated and accentuated in brackets. The findings will become the basis to map the orientation of big data research in construction and subsequently suggesting the probable direction for research to ensue.

3. Research Methodology

The qualitative research design was adopted for this study. According to Bryman (2008), qualitative research is a research strategy that typically emphasizes on words rather than the computation of data. In this regard, the aim is to provide a thick explanation about a phenomena following the specific issue identified from the the literature (Elo & Kyngas, 2008; Fellows & Liu, 2008). The decision for adopting to the strategy was also guided by the objectives of the study. As the research objectives include analysing the current extent of big data research and mapping out its orientation and potential application, these are better achieved by going deep through an analytical explanation of the existing research (Creswell, 2005).

Desk study method was used to collect the data required for attaining the first and the second objectives. According to Travis (2016) desk study relied on the researcher's skill to review the previous research findings in order to obtain an expansive comprehension of the study area. This method was adopted as it provides the fastest and inexpensive method in understanding the realm of the research, where a thorough review was made to obtain a cross sectional insights on big data in the construction industry.

As the study is currently on going, a series of interviews are planned to consolidate and validate the insights that are to be gained from the desk study. The interviews are planned to be administered with personnel who have experienced big data and is aimed to identify the potential application of big data in construction. According to Rubin and Rubin (2011), the qualitative interview is a discussion where the researcher aides a conversational accomplice in a broadened exchange. The interviews will allow the researcher to expand the questions to the extent that they are willing to share. Accordingly, the desk study is important in this regard as it gives the researcher a gist of the previous research findings before the interviews are carried out. For this reason, this paper is organised to highlight the analytical method employed in the desk study and the findings derived therein. These are concurently presented and discussed in the ensuing sections.

4. Findings and Discussion

The important concepts on big data excerpted from the review were structurally analysed by following the steps in the framework known as *SALSA*. The acronym stands for **S**earch, **A**ppraisa**l**, **S**ynthesis, and **A**nalysis and was introduced by Booth, Sutton, and Papaioannou (2016). A complete application of the *SALSA* framework was illustrated in a study by Shamsulhadi, Fadhlin, and Hamimah (2015) and was further methodologically discussed by Shamsulhadi and Fadhlin (2016) and Zafira, Shamsulhadi, and Roslan (2018). In the studies mentioned, it was observed that the Nvivo software was predominantly deployed to assist in the analytical process. Part of the analytical outcomes as presented in Table 2 had followed the processes as outlined by the previous studies and include the usage of the Nvivo software as well. This approach was intentional to maintain the rigour as justified in the illustrated research. Details of the processes carried out for the study are further explained in the following sections.

