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# Mapping the Barriers of Big Data Process in Construction: The Perspective of Construction Professionals

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**Abstract:** This study identifies, maps and thematizes the barriers to the big data process in the construction industry from the perspective of construction professionals. Australian construction professionals with varying experiences in the big data process were interviewed. Qualitative data analysis identified forty barriers in the big data process and five themes: people, knowledge, technology, data, and environment. The barriers were further mapped, with some transcending more than one stage in the big data process. Many of the barriers have not been empirically identified in previous studies. By implication, mapping the barriers across the big data process enables professionals/construction firms to visualize the potential lapses before and/or during implementation. Therefore, the study offers professionals/construction firms strategic insights and operational perspectives for planning and deploying big data processes.

**Keywords:** big data process; construction industry; digitalization; technology; knowledge; people; environment; data

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## 1. Introduction

Ribeirinho et al. [1] reported digitalization as one of the strategies bound to radically change the face of delivering construction projects. However, the construction industry is noted for low uptake in digital technologies [2]. Digitalization sets the construction industry into a data-driven economy, as insights from data can inspire and drive decision-making. The call for digitalization means that the low productivity rhetoric in the construction industry could improve: European Construction Sector Observatory [3] survey has shown that improving productivity, reducing cost and market demands have necessitated digitalization in construction. Moreover, data generated on construction projects will astronomically increase because each digital technology can generate massive amounts of heterogeneous data within seconds [4,5]. This makes big data a disruptive and new norm for the construction industry [1]. The characteristics of data from high data streaming technologies generate large volumes of different data formats, which are elements of big data applications. For instance, KPMG China’s [6] report on “building technology advantage” in the construction industry identified high streams of data-generating devices like drones, remote monitoring, radio-frequency identification and smart sensors.

According to Davenport [7], the generation of high streams of heterogeneous data, processing and application through digital technologies to improve processes is described as big data application. Such description demonstrates that a holistic approach to understanding big data is considered from a process view, thus considering the movement of data from the big data sources, storage, and processing to its application. Therefore, this study defines the big data process as generating, storing, and analysing data to provide business value to construction firms or the industry. The big data application has gained prominence and relevance in the construction industry through practice and research. For example, the ongoing high-speed two (HS2) project in the UK has employed various digital tools and data analytics in the delivery [8]. Meanwhile, research has explored the potential [9] and actual benefits of big data to projects [4] and organizations [5]; conceptual capabilities [10]; expertise development [11]; sentiment analysis for managing stakeholders [12]; determinants of big data analytics [13]; and big data in the context of sustainability [14].

As the awareness and research of big data are increasing in construction, it has become necessary to know the challenges that can affect the big data process in construction. Notwithstanding, four studies identified some big data-related challenges:

a. Bilal et al. [9] reviewed the literature on big data and identified some potential barriers,
b. Konanahalli et al. [15] identified some barriers to big data in facilities management,
c. Reyes-Veras et al. [16] identified some barriers to big data adoption, and
d. Yu et al. [17] about the utilization of big data in projects.

In as much as these studies tried to examine the barriers, the following observations are made from their findings:

i. Findings in (b) and (c) related to general technology adoption issues like high cost of investment, lack of government support, etc.;
ii. The findings of (a) and (d) is a general review of literature on big data and potential barriers, although (d) collated, designed a predetermined set of barriers and asked professionals to rank 17 potential barriers in construction;
iii. None of the existing studies examined the barriers in detail about their implications to the big data process; and,
iv. There is limited information about the knowledge areas (themes) contributing to the barriers in the big data process.

These findings left much to be desired because the current literature has not identified the day-to-day peculiar big data process challenges experienced by construction professionals. In addition, big data applications are process-oriented. Getting the best out of the process requires understanding the challenges at each stage of the big data process, which current literature is yet to address. Finally, extant literature has limited information on the knowledge areas (themes) contributing to the challenges in the big data process. Based on the gaps, this study is guided by the questions, what are the barriers associated with the individual stages of the big data process? Moreover, what are the themes contributing to the barriers in the big data process?

To answer the research questions, the identified barriers must be mapped and thematized across the big data process, making it easier to visualize and understand the potential barriers to encounter at each stage of the big data process. Therefore, this study identifies, maps and thematizes the barriers in the big data process.

Significantly, this study addresses the challenges of understanding industry 4.0 applications by considering process-related issues, as recommended by Chan [18]. In practice, this study will enable construction professionals to visualize the potential lapses likely encountered at each stage of the big data process. This will equip them to plan effectively through their risk management process, thereby providing operational and strategic insights that benefit their respective firms. Thematizing the barriers will enable researchers to compare themes to theories and themes identified in other digital-related studies. Finally, the findings of this study will help practitioners and academics in the construction industry to understand and extend their knowledge base relating to big data.

## 2. Conceptual Framework

Theory, literature, and experience have been identified as the sources of information for constructing a conceptual framework [19]. Table 1 shows a conceptual framework of the theoretical and literature sources on the left-hand side (LHS) and the big data process stream based on experience on the right-hand side. The two sides contributed to deriving the conceptual barriers for this study. Theoretically, the Technology-Organization-Environment (TOE) framework by Tornatzky and Fleischer [20] was adopted. It describes an organization's entire journey of technological innovation: innovation development, adoption and implementation. The TOE has been one of the old frameworks for advancing technological innovation studies in information systems, and big data barriers can be explored using the TOE. In big data research, TOE has been used to assess the readiness and capabilities of big data in retail organizations [21]. Alaskar et al. [22] explored the role of competitive pressure as an environmental variable to moderate technological (complexity, compatibility and expected benefits) and organizational factors (top management support and organizational readiness) to predict the intention to adopt big data analytics in supply chain management.

The definition of big data centralizes data, technology, and application [7,23]. Meanwhile, the role of individuals and organizations cannot be overemphasized. Li et al. [24] and Atuahene et al. [11] considered these from different perspectives, which formed the basis for considering them as the literature perspectives. The former study thematized barriers on big data embedded technologies in the smart factories field, which have a bearing from the TOE framework. For example, the definition of big data emphasizes technology and data, which relates to technology, whilst people and organization-wide are within the organization and environment themes in TOE (Table 1). Li et al. [24] thematize the barriers; therefore, it was adapted to identify construction-based barriers. Atuahene et al. [11] study explored big data expertise development in the construction industry; however, these identified issues are also potential barriers to big data in the construction context. The theoretical and literature sources formed the basis for the research themes on barriers: technology, data, people, knowledge, and environment (Table 1).

