The fourth industrial revolution (4thIR) and the construction industry - the role of data sharing and assemblage

T O AYODELE¹ and K KAJIMO-SHAKANTU²

¹,² Department of Quantity Surveying and Construction Management, University of the Free State, Bloemfontein, 9300, South Africa
E-mail: Ayodele.t.oluwafemi@gmail.com

Abstract
The technological shift over the last half-century has been termed the fourth industrial revolution (4thIR). Underpinning this digital innovation is the increasing need for data sharing and assemblage in the construction industry. The study seeks to explore the nexus between data sharing and assemblage in the industry and the 4thIR. This paper adopts a desk-based study approach and review of secondary literature on the role of data in the drive for automation in the construction industry, challenges to data assemblage, and benefits of data sharing to stakeholders. The study reveals that factors that serve as debacles to data sharing/assemblage include: unstructured nature of data, silo operation, confidentiality issues and motives of personal benefits. However, a major advantage of data sharing is the benefit of increased digital and technological compliance in the industry. The study is part of ongoing empirical research. Hence, the findings are an aggregation of perspectives/submissions from extant studies. This study presents the first attempts at exploring the preparedness of the construction industry for the 4thIR from the perspective of data and information needs of the industry.

Keywords: 4thIR, challenges, construction stakeholders, data, data assemblage, data sharing, technological innovations

1. Introduction
The last half-century has witnessed a tremendous digital and technological shift which has revolutionized processes and human exchanges. Schwab [1] termed these innovative technologies as the fourth industrial revolution (4thIR). The 4thIR is characterised by its digital and automated influence on man’s interactions and operations, cutting across sectors, economies and international exchanges. The rapid-paced technological shift triggered by the 4thIR has unlocked markets, facilitated rapid industrialization across economies, transformed industrial operations and significantly influenced business models and interactions [2]. Industries are beginning to align their operations with the technological innovations accompanying the 4thIR. However, while the evolution of the 4thIR still appears at the rudimentary stages, it is expected that the industry stakeholders across different sectors adopt an integrated, comprehensive and inclusive approach to the accompanying changes brought about by the 4thIR [1].
Technological revolutions as a result of the 4thIR have led to an increasing global drive for the integration of innovative technologies into activities and processes across industries, and this is beginning to impact on the mode of project design, construction and operation in the construction industry (CI) [4]. Thus, the industry is not immune to the attendant changes been triggered by the 4thIR. However, when compared with other industries, the CI appears to be slow-paced in integrating innovative technologies into its operations [5][6]. The heavy footedness of the CI in adopting innovative changes and technologies into its operations [8][9][4] could serve as a bane in the drive towards full integration into the innovations of the 4thIR. The CI must increasingly integrate automation and digital technologies into its operations for her to keep pace with emerging global technological drive. Thus, given the increasing influence of automated and digital processes on the operations of other sectors, stakeholders in the CI need to prepare proactively for the attendant interferences associated with these trends. The industry stakeholders must be aware that the narrative is changing globally from the traditional silo operation [10] to collaborative practices through the adoption and integration of digital and automated technologies.

While the CI may not have kept pace with the level of technological advances as observed in other industries, the CI has witnessed some important digital shifts in the last couple of years. The increasing uptake of BIM and other digital technologies by the construction firms are positive trends in this direction [4]. Thus, an important first step towards a fully automated and digital CI is an increased uptake of BIM and other innovative technologies such as robotics, artificial intelligence (AI), augmented/virtual reality, data analytics and cloud/mobile computing among others. However, underpinning the uptake of these innovative technologies is the need for robust and compatible data sets across different stakeholder platforms. Thus, if there is to be an increased uptake of these innovative technologies, the need and use of data by CI stakeholders become germane. This underscores the need for data sharing and assemblage in the CI.

The remainder of the study is sectioned into two. Following the introduction is the literature review which has three subsections, focusing on the role of data in the CI and the 4thIR, challenges to data sharing and assemblage and the benefits of data sharing and assemblage in the CI. Subsequently, some recommendations and conclusions derivable from the review were put forward. It is expected that this study will provide useful information to stakeholders in the South African CI by stimulating interest in increased data sharing and assemblage. This is with a view towards making the industry take optimal advantage of the benefits derivable from the automation and digital trends brought about by the 4thIR.