4.1 Searching

The exploratory nature of this study had naturally required the

***Table 2** Big Data research from various literature*

No	Big Data research area from the literature review	Authors
1	BD with Visual Analytics used for (**building performance)** comparison that leads to renovation and construction with low (**energy**) consumption.	(Ioannidis et al., 2015)
2	LEED uses actual data to verify the (**building performance**)	(Davis, 2015)
3	Improve **(project management)** by using technologies or sensors for (**performance**) monitoring and tracking	(Wood, 2016), (Bleby, 2015), (Yang, Park, Vela, & Golparvar-Fard, 2015)
4	Cost efficiency (**design**) through a real-time, data-focused predictive model.	(Sadhu, 2016)
5	BD assist in (**project management)** to ensure the project is delivered on (**time**) and (**minimize delays)**	(Sadhu, 2016), (Rijmenam, 2015), (Faure, 2016), (Augur, 2016), (Akbar, 2017)
6	Real-time data sharing to improve (**communication)** between stakeholders	(Rijmenam, 2015), (Augur, 2016)
7	Resource tracking through sensors-equipped assets or machineries. (**resource management**)	(Rijmenam, 2015), (Augur, 2016), (Azzeddine Oudjehane & Moeini, 2017), Akhavian and Behzadan (2015)
8	Deriving information from stakeholders to improve the (**planning**) process and (**project management**)	(Caron, 2015)
9	Integration of information technologies with data handling in facilitating (**decision-making**) for (**project management**)	(Martínez-Rojas, Marín, & Vila, 2015)
10	BD generate (**prediction**) system for construction businesses bankruptcy	(Hafiz et al., 2015)
11	Drones use for construction progress monitoring for (**project management**)	(Azzeddine Oudjehane & Moeini, 2017), Knight (2015)
12	Geospatial/geo-location data for (**resources optimization**) and (**resource management**)	(Akbar, 2017)
13	Data simulation tool in reducing project (**risk**).	(Akbar, 2017)
14	BD for construction (**cost management**) through tender price assessment system (**project management**)	(Y. Zhang, Luo, & He, 2015)
15	Visual BD to improve (**communication**) among project stakeholders.	(K. K. Han & Golparvar-Fard, 2017)
16	Assess (**Construction waste management**) performance using BD	(Lu, Chen, Ho, & Wang, 2016), (Lu, Chen, Peng, & Shen, 2015)
17	Developing (**waste**) simulation tool using BD for (**Construction waste management**)	(Bilal, Oyedele, Akinade, et al., 2016)
18	Social network analysis and (**energy**) usage analyses as sources in establishing an integrated green building (**design**) model	Redmond, El-Diraby, and Papagelis (2015)
19	BD algorithms to accurately reduce the design space and enabled generative (**design**) tool	(Bilal, Oyedele, Qadir, et al., 2016)
20	BD and VR for better building (**design**) decision	(Bernstein, 2017), (Barista, 2014)
21	BD helps in generating a predictive model for (**energy)** consumption	(Moreno et al., 2016)
22	BD algorithm for (**building performance**) in terms of (**energy)** consumption	(P. A. Mathew et al., 2015)
23	Implementing prototype software called Project Dasher for (**energy**) data visualization and real-time monitoring.	(Khan & Hornbæk, 2011)
24	BD analysis used to understand energy consumption behavior thus help to improve (**energy efficiency**) in building	(Koseleva & Ropaite, 2017), (Janda et al., 2015)
25	Real-time (**energy**) consumption data monitoring and control to improve energy efficiency	(Wei & Li, 2011)
26	BD-based platform to visualize workers' unsafe (**safety**) act in real-time	(SY Guo, Ding, Luo, & Jiang, 2016), (Shengyu Guo, Luo, & Yong, 2015)
27	Use wearable to track worker proximity to rolling (**safety**) exclusionary zones	(Wood, 2016)
28	Use drones to check on site (**safety**)	(Oudjehane & Moeini, 2017)
29	Real-time (**safety**) tracking and data visualization technologies improve (**safety**) understanding.	(Teizer, Cheng, & Fang, 2013) (Hampton, 2015)
30	Application of BD-driven BIM system in improving construction (**safety**)	(S. Zhang, Teizer, Lee, Eastman, & Venugopal, 2013)
31	Integrating BIM data with external data such as Linked Open Data (LOD) for better (**project management**) and reduce project (**risk**)	(Curry et al., 2013)
32	Sensor based fire-fighting system for skyscraper building in associate with the authorities help in fire detecting as well as evacuation process (**safety**)	(Stankovic, 2014)
33	Predicting site injury and workers' behavior towards (**safety**) through 3D skeleton motion model from videos.	(S. Han, Lee, & Peña-Mora, 2012)
34	Data from robotics and automated equipment has the potential to improve job (**safety**) and enhance construction (**productivity**).	(Skibniewski & Golparvar-Fard, 2016)
35	Capturing (**safety**), quality and performance data for real-time analysis in improving site (**safety**) and construction work (**productivity**).	(Bleby, 2015)
36	Big Data from mobile apps for contractor to track **(resource)** and document schedule changes to enhance **(resource management)**.	(Sadhu, 2016)
37	**(Energy**) consumption prediction through computational models developed based on user behavior for better (**energy management**).	(C. Chen & Cook, 2012)
38	BD in (**design)** model comprises of architectural, structural, and building services data to enhance (**design)** efficiency	(Porwal & Hewage, 2013)
39	Past project data-driven (**design)** to improve (**design)** decision and efficiency.	(Barista, 2014)

Source: As shown

researcher to search the relevant literature concerning big data in construction. For this purpose, the researcher had first established the search parameter and subsequently drawn the relevant keywords from the aim and objectives of the study. A snowballing technique was then exercised where literatures were identified through the backward and forward approaches (Webster & Watson, 2002).