**Table 1.** Conceptual framework on big data barriers.

| **LHS: Theoretical and Literature Sources** | | | **Conceptual Framework** | | **RHS: Big Data Process Stream** |
|---|---|---|---|---|---|
| *TOE* | Big data embedded solution (Li et al., 2019) [24] | Big data expertise (Atuahene et al., 2020) [11] | *Research themes on barriers* | *Research big data process* | Process streams contextualise from Davenport (2014) [7] and Gantz & Reinsel (2012) [23] |
| Technology | Technical | Technology availability | *Technology* | *organizational-external (OE); BDS; Overlap of BDS-BSP; BSP; Overlap of BSP-BDA; and BDA* | Big data sources (BDS) |
| | Data | Data management strategy | *Data* | | |
| Organization | People | Individual drive | *People* | | Big data storage and processing (BSP) |
| | | Knowledge (Training) | *Knowledge* | | |
| | Organization-wide | | *Environment* | | Big data application (BDA) |
| Environment | | | | | |

On the right-hand side of the conceptual column is the big data process stream, based on earlier authors' definitions of big data [7,23]. These studies identified three stages of the big data process. Big data sources relate to the generation of large data in construction activities, big data storage and processing concerns the storing and processing of the data for insights, and big data application is where the analysed data is applied for the benefit of the organization. The stages' purpose is to simplify and enable users to visualize the barriers from an operational view. For example, the big data sources stage is impaired when there are issues with using the wrong technology to capture data.

The conceptual framework column contains the research themes on barriers extracted from the LHS and the research big data process from the RHS (Table 1). Technology, data, people, knowledge, and environment are the research themes considered for this study. These are the commonalities between the theory and literature sources. Technology describes the barriers associated with deploying diverse forms of technology. Data are the lapses associated with capturing activities, processes, or products in the big data process. People as a theme is the challenges of the individuals performing their roles. Knowledge is described as the challenges relating to the technical know-how or knowledge in the collection, management, and application of big data, as far as construction is concerned. The environment considers threatening conditions within and outside the organization with the potential to obstruct the big data process.

Likewise, the conceptual framework considers the three stages of the big data process as identified in the RHS. Meanwhile, it is argued that some barriers could relate to more than one stage; therefore, the need to consider overlaps between the stages as independent. Examples include the overlap of BDS-BSP and the overlap of BSP-BDA (see construction—research big data process in Table 1). Moreover, some of the barriers could relate to all the stages. They might not directly fit into the defined stages and might be considered from the organizational or external perspective, hence an organizational-external stage. The research themes and research big data processes form the basis of analysis for this study. It is important to note that the barriers to be identified will be mapped to them. For instance, the problem of resistance to change [16] becomes a people problem from the theoretical and literature perspective. On the other hand, it becomes a barrier relating to the organizational-external context of the big data process because it does not fit into any of the defined stages.

For practitioners and researchers in the construction industry to appreciate the challenges in the big data process, this study identifies, maps and thematizes the barriers in the big data process to offer strategic and operational insights into the construction industry.

## 3. Materials and Methods

Big data involves integrating technology, structures, processes, and people like other digital applications [25]. Therefore, to have an in-depth understanding of the lived experiences of construction professionals as far as the obstacles of the big data process were concerned, this study used a qualitative approach through a phenomenological study. The data collection for the study was conducted between June 2019 and March 2020. Figure 1 shows the research methodology and its relationship with the research questions, conceptual framework, analysis, and presentation of results. The broken linkage directly links the research questions and their answers. While the other loop shows the step-by-step activities undertaken to achieve the answers to the research question.

Semi-structured open-ended interviews were used in this study, which enables researchers to have a broader and deeper understanding of a phenomenon through individuals' experiences and lenses [26]. The interviews were within one hour for each professional and were done through face-to-face, telephone and video conferences, which were recorded. The duration of the interviews is within the range and the medium accepted in earlier studies [27].

This study explored the background and experience/behaviour interview types [28]. For background, the professionals described their journey, summarized in Table 2. The experiences-related questions considered the obstacles faced in the big data process on their projects and organizations at large, e.g., with your experience, what are the barriers you encounter in the big data process: big data sources, storage and processing, applications (benefits)?

Professionals in large construction and consultancy firms in Australia were selected through purposive and convenient sampling. The interviewees were composed of junior to senior-level staff to address bias [29]. Fifteen construction professionals from seven organizations participated in the interview with varied experiences in the big data process (Table 2). The first author conducted the interviews in English, and the transcription was done verbatim.

Earlier studies have shown that a minimum of five participants are a good fit for phenomenology [30,31]. Some earlier studies, like Papadonikolaki and Wamelink [29], studied BIM; the respondents were 14. Creswell [32] indicated that the minimum size of phenomenology research is 5. Mason [31] analysed qualitative PhD theses from the UK and Ireland, 25 phenomenology-related ones. In the review, 7–89 people participated in the studies.

