Ain Shams Engineering Journal 11 (2020) 225–230

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Civil Engineering

Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders

Wesam Salah Alaloul *, M.S. Liew, Noor Amila Wan Abdullah Zawawi, Ickx Baldwin Kennedy

Department of Civil and Environmental Engineering, University Technology PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia

ARTICLE INFO

Article history:
Received 13 July 2019
Accepted 25 August 2019
Available online 15 October 2019

Keywords:
Industrial Revolution 4.0
Construction industry
Innovative technologies
Internet of things (IoT)
Challenges
Opportunities

ABSTRACT

The trend of digitization, automation and the increased use of Information and Communications Technology (ICT) have been envisioned as the main concept of the Industrial Revolution (IR) 4.0. Comparing the progressions between multiple industries, the construction industry is reluctant in incorporating these innovative technologies into its common practices despite the drastic developments demonstrated by the other industries. Numerous challenges exist from multiple aspects which prevent the engagement of IR 4.0 within the construction industry. A comprehensive review is conducted to identify the main problems which delay the implementation of IR 4.0 related technologies within the construction industry and opportunities attained in the long run. Then a questionnaire survey was conducted where the collected data was analyzed. This study shows that the critical factor affecting the successful implementation is the social and technical factors. However, all the contributing factors established a significant influence on the successful implementation despite the identified critical factor.

1. Introduction

Ever since the industrialization era began in the 1700s, each industrial revolution carried its own significant role in the advancement of today's development. In 1700s, mechanical looms were first introduced which were driven by the power of water and steam on mechanical equipment and replaced the agricultural sectors, further enhancing the economic structure. The Second Industrial Revolution occurred in 1870s, where electrical energy was introduced which formed a major system known as mass production. These revolutions relied on the number of human capabilities to achieve more.

During the 1970s, the Third Industrial Revolution occurred with the rise of electronics. The innovation of technology from analogue electronic and mechanical devices to today's digital technology available is referred to as Digital Revolution. Today, the Fourth Industrial Revolution (IR 4.0) is built upon the Digital Revolution where technology and people are connected. The technological breakthrough has found new ways of demonstrating its abilities by blurring the lines between the physical, digital and biological entities [1]. The revolution not only presents modern techniques supporting every component within industry but sustainability [2], where renewable energy and energy efficiency are two central components [3]. Renewable energy still contributes 19.2% in consumption [4] where energy efficiency is influenced by technological innovations in the industry [5,6] though the implementation is difficult [7]. The IR 4.0 aims for a viable and sustainable manufacturing system [8] and have the higher level of the complexity for integrating the production and products processes [9], where it become part of the sustainable system [10]. All the three dimensions of sustainability; social, economic and environmental, values in the creation of sustainable industry by using industry 4.0 [11] and utilized for long term competitiveness [12]. It is important to have consideration on tactical, operational and strategic dimensions as well for short and long term impact towards sustainability [13].

By focusing on the areas of specialization, the progression has altered manufacturing processes thus, forging constructive economic prospects. Originating from Germany, the government supports this futuristic idea by endorsing the automation of industrial processes [14]. IR 4.0 has been established as a term for the industrial developmental process made up of automation and data exchange and was first introduced to public as "Industries 4.0"

* Corresponding author.
E-mail address: wesam.alaloul@utp.edu.my (W.S. Alaloul).
Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2019.08.010
2090-4479/

with the aim to drive the implementation of IR 4.0 within the German manufacturing industries [15,16]. This Working Group was formed by multiple representatives from different backgrounds. The IR 4.0 workgroup developed a strategic application work plan to increase the German industrial competition globally which led to the adoption of the German federal government into its 2020 High-Tech Strategy [17].

The trend of digitization, automation and the widen use of Information and Communications Technology (ICT) in the industry contain technologies of cyber-physical systems, Internet of Things (IoT), cloud computing and cognitive computing, described as IR 4.0.