To achieve this, the UTM Library Online Database which contained access to academic journals from Emerald, Science Direct, IEEE Xplore Digital Library, and Springerlink was searched. The main keywords used in searching the literature were "big data" and "construction industry". Additionally, the Boolean operators, truncation characters and wildcards were also used in selecting the relatable journal articles. Based on the search results, a large numbers of big data articles were displayed from both construction as well as other domains. However, the results were again filtered where only the content that portrays the presence of big data in the construction industry was of particular interest.

4.2 *Mapping Ideas and Analysis*

Mapping involves putting together different strands that make up the topic to enable analysis and synthesis to be undertaken. The process involves accumulating the literature content from the review and sorting the list into categories for the purpose of establishing connections (Hart, 1998). According to Hart (1998), the aim of this process is to dynamically reduce the huge amount of information extracted from the review with due emphasized given to extract the main points of the argument. For this study, a featured map, in a form of a table proposed by Hart (1998) was developed and showed in Table 2. The table showed the results of the analysis which has taken place by reflecting the words (or terms) derived from the extracted data. These were reflected as the features which had characterised the literature and a structural form of recognition of the leading concepts. Despite, at this stage, it appears that the concepts derived were rather disjointed and had followed the individual reflection from the sources. This necessitates the next step in the process - synthesis.

4.3 *Synthesis, Mapping and Discussion of the Outcomes*

Concepts that arised from the analysis were synthesized through the aggregative approach in which the concepts were grouped into relatable themes or area. This process was carried out by using the Nvivo software where apart from its ability in mapping out the outcome, proved to be useful in espousing the weightage which could exaggerated certain number of concepts. The frequently mentioned concepts were mapped out through the word frequency command. It counts the frequency of a particular word or phrase or a set of alternative words fed from the analysis. In relation to this study, the 'Word Frequency Query' in Nvivo was used to reveal a specified concepts of big data that have been mentioned the most. Hence, the predilections of big data in construction were obtained thus attaining the second objective.

A model which was developed from the synthesis is presented in Figure 1. It shows that prior research on big data in construction had centered around 'management' especially 'project' management, 'energy' management and 'resource' management. In this context, big data in 'project management' involves those linked-construction data in cloud base that provides broad understanding on complex project. It was submitted that big data leads to a better 'project management', especially in ensuring that cost efficiency was achieved as well as minimizing delays. Likewise, big data initiated by the IoT devices such as drones, sensors or smartphones aid in recording construction work progress and monitoring work performance. It was postulated that a real -time data was able to be provided so that actionable actions could be taken in enhancing the project productivity. Additionally, the IoT devices also generates data on the 'safety' aspect such as workers' safety behaviour on site and site safety conditions through sensors, automated equipments, tracking devices as well as visualization technologies.

Big data also contribute to a better project management through data wise enhancing 'decision-making' process especially in predicting the project orientation that leads to lower project risk.

On the other hand, 'energy management' encompasses the integration of IoT or BIM with big data analytics in understanding the building energy consumption to increase energy efficiency and add to building performance. Energy analyses further assist in decision making 'design' framework where the results could be the determinant in generating integrated models for building design. Also, big data provide an aerial view on all aspects of the built environment that facilitates a better decision-making design framework.

Correspondingly, resources tracking and monitoring through sensors or mobile apps helped to enhance the decision-making for 'resources management' and ensure resource optimization. Other big data potential application reviewed from the literature includes construction waste management as well as data-sharing efficiency to improve communication.

Based on the discussion, the theoretical orientations obtain from the analytical processes could be summarised as: (1) project management; (2) safety; (3) energy management; (4) decision making design framework and (5) resource management. Table 3 recapitulates the interpretative context of the most frequent big data research area in relation to the findings previously presented in Table 2.

The findings from this study had revealed five current directions of construction big data research. Despite being bounded with the number of articles that were obtainable from the search, the findings nevertheless had shed some lights on the areas currently being pursued by researchers in construction domain. This information could be harnessed by the current and future researcher in charting their path and further justifying the significance of their research.