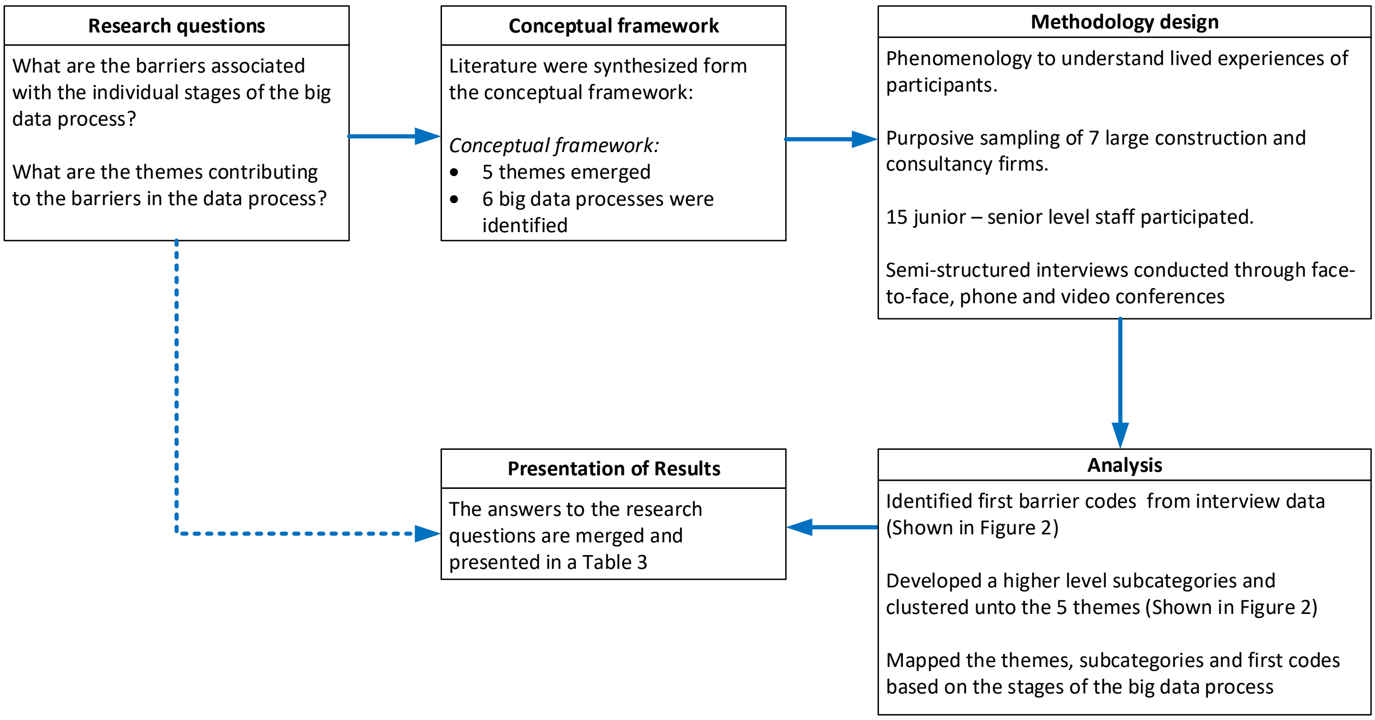


**Figure 1.** The connection amongst research questions, conceptual, methodology, analysis, and results.

**Table 2.** Information of research participants.

| Portfolio | Hierarchy Level | Years of Experience | Big Data Process Experience | Code Name |
|---|---|---|---|---|
| Operations Manager | Senior | 12 years | Big data application | R1 |
| Project Administrator | Middle | 11 years | Big data source, storage and processing, and application | R2 |
| Contract Administrator | Middle | 15 years | | R3 |
| Contract Administrator | Middle | 11 years | | R4 |
| Project Engineer | Middle | 10 years | | R5 |
| Site Engineer | Junior | 4 years | Big data source, storage and processing | R6 |
| Site Engineer | Junior | 2 years | | R7 |
| Managing Director | Senior | 26 years | Big data application | R8 |
| Commercial Delivery Manager | Middle | 9 years | | R9 |
| CAD Manager | Middle | 4 years | Big data source, storage and processing, and application | R10 |
| Project Manager | Senior | 20 years | | R11 |
| Director/ Quantity Surveyor | Senior | 17 years | | R12 |
| Commercial Manager | Middle | 23 years | | R13 |
| Commercial Manager | Middle | 25 years | | R14 |
| Commercial Manager | Middle | 20 years | | R15 |

Moreover, Malterud et al. [33] researched 'sample size in qualitative interview studies: guided by information power'. The study argued that interview sample size should be determined by the aim (broad or narrow), specificity (dense or sparse), theory (applied or none), dialogue (strong or weak), and analysis (case or cross-case). In this study, the aim was narrow, the characteristics of the participants were specific to the aim, the conceptual framework was a guide to the study, the dialogue was strong that necessitated the need for the questionnaire validation, and the analysis considered all participants based on the aim as one case and ensured that the participants have diverse experience. Applying the examples of this study to the information power [33] indicates that the number of participants was adequate.

The research questions were validated through three stages. Firstly, an expert on the Internet of Things and big data analytics reviewed the questions to check the content and construct validity. Secondly, two construction management faculty members reviewed the questions further. Finally, the questions were slightly revised, which was rolled out by pre-testing them with four professionals, with two transiting into academia—these helped to restructure the questions for easy comprehension by construction professionals.

Using NVivo software, a three-stage thematic analysis was performed on the interview data (see Figure 2); in between was a recursive analysis to ensure that the same item was not coded as new—the three-stage analysis aimed to derive subcategories from the coded items and group them under the five themes in Table 3. A code could be a word or phrase that 'symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data' [34]. Inductive coding was adopted to capture codes naturally emerging from the research data without being based on any theoretical underpinning. Linneberg and Korsgaard [35] indicated that inductive coding 'stay close to the data', meaning that the exact words from the research data become the code. An example is InVivo coding.

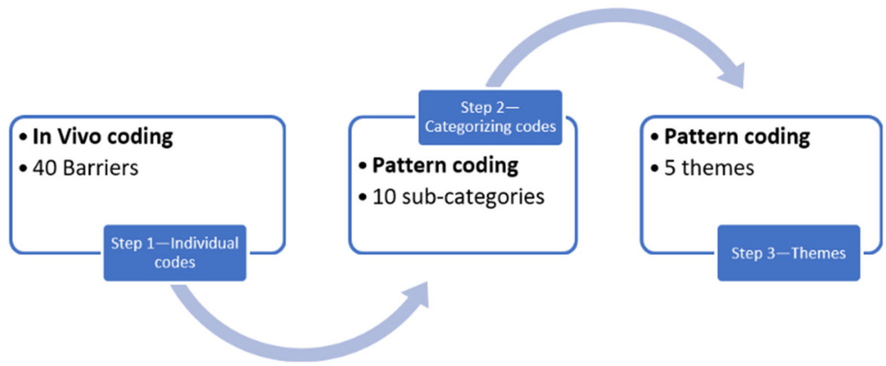


**Figure 2.** Process flow of thematic analysis.

**Table 3.** Mapped and thematized barriers of the big data process.

| Themes | Sub-Categories | Barriers | Big Data Process (X = *Barriers Relating to the Stages in the Big Data Process*) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | OE | BDS | OBDS-BSP | BSP | OBSP-BDA | BDA |
| People | *Behavioural* | B04: Compelling people to use technology | | | X | | | |
| | | B33: Resistance from people | X | | | | | |
| | *Awareness* | B06: Data input by multiple people | | | X | | | |
| | | B14: Human involvement | X | | | | | |
| Knowledge | *Knowledge–experience* | B08: Difficulty in knowledge sharing | X | | | | | |
| | | B15: Inadequate data capture knowledge | | X | | | | |
| | | B21: Lack of technology know-how | X | | | | | |
| | | B32: Reliance on experience | | | | | | X |
| | *Inefficient training* | B13: Getting right people to train | X | | | | | |
| | | B16: Inadequate training | X | | | | | |
| | | B18: Irrelevant training | X | | | | | |
| Technology | *Technology induced* | B02: Barriers associated with devices | | X | | | | |
| | | B23: Limited storage capacity | | | | X | | |
| | | B36: Transferring data across system | | | X | | | |
| | *Lack of access to technology* | B20: Lack of access to technology | X | | | | | |
| | | B37: Unavailability of relevant data platform | | | | X | | |