The concept of IR 4.0 is to digitize industrial processes to accomplish an adaptive yet extensive production and service network [18,19]. Like manufacturing industry, construction industry performance can be enhanced through IR 4.0 [20]. The implementation of IR 4.0 renders an area where every mechanized automation will be interconnected through technological advancements to operate and share information without the need of humans which will improve the efficiency. The industry develops a concept called — smart factory, where cloud computing and cognitive computing stores data and make decisions. The IoT however, comes functional with cyber-physical systems, allows humans to monitor the processes in real time without physical presence and proven the capabilities of vision of IR 4.0 manifest [19,21].

The benefits are clear through its implementation as it improves the product quality while it decreases time-to-market and enhancing operation performances. However, the construction industry hesitant in implementing these concepts despite the countless benefits offered by the other industries. Even in the complex construction environment reluctance of implementing IR 4.0 was shown within the construction industry [22]. Where the entire construction value chain involves multiple fragmented counterparts from all levels with a diverse background to cater the specific needs and uniqueness of each project. This phenomenon has increased the difficulty of execution and further limits the ability for small and medium-sized enterprises (SMEs) to invest in new technologies [23].

Regardless of the challenges faced, the construction industry should improvise and adapt the ever-changing global economy. According to Marr [17], the advancement not only connect developments around the world which will recreate an existing environment but also carrying the ability to reverse the impacts caused by previous industrial revolutions.

The construction industry still struggling to adopt IR 4.0 concepts despite the clear benefits it offers. There are a few complications within the construction industry which contributes to incompatibility. According to Oesterreich and Teuteberg [23], the problem includes complexity, uncertainty, fragmented supply chain, short-term thinking, and culture. The construction projects are complex due to the involvements of many stakeholders in project which is unique. The level of uncertainty of a project is also deemed through its unpredictable environment adding complications to the project. The fragmented supply chain and short-term thinking of construction companies have limited the capabilities where the short-term nature of construction projects is an obstruction to innovation. Where the culture of the construction industry is known for its reluctant practices in adaptation [24].

The aim of this study is to identify the challenges of implementing innovative technology within the construction industry and the opportunities offered in the long run while correlating the main factors which influence the successful implementation of IR 4.0 within the construction industry. By understanding the current practices and perspectives of the construction industry, the solution formed to tackle these challenges will be significant.

Hermann et al. [25] visualized the IR 4.0 as a "smart factory" where Cyber-Physical Systems does not only monitor processes but also make decentralized decisions through a virtual copy of the physical integrated smart factories in the real world. Cyber-Physical Systems allows the collaboration of assigned parties throughout the value chain to connect and function, both human and machines instantaneously through IoT.

2. Materials and methods

2.1. DMAIC work plan

The study was conducted by applying principles of Six Sigma Quality Initiative method, DMAIC. DMAIC (Define, Measure, Analyze, Improve, and Control) is a data-driven development process to enhance companies' strategic business plan to utilize as development framework for improvements, not limited to Six Sigma only. Conditions of each phase are defined and reviewed repeatedly before proceeding to the next phase where the best results obtained through this methodology when the application process is flexible to satisfy the demands by eliminating unnecessary procedures even though the framework is deemed rigid.

To obtain optimal results, each phase within the DMAIC process carries different roles, mentioned as the following:

1. Define by explaining IR 4.0 within the Construction Industry.
2. Measure the position of respondents within the company, the number of people who have experienced IR 4.0 personally, what IR 4.0 technology have they used and how long have they been exposed to these technologies.
3. Analyze the experience with IR 4.0 technologies, what are the challenges and opportunities offered, what are the factors which influence the implementing of IR 4.0.
4. Improve by suggesting alternatives and recommendations in this study.
5. Control developed a process on what should be emphasized.

2.2. Data analysis

The Statistical Package for Social Science (SPSS) was used to analyze the gathered data for reliability and validity and MS Excel for Average Index (AI) and Relative Importance Index (RII) [26].

2.3. Average Index (AI)

The AI method is used to evaluate the influencing factors and identifying the most critical factor in IR 4.0 having higher impact on the construction industry [27].

The AI equation is as follows:

$$Average\ Index(AI) = \frac{\sum(W \times n)}{N} \tag{1}$$

where W: scale weightage from 1 to 5, given to each factor by respondents; n: frequency of respondents, N: total number of respondents.