2. Literature Review
2.1 Role of data in the Construction Industry (CI) and the 4thIR
The CI contributes significantly to employment and the economic growth of countries. However, if the industry’s contributions and productivity are to be sustained, an increase in the uptake of automated processes and emerging technological innovations become germane. The adoption of BIM and other digital technologies are important first steps in automating and digitalizing the processes in the CI. According to Becerik-Gerber et al [11], the uptake of innovative technologies is steadily increasing among stakeholders in the CI.

Researchers have noted that technological innovations associated with the 4thIR will open up new levels of data sharing in the CI. This will lead to increased use of integrated contracts, development of open standards for data sharing, accessibility to data on design, costs, and schedules among others. The integration of digital technologies into construction activities and processes presupposes the availability and exchange of data on costs, design, schedules, sustainability, etc among project stakeholders. Data underpins the digital and technological trends in the CI [12]. The rising uptake of digital and automated systems will be of optimal benefit where industry stakeholders make concerted efforts towards an increased level of data sharing and assemblage [12]. Highlighted
among the major areas of transformation within the CI at the WEF [4] annual meeting is the need to optimize the use of data and digital models. Data availability, accessibility, and assemblage are essential factors when aggregating the dynamics of the CI. Thus, to fully integrate into the derivable benefits associated with digital and automated systems, data sharing must be encouraged among the professionals in the CI.

Aibinu [12] noted that data serves as an important decision support tool for firms in providing value-added service to the client. Thus, with increasing clients’ sophistication and desire for high investment returns, issues relating to data sharing and assemblage are becoming a focal point across industries; evidently, the CI is not left out [7]. Data is of immense importance to CI stakeholders and firms [13]. The data need within the CI is linked to the apparent paucity of structured data and the importance of data for decision making and optimizing/allocation of resources. Investors often regard the lack of data as a major risk factor. The increasing adoption of BIM and other automated and digital technologies will improve data sharing in an accurate, consistent and collaborative manner among construction stakeholders. It might thus be expected that with increasing uptake of digital technology, data will be created, stored and shared in more collaborative ways among construction stakeholders. However, as opined by Serwadda et al [14] there are concerns among stakeholders especially in the global south, regarding the level of preparedness to embrace data sharing and assemblage. With the increasing uptake of innovative technologies, the data need in the industry becomes more amplified. Thus, if the increasing uptake of digital technologies will be sustained, the stakeholders must be willing to make data available and accessible.

2.2 Challenges to data sharing and assemblage

Construction activities are data-driven [15]. Large amounts of data sets relating to specifications, BOQ, construction program, progress reports, quality assessment, comparative cost data, location data, spatial data, design variables, users behaviour, and market information are generated during the various stages of a project. These data set ought to be easily accessible and available to various stakeholders. However, CI stakeholders are increasingly having difficulty in accessing construction data [6]. Several issues have been identified in literature which often impact on data sharing practices among CI stakeholders. Data is increasingly being recognized as a competitive tool for businesses [16]. Most firms regard accessibility to data as a means of securing a competitive advantage over other firms, this understanding limits the level of data sharing among industry professionals [17]. Thus, fears about divulging classified data to competitors inhibit stakeholders' interest in data sharing. Also, the diversity of the CI presupposes that various stakeholders will have different interests and stakes regarding data sharing and assemblage [3]. Most often contractors perceived fewer benefits from data sharing to themselves than clients and consultants [6]. Furthermore, due to poor motivation, lack of incentives and drive for personal benefits, stakeholders decline to disclose data [18]. Hence, the willingness to share data among CI stakeholders is often challenged by the level of perceived personal/firm-level benefits. It can then be submitted that the benefits of data to the individual/firm appear to override the perceived common benefits derivable from data sharing and assemblage at the industry level.