5. Conclusion and Recommendation

The study has managed to draw important insights on the specific areas in construction big data research. These were achieved through the accomplishment of the following objectives: (1) to analyse the current extent of construction big data research; (2) to map out the orientation

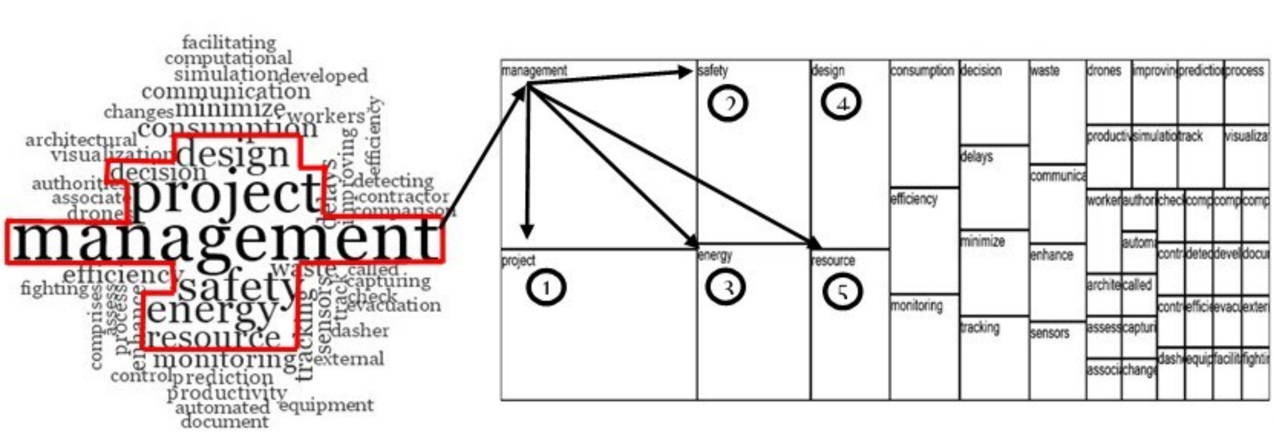

Figure 1: *Generated model representing the frequency of big data research area*

Table 3 The context of big data research area and details

Context of big data research	Important key-words	Detail of research area
Construction Project Management	monitoring	Progress/performance monitoring through IoT devices
	time, cost	Better time and cost management
	Decision-making	Making decision using predictive data that leads to lower project risk and
Safety	Site safety, workers' safety behaviour	Big data generated through IoT devices in tracking and visualize site safety conditions as well as workers' behaviour towards safety
Energy management	Consumption, building performance	Enhancing energy efficiency and building performance through an understanding of building energy consumption
Decision-making design framework	Decision-making	Big data for prompt and informed decision-making
Resource management	Resources tracking	Resources tracking through IoT devices to improve resources utilization efficiency

Source : Researcher

of the current construction big data research; and (3) to suggest the current directions of construction big data research. As the foregoing discussions have shown, a structured analytical framework has been employed to analyse the resources obtained, assisted by the used of NVivo. This has permitted a wider inclusion of resources, thus had broadened the base for the qualitative analysis to take place.

As the study has shown, the current extent and orientation of the present construction big data research covers a diverse research area. It reflects from the analysis that big data research on monitoring, tracking and decision making are intensively being pursued by researcher in construction. Apparently, this suggests the rapid pace of big data development in construction and the on-going interest to harness the technology for common good.

Besides, the study had also suggested that the current directions of construction big data research could be translated into five specific areas. This covers construction project management; safety; energy management; decision making design framework and resource management. Of the five areas mentioned, big data for construction project management was identified as the area which research is really intensified. This follows as the construction industry is a data-dependent industry hence data must be managed efficiently with the right tool to ensure the success of a project.

As the study has shown, construction big data research offers a potentially good prospect to improve the industry. It is a step ahead of the current digitalisation effort and bring a new wave in obtaining insights from the voluminous amount of data. As the study reported in this paper is still on-going, it is interesting to contemplate the industry's views on the findings discussed here. This shall include what and how would the industry profit from the adoption of big data. The authors recommend a study to be conducted on the challenges impeding the adoption of big data in construction as well as readiness in embracing to big data. This effort shall increase the depth and breadth of the current knowledge which could further bolster the industry's understanding on big data.

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