The classifications of the rating scales are:

1 = Strongly Disagree ($1.0 \leq$ Average Index < 1.5), 2 = Disagree ($1.5 \leq$ Average Index < 2.5)
3 = Neutral ($2.5 \leq$ Average Index < 3.5), 4 = Agree ($3.5 \leq$ Average Index < 4.5), 5 = Strongly Agree ($4.5 \leq$ Average Index ≤ 5.0)

2.4. Relative Importance Index (RII)

Kometa et al. [28] used the RII method to determine the importance of the various factors towards the cause. The RII value has a range of 0 to 1 where the highest value indicates the criticalness. The equation is as follows:

$$Relative\ Importance\ Index(RII) = \frac{\sum W}{A \times N} \quad (2)$$

where W: scale weightage from 1 to 5, given to each factor by respondents, A: highest weightage given, N: total number of respondents.

2.5. Reliability test

To check the consistency of the gathered data Cronbach's Alpha coefficient is utilized where the coefficient value ranges from 0.00 to 1.00, where 1.00 indicates the higher internal consistency. The measurement process is reliable if the obtained coefficient value is greater than 0.6 [29].

2.6. Validity test

Lester et al. [30] analyzed that the value obtained by the square root of reliability provides an upper bound for its correlation where the reliability of 0.65 can never correlate greater than another reliability of 0.81. The equation for the validity test is as follows:

$$S = \sqrt{Reliability} \quad (3)$$

where S = validity

3. Results and discussions

The main factors which influence the successful implementation of IR 4.0 within the construction industry have been identified and correlated with the analyzed data. The survey questionnaires were distributed to multiple construction companies to obtain the perspective of the professionals within the construction industry. The questionnaires were distributed through emails and hard copy, resulted in 100 valid responses out of 160 and were statistically evaluated. Table 1 presents the profile of the respondents.

From the Table 1, 53% respondents are unaware of the implementation of IR 4.0 technology within the construction industry while 34% have been exposed in some part of their working experience. However, only 13% of the remaining respondents are unsure with the technology used are listed as the technology related to IR 4.0. The distribution of respondent's position within their respective companies. 32% of the respondents held managerial positions, 33% of them are engineers and 6% of quantity surveyors. The remaining 29% of the respondents consist of people working as other position such as Research & Development Personnel, Project Delivery Partner, Steel Manufacturer, Authority, etc. This supports the distribution of work group where major part of the response falls under the expert category. The distribution of companies' profile includes 41% of the respondents work as contractors while 15% of the respondents work as developers and 11% as clients. Consultants up to 13% and remaining 20% had other profiles such as the Government Agency, Service Providers, Operators, etc. The data collection has covered the essential sectors within the construction industry with a minimum of 10% of the identified sectors. The list of technology related to IR 4.0 was obtained by a study conducted by Oesterreich and Teuteberg [23] as discussed in Table 2.

The list of technology related to IR 4.0 in a continuous section when provided to the 13% of the respondents who chose 'maybe' responded positively, affirmed to have been exposed to IR 4.0 related technologies in the construction industry before. After the change in perspective, 47% of the respondents in the construction industry were familiar with the technologies related to IR 4.0 rather than 34% previously [31].

The Measuring process of the DMAIC structure were verified by identifying the IR 4.0 related technologies and concepts. 47% of the respondents were exposed to IR 4.0 related technologies. The most common technologies utilized are Social Media and Building Information Modelling (BIM) as shown in Fig. 1. The middle range (40–60%) of the combined technologies were Modularization/Prefabrica tion, Internet of Things (IoT)/Internet of Services (IoS), Digitization, and Automation. Given the list of technologies, the data concludes that all the Industry 4.0 related technologies have been implemented and utilized. An extra technology was also identified by a respondent which is Building Management Systems (BMS) [32]. Despite the uneven range, this has proved the statement where these innovative technologies have achieved a certain level of maturity within the construction industry.

Questions were designed to complement the seven factors which influence the implementation of Industry 4.0. Respondents

Table 1
Respondents' profile.