Studies such as Ahmed et al [19] and Che-Ibrahim et al [20] submitted that data sharing is also influenced by organisational behaviour and inclinations. Issues of organisational behaviour and inclinations are a source of concern among CI stakeholders [10]. Multinationals and large firms do not usually see the need to share data, as opposed to smaller or startup firms. This is premised on the perceived access to data being enjoyed by these large firms. Hence, collaborative efforts and data sharing practices may not be much appreciated and encouraged by larger firms owing to the perceived market dominance and access to data. This behaviour will adversely impact on the smaller firms and other industry stakeholders. Another challenge lies in the complex supply chain structure, stemming from the multiplicity of subcontractors, contractors, suppliers, and consultants [21].
noted that access to data embedded in the supply chain is becoming more difficult for consultants, clients, and other CI stakeholders.

Also, data generated during projects are often not maximally used owing to the inconsistent means the data was produced and shared by the stakeholders. Data collated across firms are not often compatible with other databases, owing to the unstandardized method of data assemblage during project execution. Most of the data generated and stored in the firms' databases during projects are usually unstructured data. The unstructured data account for about 90% of the data available in the CI [22]. Unstructured data are fraught with issues of manageability which often impedes the use to which the data can be put [23]. Also, unstructured data comes with the challenge of interoperability and compatibility across different platforms [10][24][3]. Other challenges associated with unstructured data include inconsistency in content [25] and difficulty in understanding the data set [7]. Incompatibility and interoperability of data undermine the usefulness of the data for industry stakeholders.

The challenge of data compatibility and interoperability becomes herculean because there are no universally accepted standards for data gathering and assemblage in the CI. Nassar [26] submitted that the lack of standardization concerning project data collection and storage, and the unorganized and unstructured mode of data storage are major issues militating against data sharing and assemblage in the CI. Lack of standardization is often amplified by the CI’s silo operations. The issue of unstructured data and the resultant effect of the unstandardized approach to data gathering, to other issues of incompatibility and interoperability, can impact adversely on the competitiveness of the CI with respect to cost management, and investment/financial decisions to mention a few [3].

Also, the CI is project-based, multi-disciplinary firms form a short-term alliance to complete projects. The alliance is based on contractual terms, and upon project completion, the contract is terminated. This form of project execution could lead to ineffective data management. Most often due to the failure of project participants to share and keep data collected during the project, data becomes lost [27]. Also, other issues such as data gathering in ad hoc manner, varying methods of recording data, different access and availability of data management tools, poorly defined roles for the multiple stakeholders and differences in participant experience, background and knowledge base often serve as debacles to data sharing an assemblage in the CI [13].

Despite the increasing data need in the CI, the decline in the use of BOQs, difficulty and cost of data collation and assemblage, lack of generally accepted standard of cost break down, lack of uniformity in procurement practices, the failure to realize the benefits of data sharing, the resistance of stakeholders’ to change, and the integrity of the data; due to alterations leading to inaccurate, corrupted and incomplete data has posed a challenge to data assemblage in the CI [6]. Other major causes of concern among industry stakeholders relate to issues of data ownership, clients' confidentiality and the commercial value of data [7]. Besides, the organisational culture, perspectives of stakeholders, and the degree of trust are other factors that influence data sharing in the CI [13]. Also, behavioural factors such as leadership role, reciprocity, accountability, communication, and commitment are found to impact on data sharing [20]. Lee and Whang [28] noted that major concerns for data sharing are mutual cooperation, confidentiality, technology capabilities, timeliness and accuracy of data. Ahmed et al [19] posited that the challenge to data sharing and assemblage in the construction industry relates to obtaining accurate data, and understanding the relevance and importance of data sharing and assemblage, storing of data in silos in an unstructured format and skill requirement of stakeholders.

Commercial-scale application and production of digital technologies have remained limited in use owing to the challenge of lack of data [4]. Apparently, most digital and innovative technologies rely on data inputs. The challenge of data sharing and assemblage becomes tasking when situated within the context of the individual drive for competitive advantage, lack of standardized approach to data collection leading to issues of interoperability and compatibility, organisational behaviour/culture, the complexity of supply chain, and the multidisciplinary nature of the CI. Other mitigating factors
such as the need for clients’ confidentiality, trust, reciprocity, timeliness, and accuracy of data, communication, and poorly defined roles of project stakeholders among others influence data sharing and assemblage in the CI.