**Table 3.** *Cont.*

| Themes | Sub-Categories | Barriers | Big Data Process (X = *Barriers Relating to the Stages in the Big Data Process*) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **OE** | **BDS** | **OBDS-BSP** | **BSP** | **OBSP-BDA** | **BDA** |
| **Data** | *Non-utilization of data* | B01: Analytics limitations | | | | | X | |
| | | B19: Lack of access to sensitive data | | | | | X | |
| | | B28: Not knowing the benefits of data | | | | | | X |
| | | B31: Not utilizing data | | | | | | X |
| | | B38: Uncertainty on accuracy of data | | | | | | X |
| | *Improper data labelling* | B07: Difficulty in finding data | | | | | X | |
| | | B17: Irrelevant data capture | | X | | | | |
| | | B26: No detailed description of data | | | | X | | |
| | | B35: Spending much time to find data | | | | | X | |
| | | B40: Unorganized data | | | | X | | |
| | *Data chain issues* | B03: Bombarded (sic) with more data | | X | | | | |
| | | B09: Duplication of captured data | | X | | | | |
| | | B24: Limited time for data chain | | | X | | | |
| | | B25: Manual handling of data | | | | X | | |
| | | B29: Not synchronizing data | | | X | | | |
| | | B30: Not uploading data | | | X | | | |
| **Environment** | *Business environment* | B05: Connectivity (internet) issue | X | | | | | |
| | | B10: Environmental conditions | | X | | | | |
| | | B12: Forced adoption | X | | | | | |
| | | B22: License (time and cost) | | X | | | | |
| | | B34: Restriction on using technology | | X | | | | |
| | | B39: Uniqueness of project | X | | | | | |
| | *Leadership* | B11: Firms led by non-technology savvies | X | | | | | |
| | | B27: Not investing in new technology | X | | | | | |

**OE**: organization-external; **BDS**: big data sources; **OBDS-BSP**: big data sources and big data storage and processing overlap; **BSP**: big data storage and processing; **OBSP-BDA**: big data storage and processing and big data application overlap; **BDA**: big data application.

InVivo coding was used to code the exact words the participants spoke, 'which results in rich data' [36]. Therefore, Individual verbatim phrases were coded from the interviews, forming the first coding level. This study prioritized a code's emergence over its occurrence frequency, as applied in Atuahene et al. [25]. Forty barriers in the big data process were identified from the analyzed data. For easy identification, alphanumeric was applied to the codes, i.e., B01–B40. The alphabet 'B' means barrier, and the numbers were based on the initial letter of the codes in ascending letters, e.g., B01 is analytic limitations and B40 unorganized data.

Pattern coding was employed in the second stage by enabling the authors to identify, arrange, group, and report the themes in the data, which is based on inference from already identified codes [37]. At the second level, the codes were clustered based on the centrality of concepts that emerged, for example, lack of access to technology and unavailability of relevant data platforms, portraying the message of access to technology. However, from two diverse perspectives, the two codes were clustered under a lack of technology access. In a related example, barriers associated with devices, limited storage capacity and transferring data across systems also point to some limitations related to technology use. Therefore, these were clustered under technology-induced because the technology can capture as much information based on its capacity if the magnetic components of a technology make it impossible for it to be used around steel elements to capture data or due to incompatibility of different technological applications. At the sub-categories level, lack of access to technology and technology-induced emerged, and these relate to the technology theme as identified within the conceptual framework (Table 1). The same approach of analysis was deployed on the others.

Furthermore, the individual codes were mapped to the big data process to visualize the codes according to the data movement. The second-stage code was done by (i) mapping the codes according to the big data process and (ii) clustering the codes into sub-categories. As shown in the research big data process of the conceptual framework (Table 1), the big data process includes organizational-external context (OE); big data sources (BDS); big data sources and big data storage and processing overlap (OBDS-BSP); big data storage and processing (BSP); big data storage and processing and big data application overlap (OBSP-BDA); and big data application (BDA) (Tables 1 and 3). In the case of the latter, ten sub-categories emerged. A recursive analysis was repeated to ensure that the classification for the big data process and the ten empirical categories were appropriate.

The final and third stage analysis focused on assigning the subcategories to the five research themes from the conceptual framework (Table 1); these are explained further in the results and discussion section.

## 4. Results and Discussion

This section presents results and discussions on barriers in the big data process. Understanding and knowing the individual barriers is insufficient in having a comprehensive view of the obstacle at stake but positioning them in a context through a sequence becomes more useful to the construction firm by mapping them in the big data process and empirical themes. The analyses of the data are summarized in Table 3. Table 3 shows the big data processes identified, mapped and thematized barriers.

### *4.1. People Barriers*

People emerged as a theme from the results, supported by behavioural and awareness barriers related to the big data process's OE and OBDS-BSP stages. These were the categorized barriers supporting the People theme. *Resistance from people (B33)* was the only identified barrier within this theme consistent with existing construction [16,17] and general big data literature [24,38,39], which is within the people theme in this study. Several studies on digital technologies/industry 4.0 have also identified the same barrier within the context of those studies. The resistance level tends to increase when (construction) professionals realize that their work is on the line [24]; when older people not experienced in using technologies decide to treat these technological innovations, big data in this context, as an irrelevant technology in the industry. This issue is exacerbated when it reaches the level where these professionals are forced to use these technologies. For instance, some respondents highlighted the challenge of using big data applications in their construction companies as they compel *people to use technology (B04)*. Many of their people/employees are technology-phobic and would prefer if the performance of their duties had nothing to do with technology, a complication affecting work performance. These are barriers explaining the behavioural components of the people theme.