S. No.	Variable	Category	Frequency	Percentage (%)
1	Exposure to IR 4.0 Technology	Yes	34	34
		No	13	13
		Maybe	53	53
2	Age Group	20–29	23	23
		30–39	19	19
		40–49	26	26
		>50	32	32
3	Years of Experience	<5 years	24	24
		5–10 years	8	8
		11–15 years	15	15
		>15 years	53	53
4	Position in the Company	Project Director/Manager	32	32
		Design Engineer	9	9
		Project Site Engineer	24	24
		Quantity Surveyor	6	6
		Others	29	29
5	Company Profile	Developer	15	15
		Consultant	13	13
		Contractor	41	41
		Client	11	11
		Others	20	20

Table 2
List of technologies.

Cluster	Key technologies in the context of IR 4.0
Smart Factory	Cyber-Physical, systems/Embedded systems Internet of Things/Services Automation Modularization/Prefabrication Additive Manufacturing Product-Lifecycle-Management Robotics Human-Computer Interaction
Simulation and Modelling	Simulation Tools/Simulation Models Building Information Modelling Augmented Reality (AR)/Virtual Reality (VR)
Digitization and Vitualization	Cloud Computing Big Data Mobile Computing Social Media Digitization

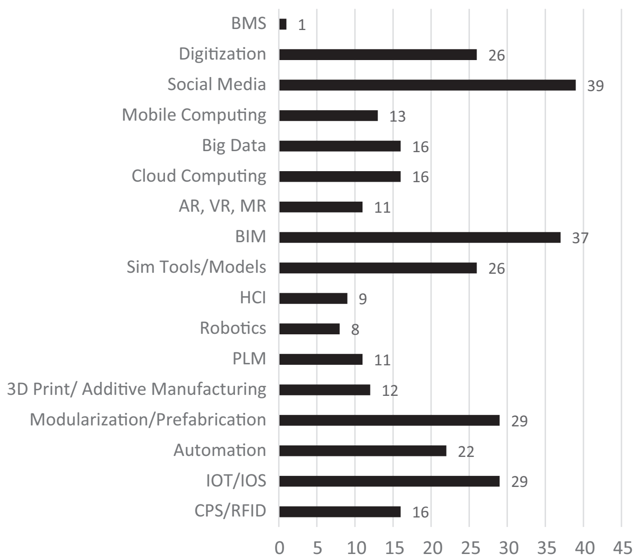

Fig. 1. Industry 4.0 related technologies & concepts.

were prompt to rate their viewpoints towards the given questions within a scale of 1–5 where 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree or Disagree, 4 = Agree and 5 = Strongly Agree. Fig. 2 shows the criticalness of the factors where Social comes as the most influential, Economical and Technological factors fall as second and third while Political as the least argued factor. The margin differences between the two Economical and Technological factors are very small. The AI and RII values for Economical and Technological factors are 4 (AI), 0.8 (RII) and 3.98 (AI), 0.796 (RII) as shown in Figs. 2 and 3.

The value of Reliability and Validity Test obtained from SPSS and the gathered data is valid The Cronbach's Alpha has a value

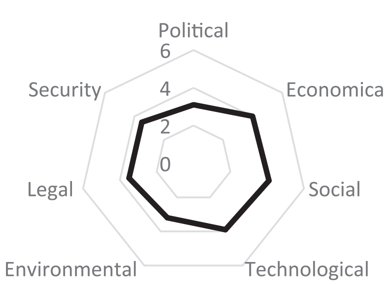

Fig. 2. Average index.

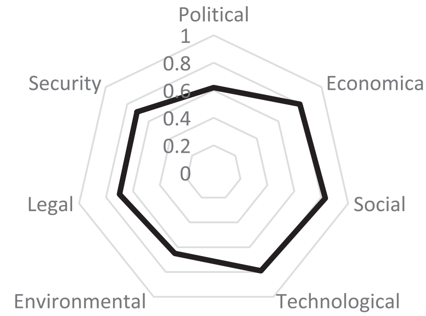

Fig. 3. Relative importance index.

of 0.74, which means that the internal consistency is good. Where the validity test value of 86% shows that the findings of the survey conducted are reliable.

Table 3
Challenges of IR 4.0.