2.3. Benefits of data sharing and assemblage
The benefits derivable from data sharing and assemblage in the CI cannot be overemphasized. The data generated at the individual/firm-level would be beneficial to other stakeholders when assembled and transformed into intelligence [12]. It is expected that data is valid, reliable, current, transparent and comparable with international standards [25]. However, it has been noted that poor data and unreliable estimates are major sources of time and budget overruns [16]. Spurious and incompatible data undermines timely project delivery. Data serves as a strategic tool for stakeholders in minimizing cost [29]. Also, data sharing and assemblage enables stakeholders to assess the project's cost implications, and benchmark expected and actual costs. Extant studies (see, [24]) have argued that the successful realization of investment objectives is dependent on the level of access to data. Unavailability of data exposes the investment to risk, which directly impacts on the client and the firm. Data sharing will impact how projects and assets are managed while also enhancing optimal solutions and improved productivity [12].

WEF [3] noted that stakeholders' confidence is enhanced when data is accessible, detailed, and assembled in a consistent and verifiable manner. RICS Insight [6] noted some other benefits of data sharing to include the provision of benchmarks and enhanced accuracy of estimates and cost prediction. Where individuals/firms encourage data sharing and assemblage, there would be collaborations, increased data exchanges, best practice sharing and benchmarking among stakeholders [2]. Data sharing and assemblage afford stakeholders the opportunity of comparing organisational efficiencies through international benchmarks; inadequacies are detected and resolved [6]. Collinge et al [10] posited that construction data play an important role in detecting and solving complications during the project life cycle. Ahmed et al [19] submitted that advantages of data sharing include improved market intelligence, enhanced business and investment certainty, improved processes, cost reduction and cost certainty.

Historic project data helps in accurately evaluating the performance of past projects [30]. Senaratne and Sexton [31] asserted that where there is the openness of data, the knowledge gained in previous projects can be applied to current projects. This helps to prevent stakeholders from reinventing the wheels, and it also enhances the chances of learning from previous errors. Bilal et al [32] submitted that stakeholders delay project decisions or make wrong judgments due to the lack of robust data. Hence, given that the quality of investment decisions is underpinned by the quality of data input, it might then be submitted that availability of accurate data enhances stakeholders' capacity in terms of problem identification, proffering solutions and prompt decision making.

When stakeholders’ interest is sufficiently stimulated and the benefits of data sharing and assemblage are amplified, there will be a corresponding increase in the level of availability of and accessibility to data in the CI. This is expected to result in the CI being able to better harness and appreciate the attendant benefits of the 4thIR. However, before the CI can be effectively positioned to benefit from the increasing uptake of digital and automated technologies, industry stakeholders must properly recognize and value the benefits of data sharing and assemblage.

3. Conclusion and Recommendations
The increasing uptake of innovative digital technologies drives the transformation of industries and global economies, and the CI is not insulated from the effects of these disruptive influences triggered by the 4thIR. Thus, stakeholders in the CI must be strategically prepared for these disruptions and its effect on the activities and operations of the CI.
The CI is extremely dependent on data, a large volume of data sets are exchanged between project stakeholders during the construction and project life cycle [15][33]. Hence, the CI is a data-intensive field of activity [10]. Data availability and integration into construction decision processes is thus a critical component in achieving the investment objectives. There is thus a need to make construction data readily accessible and useable [6].

Ismail et al [34] submitted that over the last couple of years, the increasing integration of digital and automated technologies in construction activities has resulted in an increased volume of data generation. However, in other to maximize this increasing volume of data, the data must be appropriately assembled, analysed and shared among stakeholders [34]. A major implication from the foregoing is the need for data availability, and an examination of other equally important issues such as data accessibility, compatibility, and interoperability across different user platforms. However, RICS Insight [6] pointed out that the precision in ensuring data accuracy, compatibility and interoperability is dependent on stakeholders' willingness to assemble, share and present data in the specified format. With respect to presenting data in the specified format, there is the need for the CI to establish a generally acceptable means of data collection and ensuring compatibility across stakeholders’ platforms.