Awareness in the case of this study is about lack of communication about big data during the implementation stage, which is different from lack of awareness findings from the study of Reyes-Veras et al. [16]—lack of knowledge on the concept of big data. Awareness is explained by *data input by multiple people (B06)* and *human involvement (B14)*. From the results of this study, it can be problematic when clear lines of responsibility are not established during the construction process (Table 3). Li et al. [40] identified factors affecting blockchain technologies by stating the need to avoid work duplication. Work duplication creates confusion amongst the workforce and leads to the blame game when things go south. In this study, B06, like work duplication, was identified as a barrier in construction, not identified in earlier big data studies. Working as a team is considered a great platform to achieve significant outcomes in a construction project [41]; nevertheless, individual inefficiencies can impact the team's performance. Data input appears initially to be an easy and simple task, but it might be challenging due to forgetfulness or other human tendencies. This might have contributed to the identification by the respondents that data input by multiple people acts as a setback in construction projects. An interviewee provided an example where B06 becomes a problem, "...the whole team, not one person, in particular, is putting data in the system, so you are relying on everybody in the team to provide accurate record or data up to date, but this was the challenge when you got multiple people inputting data, that is inaccurate, and day to day inaccurate. . . [R3]". The ramification is when there is the assumption that the other person might have to perform the role of uploading or capturing data, whilst the other person might reasonably think the same for the other; therefore, the data is not generated or stored.

The emergence of *human involvement (B14)* as another barrier might downplay the earlier argument on B33. In an earlier study, scepticism about technology emerged as a barrier to technology adoption [42], and this point could be one of the reasons for B14 as well as age. This might appear contradictory because there should not be resistance since it seems not to threaten the jobs of others; however, in this study, it can be argued that both managerial and junior levels can see B14 as problematic, especially when recognized as a waste of organizational resources. For instance, a participant said, ". . . this is really about technology; at the end of the day, nothing is going to change, the big data technology is not going to prefabricate items, and there will still be hands-on people. . ." [R8].

### *4.2. Knowledge Barriers*

Knowledge is another distinct theme, explained by two subcategories spread across OE, BDS and BDA: knowledge-experience and inefficient training (Table 3). Knowledge-experience barriers relating to lack of knowledge and relying on experience include difficulty in knowledge sharing (B08), consistent with the study of Yu et al. [17] because people prefer to hold up knowledge in their head rather than share it, an interviewee confirmed this, ". . .the knowledge is rather in their head than in document, so that is the traditional way of the construction industry, it has not much changed in the taking of construction technology. . .Sharing that knowledge is sometimes difficult. . . [R12]". The research showed that acquiring knowledge could be either through experience or study. Possessing knowledge brings power to an individual and provides leverage to the individual in bargaining for benefits in construction firms. Whilst it can be clear why people hoard knowledge, employee movement from firm to firm could also account for the difficulty of knowledge sharing. Knowledge captured by individuals but not shared creates knowledge asymmetry, making individuals with knowledge wield significant power and making them the "go-to-get" people on projects. Traditionally, the stakeholders perceive such people as knowledgeable, but a negative impact is felt when such people leave the firm.

Meanwhile, the *lack of technology know-how (B21)* identified in an earlier study [16] could be another underlying factor for B08. Most of the technologies used in the construction industry produce data. Though organizations procure these technologies to enable them to work better, the respondents indicated the technology could be available. However, no one knows how to use it, e.g., R5 said, ". . .some of the companies I did work for will buy the technologies, and say it is available, but no one knows how to use, and it is not beneficial. . . It is culture thing. . .". From these narrations, uncaptured data cannot be shared, and captured but unshared data affects the firms' big data-driven initiative.

On the other hand, *inadequate data capture knowledge (B15)* has been identified in both construction [17] and general big data literature [43]. Capturing data is a skill that must be learned. The individual tasked to collect the data should also know how to handle and use digital technologies and know exactly where, when and what data should be captured in the construction process. R14 noted that ". . . another challenge is the knowledge and awareness of data collection; the construction industry is extremely a traditional industry in Australia, not like manufacturing and other industry. We have people who do not use much technology; . . .". However, if the data has been useful in addressing costs, management could enforce its continued use in the construction firm. Construction is a highly technical venture requiring expertise; therefore, people prefer *reliance on experience (B32)*, which is associated with the BDA stage. From the research data, knowledge means technology-use and construction process knowledge are the fulcrum of big data application and the obstacles its adoption brings. The inability of construction firms to use digital technologies due to lack of knowledge could make the technology "a toy" that has no use to the firm but is a "waste of resources".

The research data shows that efficient and effective use of technology in the construction industry requires people with the right expertise. Inefficient training in the big data process predominantly focuses on the OE context, though existing studies have yet to identify these barriers. Developing knowledge and expertise in the big data process requires adequate training; however, the research data have shown that it is difficult and challenging to get *the right people to train (B13)*, even when the firm is offering training. For example, an interviewee said, "... one of the other challenges will be the training of our people. It is one thing to capture the data, and that is pretty easy, capturing the data. But the ability to use the data and manipulate it to get the maximum benefit out of it is a training thing, and that is the challenge to get people the level of training they need..." [R1]. The authors argued that it might be a testament that construction professionals are either not enthused about the digital strategy of the firm or not ready to add on other responsibilities aside from the technical construction roles. Ineffective training was also seen through *inadequate training (B16)*. Training in big data technologies could not be done in a few hours within a day because there is a level of sophistication in using them, and it could be lifelong training. Finally, while training is very important, *irrelevant training (B18)* could lead to uneconomical use of organizational time and finance. It is due to the content of the training might not benefit them in their substantive roles, the time used for the training will be useful if used in another venture, or the training period is not good enough to equip them. Training becomes a go-to remedy in training construction professionals on technology use; conversely, the respondents noted that the criteria for selecting and the readiness of construction professionals to participate becomes challenging. Some interviewees said that construction professionals perceive the training as a "total waste of time".

### *4.3. Technology Barriers*

Technology-induced and lack of access to technology are the subcategories for the technology theme. These relate to OE, BDS, OBDS-BSP and BSP stages in the big data process (Table 3). *Barriers associated with devices (B02)* are technology-induced barriers and are yet to be identified in the big data literature. An example recounted by respondents [R6] was, "...the drones do have a magnetic interference block. So, if you are trying to take off from a slab and there is reinforcement in there, they struggle and don't want to land. Probably the major ones in construction are those barriers in the device...". The big data process is technology-driven from the generation, transmission, storing, and processing of the data passing through different technology platforms. Therefore, any breakdowns, hitches, or errors experienced by these technologies will affect the big data process. As indicated below, regarding the environmental challenges of using digital technologies, the constituent part of the technology could become an obstacle, and such instance limits the ability to use big data technologies around construction. *Transferring data across systems (B36)* identified in this study is consistent with earlier studies [15]. The generation of data, as intimated earlier, through devices and the processing and storing of these data are managed through other technology platforms. Data transfer inevitably faces challenges, which could be attributed to issues like internet variability, data incompatibility, or software variations. The final technology-induced barrier is limited storage capacity (B23). Storing data can be done through the cloud, flash drives, or cabinets for hard copies. These facilities are capacity-bound, and each can hold data based on capacity. In such situations, the stored data will be fragmented due to the limited capacity of the storage devices. The interviewees noted that the more the challenge—technology failure, multiple technologies, or breakdowns—the higher the possibility of demoralizing people, especially since transmission might be done repeatedly.

