INVESTIGATING MAJOR CHALLENGES FOR INDUSTRY 4.0 ADOPTION AMONG U.S. CONSTRUCTION COMPANIES

Abstract:

Purpose: The purpose of this study is to explore the challenges hindering the adoption of Industry 4.0 among construction companies.

Design/methodology/approach: The construction industry is in need of innovative technologies due to its complex and dynamic nature. The fragmented structure of the industry requires the adoption of new tools and techniques in order to record better performance in the execution of projects. In this respect, latest trends such as digitalisation, BIM, IoT are of utmost importance in terms of fostering the change in managing projects and encouraging industry practitioners adopt the change for better performance. This paper focuses on Industry 4.0 (I4.0) adoption among construction companies, which is expected to take technology to the next evolution. In this respect, a questionnaire was designed and administered to construction professionals to reveal challenges I4.0 adoption among construction firms. Among the 89 questionnaires returned, 35 of them were provided by project managers, 27 were provided by senior project executives, 18 were gathered from senior engineers, and 9 are from senior project executives. The respondents were requested to fill in the questionnaire on the Industry 4.0 efforts of their companies. The questionnaire was intended to collect the perceptions of industry practitioners working at large construction companies. The questionnaire was designed as a two-part study. In the first part, the questions were aimed at collecting general information about the respondent and company characteristics. The second part was designed to measure the relative importance of the major I4.0 challenges and the companies' level of success in tackling those challenges. Based on these, the challenges listed were ranked based on their relative importance and success indices. Finally, the Mann Whitney U test was conducted to test whether statistically significant responses exist among groups of respondents (i.e. young and old companies, large and small, high and low revenue, and main area of expertise). Significant responses were discussed accordingly.

Findings: The results of the study indicated that resistance to change, unclear benefits and gains, and cost of implementation are the major important challenges in terms of I4.0 adoption in construction projects. On the other hand, the data analysis implied that the majority of construction organizations successfully deal with the problems arising from lack of standardization, legal and contractual issues, and cost of implementing in terms of promoting I4.0 adoption.

Research limitations/implications: The study is expected to guide construction practitioners in terms of benefitting from I4.0 applications and deliver projects with better outcomes. The study is also expected to help researchers in terms developing a deeper understanding of major challenges for the industry and conduct similar research with enablers or drivers for I4.0. This study might be used as a guide for the companies aiming to start their I4.0 transformation knowing the challenges and develop strategies how to handle them. A concrete plan would help them achieve greater performance and benefit from the I4.0 implementation at maximum level. The study might also provide basis for a comparative study with different data sets from different regions. Finally, the study implies that construction firms shall prepare action plans for handling each challenge listed and monitor their performance based on the planned and actual data of their projects.

Originality/value: This study investigates the major challenges of Industry 4.0 among construction companies. This is one of the important studies, which puts Industry 4.0 focus forefront of the construction industry with a clear identification of challenges that construction organizations have to address in order to transform their organizations into construction 4.0. The study has potential to guide both industry practitioners and researchers to develop awareness for the benefits of using latest technology and fostering innovation. This is expected

to create value for construction clients in terms of achieving the product with serious gains such as time and cost.

Keywords: Industry 4.0, construction, technology, challenges, opportunities

1. Introduction

The manufacturing industry has already taken a step forward to create more effective production processes and increased customer satisfaction through adopting a full digital approach (Osunsanmi et al., 2018). This digitalisation process, interconnection, information transparency, and technical assistance for human operators are part of the Industry 4.0 (I4.0) principles, which are expected to positively affect today's production processes (Pentek and Otto, 2016; Axelsson et al., 2019). Industry 4.0 is a term used to represent a high-technology strategy articulated first by the German government referring to the development of "cyber-physical systems (CPS) and dynamic data processes that use massive amounts of data to drive smart machines" (Strange and Zucchella, 2017; Sirkin et al., 2015). Latest technological developments and innovations fostered the evolution of Industry 4.0, leading to growth and development in company performance (Maskuriy et al., 2019).