Literary evidence [34][35] shows that the uptake of digital technologies and the application of data analytics is limited in the CI when compared to other industries. Extant literature underscores the benefits derivable by the CI with the integration of digital technologies into the activities and processes of the industry. Maximizing the benefits depends on an improved level of collaboration by the stakeholders in the industry. Furthermore, aside from knowing the benefits of data sharing and assemblage, stakeholders' expectations to share data will not be achieved if the challenges being expressed by stakeholders are ignored. Hence, there is a need for an assessment of the inhibiting factors from the stakeholders' perspectives. This is expected to stimulate stakeholders' interest and ensure that concerns are reduced to the barest minimum.

Data sharing and assemblage will constitute a major part in the roles of professionals in the CI, and until the challenges and inhibitions of stakeholders are overcome, the CI cannot optimally benefit from the gains of innovative technologies associated with the 4thIR. Some initiatives that could be considered towards increasing the data sharing and assembling practices in the CI include: building up appropriate internal competencies, such as encouraging stakeholders to share data, stakeholders' enlightenment about the benefits of data sharing and assemblage and promoting partnerships among stakeholders in the industry. An understanding of stakeholders' perceptions and challenges will assist in providing solutions to the data-sharing debacle. The availability of data within the CI can be optimized when stakeholders are encouraged to disclose data and enlightened about the common benefits of data sharing and assemblage.

Building on the increasing digital and technological innovations across various industries, a number of studies such as Kamara et al [36], Ahmed et al [19] and Lee, Park and Song [37] have identified other factors that drive the need for data sharing and assemblage in the CI. Such factors include increasing globalization, increasing clients’ sophistication, increasing project/product complexity and the demand for better value for money. Other factors include dynamic customer demand, increasing clients’ scrutiny of construction costs, and the rising pressure on data transparency. In summary, with the increasing global technological changes termed the 4thIR, and other drivers necessitating the need for increased data sharing and assemblage in the CI, it might be reasonably expected that there will be an increasing interest by construction stakeholders towards data sharing and assemblage. To increase the level of data sharing and assemblage, stakeholders must prioritize integrating and analysing data sets and leverage on the advantages of automated and digital technologies brought about by the 4thIR.
References

[1] Schwab K 2015 The Fourth Industrial Revolution. Geneva: World Economic Forum.
[2] World Economic Forum 2016 Shaping the Future of Construction- A Breakthrough in Mindset and Technology. Prepared in collaboration with The Boston Consulting Group. https://www.weforum.org
[3] World Economic Forum, 2017, Responsive and Responsible Leadership. http://www3.weforum.org/docs/WEF_AM17_Overview.pdf
[4] World Economic Forum 2018 Creating a Shared Future in a Fractured World. https://www.weforum.org
[5] Oesterreich T D and Teuteberg F 2016 Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry Computers in industry 83 121-139.
[6] RICS Insight 2018 Sharing construction cost data – benefits, challenges and opportunities. https://www.rics.org/globalassets/rics-website/media/knowledge/research/insights/sharing-construction-cost-data-benefits-challenges-and-opportunities-rics.pdf
[7] RICS Insight 2019 The use and value of commercial property data. https://www.rics.org/globalassets/rics-website/media/knowledge/research/insights/value-of-commercial-property-data-rics.pdf
[8] Ostravik F 2015 Incentives for innovation in construction. Ostravik, F. Dainty, A and Abbott, C. (Eds.). Construction Innovation. United Kingdom. Wiley Blackwell. pp. 13-28
[9] Whyte A and Donaldson J 2015 Digital model data distribution in civil engineering contracts Built Environment Project and Asset Management 5 248-260.
[10] Collinge W H, Harty C, Liu K and Tang Y 2009 Improving information sharing across construction stakeholders: an organizational semiotics approach. In CIB Joint International Symposium: Construction facing worldwide challenges.
[11] Becerik-Gerber B, Gerber D J and Ku K 2011 The pace of technological innovation in architecture, engineering, and construction education: integrating recent trends into the curricula Journal of Information Technology in Construction (ITcon) 16 411-432.
[12] Aibinu A A 2017 Data Mining and Data Analytics: A New and Emerging Area for the Quantity Surveying Profession QS Link 2017 2 12-14.
[13] Von-Tran H and Kanjanabootra S 2013 Information sharing problems among stakeholders in the construction industry at the inspection stage: A case study In Proceedings of the 19th CIB World Building Congress, Brisbane.