Two barriers explain the lack of access to technology, thus *lack of access to technology (B20)* and *unavailability of relevant data platforms (B37)*. B20 has been found in existing general big data literature but not in construction [38,43]. The impact of technology cannot be overemphasized, but working with stakeholders who do not have access to them contributes to some challenges in the big data chain, as respondent R5 said: "...the challenge is getting subcontractors on board, it is all good when referring to platforms or whoever to find new technology and trying it for a minute, but without the trades not having no iPad on site, things like that do not work... so a lot of small subcontractors just do not have access to those technologies as simple like iPad on site... so pulling up some defects... challenging...". According to Oracle Corporation [44], the rationale for big data technologies is because of the inability of traditional platforms to deal with large heterogeneous datasets. The inability to get an appropriate platform to manage these data create bottlenecks in the process. This is similar to barriers found in some studies [38,45]. Performing advanced analytics on data requires getting the right big data infrastructure to deal with the specific data in use. As indicated in the transcripts, there is often an imbalance on a project; whilst one firm has access to technology, another firm might not. This creates continual problems in the construction process, e.g., in updates of phases in the project, required deliveries, corrected defects, or identified defects on projects from various digital reporting platforms.

### *4.4. Data Barriers*

From the interviews, data emerged as a theme across the big data process except for the OE stage, supported by three subcategories: non-utilization of data, improper data labelling and data chain issues (Table 3). These results show that data are not necessarily used, hence the non-utilization of data. Data captured in images and videos are rarely processed and analyzed due to *analytics limitations (B01)*, a barrier noted by Bilal et al. [9]. The inability to perform robust analytics on these datasets leads to a reactive response attitude, where construction professionals have a casual look at them only when something goes wrong in the construction process. In such a compromised situation, a defect might have been made already and rectifying it will require extra time and cost. Reyes-Veras et al. [16] raised security concerns as a challenge in big data due to no structured protocol for protecting the sanctity of the data.

On the contrary, this study identified that security control of datasets creates a *lack of access to sensitive data (B19)*. The problem arises when team members are restricted from accessing data, and this means that some jobs that rely on sensitive data will be halted until approval is given, leading to project delays. At the application stage of the big data process, *not knowing the benefits of data (B28)* was identified to inhibit big data usage, as done in some studies [17,46]. Data generated in the project might not be used afterwards because of inexperience or not knowing the potential benefits of old data to the other projects. From another perspective, since construction professionals do not have exemplary projects using big data [17], it influences the idea of *not utilizing data (B31)* in the construction process [46]. Li et al. [24] explained that these problems (B28 and B31) stem from the inability of the firm to appreciate and accept the need to use big data to maximize its processes and operations. Though this can be a barrier on its own, it may contribute to the construction industry's poor data culture due to B28 and *uncertainty on the accuracy of data (B38)* demonstrated in the literature [15,47]. The circumstances of quickly generating data contribute to achieving the velocity and volume characteristic of big data. Decisions based on inaccurate data lead to disaster, damaging the integrity and reputation of people or firms, and anti-data-driven industry. Conversely, the situation where old data are revised with new ones without the knowledge of all team members can result in doubts about using data and complicate decision-making. The results are questioned when people recognize the entrenched positions of others involved in the analysis [24], and it increases experience-driven solutions.

Improper data labelling had five barriers. This subcategory describes the bad nature, description, and characteristics of data generated and used on projects. Big data technologies provide the opportunities to capture as much data in construction as possible; however, that could contribute to *irrelevant data capture (B17)*. In reflection, if the individual assigned to capturing has insufficient knowledge about construction activities could contribute to this barrier but could be helpful to solve some issues, e.g., "...A lot of what we capture might not be useful at all, but something we do capture might become critical to help us with an issue that comes up..." [R5]. *No detailed description of data (B26)* emerged as another challenge in this subcategory. Bilal et al. [9] pointed out some potential pitfalls of big data in construction and suggested quality issues with data related to B26, though no further description was provided. Construction projects are time-bound, and it is imperative to access data promptly; however, B26 leads to more time to locate data. Like B26, *unorganized data (B40)* emerged and could be associated with the data quality issue flagged in an earlier study [9], e.g., "...challenges of data are not coming in an organized manner, not well grouped or kind of ..." [R13]. The inability to classify like-items of big data could short-change the use of data and become a risk because the completeness of the data might be questionable, and using incomplete data could have dire consequences.

The barriers mentioned above also create other problems in the big data process: *Spending much time to find data (B35)* [15] and *difficulty in finding data (B07).* Time is seen as a resource, and any other activity that takes away time from the construction project is deemed an impediment. Data becomes powerful when it is manipulated and interpreted within the right context. However, encountering difficulties in identifying relevant data becomes time-consuming and can stall the construction project process where data is critically needed, especially when data are manually stored in hard copies. For instance, R9 said: "...and again that data is buried in a folder somewhere... how do we pull that data out is again a manual process and I worry that it is a lot and too hard to do, but if we did it the value of that data will be insane...". The other perspective identified in the results is when the person who stored the data has left the organization for new staff. These new staff often cannot locate the exact position where the data was stored. From a business perspective, such conditions become problematic, considering that different datasets are generated on the project often serendipitously. The non-labelled data can create tensions within the project team or the data capture and storage unit, possibly leading to a "blame game mindset" among the project team. At a higher level, it deprives the construction process of relying on insights from the data generated and stored using organizational resources: time, people, technology, and finance.