I4.0 is recognized as the reference point for the Fourth Industrial Revolution and several terms such as smart factory, smart production, and smart manufacturing are used to define I4.0 in a broader sense (Drath and Horch, 2014; Oesterreich and Teuteberg, 2016). I4.0 also encompasses technologies such as cloud computing, cybersecurity, big data analytics, and service orientation (Vogel-Heuser and Hess, 2016). The main contribution of I4.0 is to facilitate computerization and interconnection in industries resulting in a production chain automatically and flexibly adapted as well as to come up with new service types and business models for the value chain (Liao et al., 2017; Lu, 2017). Having been adopted in various industries, I4.0 also inspired the construction industry, which needs more efficient production chains and business models (Axelsson et al., 2018). This transformation is identified as 'Construction 4.0' representing the digitalisation of the construction industry (FIEC, 2015). The transformation is possible through the application of existing and emerging technologies offered by I4.0 (Oesterreich and Teuteberg, 2016). I4.0 has already promoted the use of various digital technologies such as smart materials, sensor systems, and intelligent machines in the construction industry. Among those, Building Information Modeling (BIM) took the key role for the digital information of a project for creating and managing the digital information of an asset (Craveiro et al., 2019; King, 2018). However, the construction industry is conservative towards benefitting from the innovative technologies of I4.0 despite the benefits mentioned in previous studies (Hampson et al., 2014). Previous studies indicated that the construction industry is way behind in implementing new technologies in a timely manner (Hargaden et al., 2019; Klinc and Turk, 2019). Moreover, it was further mentioned that the construction industry is changing its target from mass production to consumer-specific products, which are easier to control with the use of I4.0 principles (Klinc and Turk, 2019). Also, the construction industry has a fragmented nature consisting mostly of small to medium enterprises (SMEs), which necessitates a considerable effort for coordination. Furthermore, SMEs have limited resources to foster themselves for innovative technologies (Arayici and Coates, 2012; Dallasega et al., 2018). The studies in the construction industry reveal that only a small portion of construction companies are capable of achieving the complete use of digital tools (Dallasega et al., 2018). It was further mentioned that there is no sound organizational strategy for implementing I4.0 (Sony and Naik, 2020). Therefore, the construction industry is not in a comparable position to some other industries such as manufacturing, which greatly benefits from the digitalized value chains enabled by I4.0 (Lasi et al., 2014). This proves that the construction companies need guidance for transformation to I4.0.

Given this background, it is clear that there is a gap in the literature in terms of transitioning the construction companies into I4.0 for its implementation and adoption in the construction industry. As previous studies pointed out, the construction companies are facing challenges while engaging in a complete digital transformation. Moreover, the companies do not have a clear map of how to advance with this transformation with the effective use of resources and in-house personnel. The major problem that the companies having in fully digitalizing and innovating towards achieving the principles expanded by the I4.0 stems from the fact that the challenges brought by the digital transformation and technology adoption are not conceived in full sense. Hence, this study aims to reveal the challenges for I4.0 adoption by the construction companies. The study also identifies the opportunities brought by the I4.0 adoption so that construction companies might best benefit from the integration of technologies promoted by I4.0. Within this context, a questionnaire was administered to large-scale construction companies in the United States and the results were discussed accordingly. The main contribution of this study is to lead industry practitioners to recognize the main challenges before the I4.0 transformation and adoption of technology for a complete digitalisation. This will eventually result in enhanced project performance and management success in dealing with the innovations brought by the era. The study also encourages researchers in terms of shifting the focus to the challenges for I4.0 rather than the opportunities since the opportunities are practically experienced, whereas the challenges are still not comprehended well by the majority of companies. Researchers might benefit from the challenges identified in this study to develop I4.0 implementation models both statistically and conceptually. The identified challenges might also guide a country in terms of recognizing future challenges and revisiting their strategies towards digitalisation accordingly. Thus, the up-to-date data collected in this study is an opportunity to those, who are seeking a successful transformation process.

2. Literature Review

I4.0 is a broad term presenting a new stage in the Industrial Revolution, which focuses on automation, real-time data, machine learning, interconnectivity, and smart digital technologies (EPICOR, 2019). Baur and Wee (2015) define I4.0 as a ‘‘confluence of trends and technologies promises to reshape the way things are made’’. It is also defined as ‘‘a new technological age for manufacturing that uses cyber-physical systems and Internet of Things, Data and Services to connect production technologies with smart production processes’’ by the German government (Kagermann et al., 2013; MacDougall, 2014). I4.0 helps improve manufacturing organizations in terms of their business models and production processess through cyber-physical technologies. Hence, it is perceieved as a way of revolutionizing industries such as manufacturing, energy, healthcare, and urban areas/frameworks like the built environment. Fargnoli and Lombardi (2020) mentioned that I4.0 technologies such as the Internet of Things (IoT), autonomous robots and vehicles, simulation, blockchain and cyber security, and virtual reality have a considerable impact on competitiveness regarding production technologies, financial performance, and workforce empowerment. Considering the benefits provided by I4.0, the construction industry also has the opportunity to create more efficient production processes, business models, and value chains through I4.0. This is possible through the transforming technologies and trends brought by I4.0. The technologies promoted by I4.0 such as BIM, prefabrication, wireless sensors, 3D printing and automated and robotic equipment (Buehler et al., 2018) might act as a catalyst for a more industrialized and automated construction industry (Sawhney et al., 2020).