[14] Serwadda D, Ndebele P, Grabowski M K, Bajunirwe F and Wanyenze R K 2018 Open data sharing and the Global South—Who benefits? Science 359 642-643.
[15] Sarkar D and Thakkar P 2018 Integrated BIM-Cloud Model for Enhancing Coordination and Communication in Real Estate Projects in India International Journal of Construction Project Management 10 55-68.
[16] Ahiaga-Dagbui D D and Smith S D 2014 Dealing with construction cost overruns using data mining construction management and economics 32 682-694.
[17] Leppikorpi T 2018 Utilizing information systems in inter-organizational collaboration and information sharing (Master's thesis).
[18] Maskey R, Fei J and Nguyen H O 2019 Critical factors affecting information sharing in supply chains Production Planning and Control 1-18.
[19] Ahmed V, Aziz Z, Tezel A and Riaz Z 2018 Challenges and drivers for data mining in the AEC sector Engineering Construction and Architectural Management 25 1436-1453.
[20] Che-Ibrahim C K I, Mohamad Sabri N A, Belayutham S and Mahamadu A 2019 Exploring behavioural factors for information sharing in BIM projects in the Malaysian construction industry Built Environment Project and Asset Management 9 15-28.
[21] Sawhney A, Walsh K D and Brown I A 2004 International Comparison of Cost for the
Construction Sector: Towards a Conceptual Model Civil Engineering and Environmental Systems 21 151–167.

[22] Jenkins T, Glazier D and Schaper H, 2004, Enterprise Content Management Technology: What you need to know, Open Text Corporation, Ontario.

[23] Childerhouse P, Hermiz R, Mason-Jones R, Popp A and Towill D R 2003 Information flow in automotive supply chains–identifying and learning to overcome barriers to change Industrial Management and Data Systems 103 491-502.

[24] Martínez-Rojas M, Marín N and Miranda M A V 2016 An intelligent system for the acquisition and management of information from bill of quantities in building projects Expert Systems with Applications 63 284-294

[25] Ruddock R 2002 Measuring the global construction industry: improving the quality of data Construction Management & Economics 20 553-556

[26] Nassar K 2007 Application of data-mining to state transportation agencies projects databases. Journal of Information Technology in Construction (ITcon) 12 139-149.

[27] Zhang P and Fai Ng F 2012 Attitude toward knowledge sharing in construction teams Industrial Management and Data Systems 112 1326-1347.

[28] Lee H L and Wang S 2000 Information sharing in a supply chain International journal of manufacturing technology and management 1 79-93.

[29] Jones S, 2012, Why ‘Big Data’ is the fourth factor of production. Retrieved from https://www.ft.com/content/5086d700-504a-11e2-9b6600144feab49a

[30] Moon S W, Kim J S and Kwon K N, 2007, Effectiveness of OLAP-based cost data management in construction cost estimate. Automation in Construction 16 336-344.

[31] Senaratne S and Sexton M 2008 Managing construction project change: a knowledge management perspective Construction Management and Economics 26 1303-1311.

[32] Bilal M, Oyedele L O, Qadir J, Munir K, Ajayi S O, Akinade O O, Owolabi H A, Alaka H A and Pasha M 2016 Big data in the construction industry: a review of present status, opportunities, and future trends Advanced Engineering Informatics 30 500-521.

[33] Al-Maatouk Q and Othman M S 2018 A framework for collaborative information management in construction industry IJAIP 11 33-44.

[34] Ismail S A, Bandi S and Maaz Z N 2018 An Appraisal into the Potential Application of Big Data in the Construction Industry International Journal of Built Environment and Sustainability 5 145-154.

[35] Pham H T H and Hoang H T, 2018, The influence of digitalization on the buyer-supplier relationships in the construction industry (Master's thesis, Handelshøyskolen BI).

[36] Kamara J M, Augenbroe G, Anumba C J and Carrillo P M 2002 Knowledge management in the architecture, engineering and construction industry Construction Innovation 2 53-67.

[37] Lee D G, Park J Y, and Song S H, 2018, BIM-based construction information management framework for site information management Advances in Civil Engineering, https://doi.org/10.1155/2018/5249548