Regarding the construction process, the management and handling of data in the big data process generate inherent challenges limiting the optimizing efficiency of big data, which explains the data chain subcategory. *Bombarded (sic) with more data (B03)* is one of the barriers. The respondents repeatedly identified the situation of being overwhelmed with large amounts of data or having many data to capture in the construction process, which frustrated the personnel tasked with data capture, alongside other roles assigned to them. For example, respondent R13 commented, "To be honest, we are bombarded (sic) with information and data. There is too much so many records...". Respondents also shared another issue of concern about excessive and growing data. This can occur, they noted, because of the conflict between head office recommendations on what to capture and site personnel's thoughts about the relevance of that data. For example, R6 said: "...another challenge I would say I face is a lot of information in those checklists that I mentioned about quality in checking about things. That comes from higher up from the national BIM manager, who determines the mainstream information we need to check on-site for the checklist. Some of them are not needed, in my opinion...". Another barrier is the *duplication of captured data (B09).* The repetition of capturing data of the same activity for different purposes can lead to the annoyance of those tasked with undertaking data entry and analysis, which frequently happens on projects. Respondent R6 indicated regarding captured data that: "... a lot of them will be covered in other processes like inspection, test plans and physical checks with subcontractor hold points... so they are quite cranky...".

The problem of time is also realized from this subcategory through the *limited time for the data chain (B24).* Those on-site face time conflicts between attending to core technical and big data responsibilities. These professionals often focus on their core responsibilities since their supervisors will likely assess those. An interviewee noted that "there is limited time to process and upload these data and generation of data. . . [R13]". The interviewees noted that *not synchronizing data (B29)* could become a stumbling block in using big data in construction because the current work environment has an interconnected system that relies on data synchronization to function well. Dealing with obsolete data whilst revised or new data is adapted could add further complications. Respondent R6 stated, ". . .everyone who collects data, say collecting data on our iPad, you need to synch that before uploading to BIM 360 field. And that is the responsibility of everyone using the iPad, who go out to find the defects, for instance, they don't synch it or upload on BIM, and no one will know if they don't fix it...". Many respondents suggest another related barrier to B29 is the inability and sometimes unwillingness to *not uploading data (B30)* by site personnel; none of them has been identified in earlier literature. For instance, a respondent stated, ". . .if we do an inspection and they might record the event and the inspection, but they might not upload the photographs, they might not upload the document. . ." [R3]. Finally, *manual handling of data (B25)* in a digitally oriented application like big data was identified as a problem, especially at the big data storage and processing stage. Handling of data can be done either manually or electronically. Construction is an old profession, and the interviewees noted that most people are comfortable using printed and paper copies of data. However, there is a high risk of an obsolete data version being used. R6 said: "Now we are trying iPad and trying to get everyone on the same page, but I find it a bit challenging, and people wanted paper copies of that. . .". This research data, reported in the narrative, points to time constraints in data handling. Some perceive that going digital becomes burdensome because it consumes organizational resources (human, technology, and time), which could be beneficial to activities on projects. For instance, for projects with many activities to capture, data becomes useless if only generated and not applied to improve the construction process. Spending such resources to generate data and losing it ultimately because of someone's negligence is devastating.

### *4.5. Environmental Barriers*

The environment theme constitutes business environment and leadership subcategories (Table 3) relating to the OE and BDS stages. The business environment represents barriers from the external environment where construction firms operate. *Connectivity (internet) issues (B05)* impede the big data process through a poor internet connection. Respondents say it obstructs data transfer from the site to project servers. For example, ". . .so we lose internet for a day, put many of our systems down. I found out in a previous work in a semi-rural setting that once we lost our landmark connection to our radar, the whole network we used broke down because it heavily relied on that. Even using a SIM card was slow and very difficult. And it was the stage where we were trying to hand over parts of the building and use our network to close our defects. I found out to be challenging. . . ." [R5]. This means that such an unpleasant situation could lead to contractual issues, like financial penalties, because of the inability to address project defects within a specific time frame. This barrier has been identified through a review [9] and an empirical study in facilities management [15]. The respondents noted that *environmental conditions (B10)* could hamper using technologies for capturing big data. The structures and engineering of most technologies are not friendly to adverse weather conditions. For instance, because of the power source (battery) used for some technologies, they become dysfunctional when exposed to rain or extreme heat. An example by Respondent R7 states: "With the drone in particular, there are certainly environmental conditions, windy, rainy days we can't get any of that information, and just too dangerous to fly the drone." Firms employing digital technologies on their projects need to acknowledge that weather conditions can impede the collection of data on projects as it halts construction activities as well.

Most of the technologies used for capturing data on construction projects could invade people's privacy because images and video data are collected from these big data sources, which imposes a barrier of *restriction on using technology (B34)*. Respondent R7 added that "...Newcastle is a no-fly zone being so close to Royal Air Force and airport... and making sure that where you are flying the drone is an area you are allowed to fly...". From inference, it is evident that national security installations and national laws, aside from privacy concerns, could inhibit big data, and the closest identified in the literature is data security [17]. In relation to B34, *license (time and cost) (B22)* was identified as a residual barrier to the big data process. This emerges when the construction firm does not thoroughly examine the impact of the big data technologies on a construction project at an earlier stage before mobilizing to the site. Otherwise, instead of professionals working on the project, resources such as time and cost will be channeled to training to get a license for these technologies. For instance, "...one of our projects, for instance, is a high rise in the city and the people using the drone will have to undergo unremote (sic) pilot license courses to be able to operate that amongst high rise buildings and that is costly and timely challenge... people have to go for multiple day course. People are highly trained in it. They end up on a project and might not always be using it..." [R7]. This approval requires licensing initially and then the training of individuals, which comes with extra costs and consumes time which might not necessarily be used in the construction process.

Moreover, the situation where construction firms are compelled to adopt some technologies is also recognized, thus *force adoption (B12)*. Force adoption in construction projects is initiated and implemented by clients in the construction industry, especially when they become exposed to the impact of big data technologies. For example, R12 stated that "...investing in that IT now, we would not have properly done that if there was not a contractual requirement to deliver because something we have to fast-track a new software, hardware and train on our staff in a short period to deliver what was contractually required...". Forced adoption discomforts many employees in firms, especially owners and financial managers, where the return on investment in big data technologies takes a long period to recoup, affecting the firm's financing. Projects requiring the mandatory use of big data technologies can force firms to meet the project's terms and conditions, which can be seen, the interviewees noted, as problematic. Finally, the idiosyncrasies of projects in the construction industry complicate the big data process because of the *uniqueness of project (B39)*. The uniqueness of construction projects poses challenges for big data applications in the construction projects because historical data captured on one project might not apply to another project as R14 stated: "...you know it is useful for a similar type of project, for future references but the problem is currently what I am using is joint venture and license where the project is unique, and you wouldn't find similar project...". Construction projects can be similar in design, but certain features will be different; such elements make it practically impossible to employ big data across projects for operational needs, especially, for example, when the construction project is bespoke.