No.	Factor	Details	Explanation
1	Political (P)	Governance	Companies within the construction support industry are mostly made up of SMEs, which restricts their ability to invest in technologies which provides with unclear benefits. The construction companies would have to rely on governing bodies and authorities to provide support towards these implementations through funding programs and also collaborative partnership
2	Economical (E)	Financial transparency	The implementation of innovative technology is costly. Further worsened by the uncertainty of a return of investment. Other hidden costs such as training and equipment maintenance would also add up to the list making it harder to implement
3	Social (S)	Cultural habits	The adoption would have a widespread effect throughout the construction processes involving multiple parties
4	Technological (T)	Technical challenges	Standards and processes would have to be redefined and enhanced to suit the construction environment. Equipment utilized elsewhere would have to be robust and the need for enhanced skills to operate these innovative technologies would increase the challenges in implementing it to normal daily practices
5	Environmental (E)	Organizational processes	Changes within organizational processes (horizontal, vertical and end-to-end) would somehow distort common execution processes. Common practices would now require to be redesigned to successfully adapt to the new changes and enhance growth
6	Legal (L)	Uncertain regulatory	Unclear separation of responsibilities withheld by each stakeholders and legal concerns through shortcomings adds up to the complexity
7	Security (S)	Threat risk	Information and data exchange would be prone to threats and placed under risky situations raising multiple IT security concerns relating to data privacy and data protection

4. Discussion

This section discusses the results of the findings obtained from the literature review and data survey. Oesterreich and Teuteberg [23] recommended that future research should explore the critical factors affecting the successful implementation of Industry 4.0 within the construction industry. This research would satisfy the research gap by fulfilling the objectives [33].

The PESTEL framework was derived from the PEST analysis to conduct market research to have an outlook on the different macro-environmental factors required to be considered. After reviewing literature from other various sources, this research suggests that security issues remain as a large contributing factor which should be considered. Security issues exist in most of the factors within PESTEL. For example, the technological factor consists of IT security issues where risk of data misuse and leaked information would pose a threat to construction companies. The legal factor however consists security issues relating to privacy and data protection. This redundancy could be removed to ensure that the factors refer towards only a specific subject. Therefore, the PESTEL framework should include security as another factor to be considered, making it PESTELS: Political (P), Economical (E), Social (S), Technological (T), Environmental (E), Legal (L), and Security (S).

Based on the findings obtained through literature review, the summary of the compiled challenges and opportunities of implementing IR 4.0 in the construction industry is demonstrated within Tables 3 and 4. The factors were ranked through the AI and RII values and illustrated through a radar chart. The Social (S) factor was proven to be the critical factor which has the greatest influence while the Political (P) factor has the least influence among all the given factors. Both Economical (E) and Technological (T) had close AI and RII values, retaining as one of the highest influencing factors. Security (S) was ranked fourth, followed by Legal (L) as the fifth and Environmental as the sixth. Both AI and RII heptagonal structure does not substantially deviates the results, shown each factor's impact on successful implementation of Industry 4.0, as the value difference for both indexes falls below 25%. This shows that all the factors contribute greatly towards the successful implementation.

Table 4
Opportunities of IR 4.0.

No	Factor	Details	Explanation
1	Political (P)	Global competitiveness	Local construction companies can enhance their competitiveness on a global scale with the most cutting-edge technologies to deliver upmost product quality and results
2	Economical (E)	Product demand and supply	Innovative technologies and concepts decrease both construction and product delivery time. The technologies would also reduce costs such as labour and material cost
3	Social (S)	Image enhancement	The digital revolution of the industry would promote a more innovative working environment rather than the conventional conditions while improving partner collaborations and also customer relationships
4	Technological (T)	Reliable productivity	The enhanced system would ensure little to no errors, increasing quality assurance. Reliable decisions could be made to achieve more effective results through sufficient information
5	Environmental (E)	Promotes sustainability	Multiple methods could be executed by using these technologies to reduce energy consumptions. The level of waste produced could also be controlled preventing pollution to the environment
6	Legal (L)	Established framework	A great widespread of this implementation would force the system to have an established regulatory reducing the uncertainties
7	Security (S)	Safety enhancement	Industry 4.0 was believed to enhance safety as different approaches could be done to execute a single project and the technology enables workers to undergo trainings or eliminate risks

5. Conclusion

Industry 4.0 has already been in the construction industry for quite a while and the technologies are on different levels of maturity. Technologies such as BIM, Cloud Computing, and Modularization have developed significantly while other technologies such as Augmented, Virtual and Mixed Reality are still being enhanced and somehow influence the sustainability in the industry. The implementation of IR 4.0 within the Construction Industry is still lacking tremendously despite having accessibility of these technologies. There are IR 4.0 practices which have been implemented within the Construction Industry and the processes have demonstrated significant impacts throughout multiple platforms. Nonetheless, the challenges transpired must be addressed by all involved parties to ensure a successful implementation. The Social factor has been identified as the critical factor which has the greatest influence towards the successful implementation, but the other contributing factors indicate that these factors are related to one another and should be addressed simultaneously. The implementation of IR 4.0 within the Construction Industry would drive the industry's performance to match with their industry counterparts such as the manufacturing and automotive industry.

References

[1] Davis N. What is the fourth industrial revolution? 2018. Available: https://www.weforum.org/agenda/2016/01/what-is-the-fourth-industrial-revolution.
[2] Hidayatno A, Destyanto AR, Hulu CA. Industry 4.0 technology implementation impact to industrial sustainable energy in Indonesia: a model conceptualization. Energy Proc 2019;156:227–33.
[3] Lemaire X. Glossary of terms in sustainable energy regulation. Renewable Energy and Efficiency Partnership, Centre for Management under Regulation, Warwick Business School, University of Warwick; 2004.
[4] Conti J, Holtberg P, Diefenderfer J, LaRose A, Turnure JT, Westfall L. International energy outlook 2016 with projections to 2040. Washington, DC (United States): USDOE Energy Information Administration (EIA); 2016.
[5] Nagasawa T, Pillay C, Beier G, Fritzsche K, Pougel F, Takama T, et al. Accelerating clean energy through industry 4.0: manufacturing the next revolution; 2017.
[6] Alaloul WS, Hasaniyah MW, Tayeh BA. A comprehensive review of disputes prevention and resolution in construction projects. In: MATEC web of conferences. p. 05012.
[7] Upadhyaya S. Country grouping in UNIDO statistics 2013;vol. 1:2013.
[8] Carvalho Núbia, Chaim Omar, Cazarini Edson, Gerolamo Mateus. Manufacturing in the fourth industrial revolution: a positive prospect in Sustainable Manufacturing. Proc Manuf 2018;21:671–8. , https://linkinghub.elsevier.com/retrieve/pii/S2351978918302105. https://doi.org/10.1016/j.promfg.2018.02.170.
[9] Kagermann H, Wahlster W, Helbig J. Umsetzungsempfehlungen für das Zukunftsprojekt Industrie. Secure the future of Germany as a production location, implementation recommendations for the future project industry 4.0, vol. 4.
[10] Demartini M, Orlandi I, Tonelli F, Anguitta D. A manufacturing value modeling methodology (MVMM): a value mapping and assessment framework for