Leadership barriers are within the control of the construction firm or the industry. There are two of them identified in this study; the first is *firms led by non-technology savvies (B11)*. The interviewees noted that most key leaders and decision-makers in these firms are typically conservative professionals with little or no interactions with big data technologies. This suggests that many anti-technology people are firm leaders and do not auger well for big data adoption in the construction industry. It is difficult for them always to see the benefits of big data or to recognize the difficulties in convincing partnering firms to change their operations by adding new technology such as big data. The second is *not investing in new technology (B27)*, which had been identified through a review and empirical by Bilal et al. [9] and Reyes-Veras et al. [16], respectively. Investment has always been an impediment to technological adoption in the construction industry because it does not fall into the high-profit margin businesses. There is also a cost dimension to training after procuring the technology. A respondent confirmed this, "...so that is a challenging one; I see the industry is fairly fragmented, and most projects are tendered unto the lowest price, typically not always, but often when you put in a tender for a job, you do not wanna (sic) go and invest in technology if it is not specifically required because your profit margin on that job is so small because you have to compete with ...firms or ten other firms. So, it is difficult to bring current technology because you need to start to train. . .” [R12]. Investing in technologies comes at a significant price and with considerable risk, creating potential financial complications in the long-term financial situation of the construction company. The cash inflows from construction projects are unlike in the retail industry, where cash comes in daily; in construction, cash inflows are set at fixed periods. Therefore, the firm’s management hesitates to invest in an innovative idea or technology if they are unsure of the return on investment.

## 5. Implications

The big data process’s organizational-external (OE) stage had the most barriers. Moreover, these barriers are across all the themes except data (Table 3). Notably, and to an extent, all the big data challenges identified by Reyes-Veras et al. [16] are within the OE stage. These are elaborated issues on the justification of the low uptake of digitalization in construction and the need for devising a process approach to examining industry 4.0, as argued by Professor Paul Chan [18]. Though only lack of access to technology (B20) related to technology, there is the need to consider a trade-off between technology and social issues (people, knowledge, and environment in Table 3) to achieve a balanced approach in addressing these issues. This implies that all themes should be considered significant. These have been the reason for social issues emerging as essential themes in technology theories, like the TOE and findings from digitalization studies in big data, as the theoretical basis for this study (Table 1). This study considers these social issues as the bedrock for the big data process and emerging digitalization in the construction industry, such as the Internet of Things, digital twins, smart contracts, etc. Because most digitalization has some similarities in its adoption, it is time to address them through a governmental-industry-academia approach.

The construction industry is usually a late adopter of digital technologies [2]. Moreover, the lack of industry-specific examples of big data makes the construction lags further [17]. The inability of organizations to plan for the uptake of big data applications could become deleterious to the finances and other resources of the firm; therefore, formidable, realistic, and well-thought-through strategies become essential. In this context, the findings of this study have practical implications. The identified and mapped barriers offer the awareness, knowledge and understanding for the effective deployment of big data in construction. This study shows that strategic and operational planning should consider the complex interaction amongst the five themes vis-à-vis the big data processes (Table 3). In the early stages of decision-making on big data deployment, the firms could review the five themes and use the results to inform them of the way forward. For example, if the review suggests people-related barriers, especially if the firm falls short of the needed workforce, then the firm could plan for recruitment aligned with the firm’s future in digital transformation (Artificial Intelligence and Machine Learning). Based on the findings, the likely candidate for the role should demonstrate strong leadership skills with a strong understanding and expertise in construction, digital technologies, and processes.

Moreover, the findings show that each stage has inherent barriers. This means that at the strategic level, the mapped barriers provide an opportunity for the firm to envision, plan and develop capabilities to mitigate against the barriers for the smooth implementation of big data at the operational level. An approach of this nature has been useful for performing risk assessment on construction projects [48], and it is equally important in the context of this study.

Bilal et al. [9] reviewed the literature to identify the potential pitfalls of big data. Ahmed et al. [46] identified challenges related to data mining through a comprehensive review and a workshop investigating the findings from the review. One of the gaps from those studies appears to have been addressed in Reyes-Veras et al. [16], thus identifying the challenges without any structured or identified barriers from the literature since big data is in a nascent area in the construction industry. Reyes-Veras et al. [16] left much to be desired because the findings related to general digital challenges. By theoretical implications, this study addressed the gap of inherent challenges of the big data process specific from the experiences of the construction professionals. Moreover, the knowledge gap in mapping the barriers in the big data process has been addressed in this study. The findings suggest that some barriers transcend across stages.

## 6. Conclusions

Digitally oriented big data applications will continue to dominate because of the high volumes of heterogeneous data generated on construction projects by digital technologies. Big data's strategic and operational benefits become useful to construction firms if there is a blueprint guide, especially when challenges are made known. It is for such reason that this study mapped the challenges in the big data process and thematized them. Three significant points were identified. Firstly, forty barriers were identified in the big data process, classified into ten subcategories, leading to five themes: People, knowledge, technology, data, and environment. Secondly, twenty-six out of the forty barriers have never been identified in review or empirical studies; these include data input by multiple people; compelling people to use technology; human involvement; reliance on experience; getting the right people to train; inadequate training; irrelevant training; barriers associated with devices; limited storage capacity; lack of access to technology; unavailability of relevant data platforms; lack of access to sensitive data; irrelevant data capture; difficulty in finding data; bombarded with more data; duplication of captured data; limited time for data chain; not synchronizing data; not uploading data; manual handling of data; environmental conditions, restriction on using technology; license (time and cost); force adoption; firms led by non-technology savvies; and uniqueness of project. Thirdly, analytics limitations, unorganized data and no detailed description of data identified in earlier studies through a general review of big data literature have been empirically detected in this study.

The findings from this study provide a valuable array of problems for construction firms intending to adopt and implement big data. The mapping of the barriers in the big data process (Table 3) could enable construction professionals to visualize the identified factors and plan towards addressing them from a strategic view. Even so, this study had the limitation of not engaging data analysts; therefore, the barriers relating to the big data application stage might need to be more comprehensive and further studies could explore it. A quantitative questionnaire instrument based on the findings could be developed for future studies to explore the barriers from broader continental research and for validation purposes. Furthermore, the relative importance of the themes will be explored in the quantitative research. Moreover, the qualitative approach to data collection has generalization limitations, and the findings should be interpreted within the context of this study.

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