sustainable manufacturing. In: International conference on sustainable design and manufacturing. p. 98–108.
[11] Stock T, Seliger G. Opportunities of sustainable manufacturing in industry 4.0. Proc CIRP 2016;40:536–41. https://linkinghub.elsevier.com/retrieve/pii/S221282711600144X. https://doi.org/10.1016/j.procir.2016.01.129.
[12] Schaltegger Stefan, Wagner Marcus. Sustainable entrepreneurship and sustainability innovation: categories and interactions. Bus Strat Env 2011;20(4):222–37. http://doi.wiley.com/10.1002/bse.v20.4. http://doi.wiley.com/10.1002/bse.682. https://doi.org/10.1002/bse.v20.410.1002/bse.682.
[13] Carlos Oliveira Cruz PG, Brito Jorgede, On the concept of sustainable sustainability: an application to the Portuguese construction sector. J Build Eng.
[14] BMBF. Industrie 4.0 – BMBF. BMBF-Internetredaktion; 2016.
[15] Kagermann H, Lukas W-D, Wahlster W. Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. Industriellen Revolution, vol. 13. VDI nachrichten; 2011.
[16] Alaloul WS, Liew MS, Zawawi NAWA. The characteristics of coordination process in construction projects. In: 2015 international symposium on technology management and emerging technologies (ISTMET). p. 159–64.
[17] Marr B. Why everyone must get ready for the 4th industrial revolution, vol. 5. Forbes Tech; 2016.
[18] Hallward-Driemeier M, Nayyar G. Trouble in the making? The future of manufacturing-led development. World Bank Publications; 2017.
[19] Seo-Zindy R. Industry 4.0 to digital industrialisation: when digital technologies meet industrial transformation; 2018 (11 June 2019). Available: industry-4-0-to-digital-industrialisation-when-digital-technologies-meet-industrial-transformation.
[20] Alaloul WS, Liew MS, Zawawi NAWA, Mohammed BS. Industry Revolution IR 4.0: future opportunities and challenges in construction industry. In: MATEC web of conferences. p. 02010.
[21] Alaloul WS, Liew MS, Zawawi N. Coordination process in construction projects management. In: Engineering challenges for sustainable future. ROUTLEDGE in association with GSE Research; 2016. p. 149–53.
[22] Alaloul WS, Liew MS, Wan Zawawi NA, Mohammed BS, Adamu M. An Artificial neural networks (ANN) model for evaluating construction project performance based on coordination factors. Cog Eng 2018;5:1507657.
[23] Oesterreich Thuy Duong, Teuteberg Frank. 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. Comput Ind 2016;83:121–39. https://linkinghub.elsevier.com/retrieve/pii/S0166361516301944. https://doi.org/10.1016/j.compind.2016.09.006.
[24] Alaloul WS, Liew MS, Zawawi NAB. A framework for coordination process into construction projects. In: MATEC web of conferences. p. 00079.
[25] Hermann M, Pentek T, Otto B. Design principles for industrie 4.0 scenarios. In: 2016 49th Hawaii international conference on system sciences (HICSS). p. 3928–37.
[26] Alaloul WS, Liew MS, Zawawi NAW. Delphi technique procedures: a new perspective in construction management research. Appl Mech Mater 2015:661–7.
[27] Majid MZAbd, McCaffer R. Assessment of work performance of maintenance contractors in Saudi Arabia 91–91. J Manage Eng 1997;13(5). http://ascelibrary.org/doi/10.1061/%28ASCE%290742-597X%281997%2913%3A5%2891%29. https://doi.org/10.1061/(ASCE)0742-597X(1997)13:5(91).
[28] Kometa Simon T, Olomolaiye Paul O, Harris Frank C. Attributes of UK construction clients influencing project consultants' performance. Constr Manage Econ 1994;12(5):433–43. http://www.tandfonline.com/doi/abs/10.1080/01446199400000053. https://doi.org/10.1080/01446199400000053.
[29] Toke L, Gupta R, Dandekar M. An empirical study of green supply chain management in Indian perspective. Int J Appl Sci Eng Res 2012;1:372–83.
[30] Lester PE, Inman D, Bishop LK. Handbook of tests and measurement in education and the social sciences. Rowman & Littlefield; 2014.
[31] Sommer L. Industrial revolution-industry 4.0: Are German manufacturing SMEs the first victims of this revolution? J Ind Eng Manage 2015;8:1512–32.
[32] Alaloul WS, Liew MS, Zawawi NAW. Communication, coordination and cooperation in construction projects: business environment and human behaviours. In: IOP conference series: materials science and engineering. p. 012003.
[33] Alaloul WS, Liew MS, Zawawi NAWA. Identification of coordination factors affecting building projects performance. Alexandr Eng J 2016;55:2689–98.

Dr Alaloul research interests are in construction management, BIM, construction materials, offshore structures decommissioning, and lifecycle cost assessment. Also, he is a certified trainer for construction costing and sustainability issues. **Dr Alaloul** was a member of several evaluation committees for development and research projects proposals.