Most of the previous studies focused on the benefits provided by the I4.0 adoption in the construction industry (Oesterreich and Teuteberg, 2016; Cooper, 2018; Dallasega et al., 2018; Osunsami et al., 2018). This adoption is introduced as ‘Construction 4.0’ in the industry (FIEC, 2017; Maskuriy et al., 2019; Sawhney et al., 2020). The European Construction Industry Federation (FIEC, 2015) mentions Construction 4.0 in their manifesto as "Construction 4.0 is our branch of Industry 4.0. We use this term to refer to the digitalisation of the construction industry." In some studies, the term is explained as the translation of the I4.0 principles into construction such as the adoption of new technologies for real time decision making (Craveiro et al., 2019; Forgues et al., 2019). On the other hand, some other studies indicate that Construction 4.0 encompasses different approaches and technologies such as big data and analytics, machine learning, artificial intelligence, virtual reality, and new business models to explain the term (Oesterreich and Teuteberg, 2016; Klinc and Turk, 2019). Oesterreich and Teuteberg (2016) indicated that the construction industry adopts the strategy of creating a smart construction site through simulation and virtual data storage to deliver faster and high-quality projects with reduced costs as part of adapting the I4.0 principles into construction. Li and Yang (2017) highlighted that the industrialization of construction is a component-prefabricated, design-standardized, management scientific, and operational method. This aims to maximize the value of life cycle and to continue sustainable development. They further indicated that BIM is at the core of construction industrialization where component testing, production, information exchange, and construction simulation are possible. Maskuriy et al. (2019) identify BIM as an essential tool for interaction and collaboration for the project life cycle and examine the current trends that BIM brings to construction projects in the context of I4.0. In this respect, they discuss the integration of BIM with other technologies such as sensor systems and intelligent machines. Fargnoli and Lombardi (2020) discussed the role of BIM utilization in enhancing safety practices. Their research concluded that BIM promotes safety climate and helps create a safer environment for workers. Garcia de Soto et al. (2019) mentioned that Construction 4.0 leads to increased productivity through digitalisation and automation of the processes.

The construction industry is less controlled and fragmented compared to the manufacturing industry (Harvey, 2003). The temporary nature of construction projects also lacks standardization of the processes, which leads to lower levels of productivity (Dubois and

Gadde, 2002; Stehn and Höök, 2008). However, increasing the productivity in construction projects and reducing the uncertainty are possible through adopting the I4.0 principles. Within this context, digital access, automation, connectivity, and digital data are key to overcoming the challenges posed by the industry (Dallasega et al., 2018). Alalout et al. (2020) studied the opportunities and challenges brought by the I4.0 implementation in the construction industry from stakeholders' perspective. They mentioned that social factors such as cultural habits and technical factors are the main barriers hindering the adoption of I4.0 in construction. They further implied that the construction industry is still lacking the implementation of I4.0 despite its numerous benefits proven so far. Garcia de Soto et al. (2019) worked on the implications of Construction 4.0 on the organizational structures and workforce. They highlighted that transforming organizations for Construction 4.0 has the potential to reduce the workforce but leads to a safer and less labour intensive work environment for the construction workers. As indicated by several studies, the implementation of new technologies in construction is slow (Klinc et al., 2010; Hargaden et al., 2019; Klinc and Turk, 2019). Hence, it is apparent that the industry is in need of a clear guide so as to facilitate this transformation and fasten the adaptation to I4.0, considering the proven benefits. This clear guide should include a complete set of challenges for I4.0 that the companies recognize for them to revise their strategies accordingly for a full and succesfull transformation. Thus, it is of utmost importance to reveal the challenges for adopting I4.0 for improved performance in construction projects.

According to Table 1, nine challenges were identified as the major barriers before the I4.0 adoption at construction companies. The first challenge identified is the cost of implementation which is troublesome for companies aiming to achieve maximum benefits from the I4.0 transformation. Alaoul et al. (2020) implied that the implementation of an innovative technology brings along a considerable cost burden. Moreover, the cost of training and equipment maintanence, which are hidden costs, also leads to a challenging implementation process along with the uncertaintly associated with return of investment. This hinders the investment in innovative technologies by the construction companies, which hesitate to adopt I4.0 due to the high investment costs and uncertainties of the benefits (Oesterreich and Teuteberg, 2016).

Construction is a fragmented and conservative industry (Ahmad et al., 1995; Nam and Tatum, 1997). This leads to a lack of willingness to adopt new technologies and innovations, which in return creates resistance to change. Chan et al. (2019) implied that the major barriers for BIM adoptions stem from the fact that construction stakeholders are resistant to change emphasizing that the lack of standards for BIM hinders companies to adopt change in the Hong Kong construction industry. Hemström et al. (2017) further indicated that the contractors in Sweden are particularly resistant to change to remain successful in the industry, which is dominated by a few large contractors. Therefore, the companies fail to fully adopt and understand the benefits of the I4.0 transformation due to resistance to change towards such adaptation. Hence, the resistance to change is an important challenge that the companies must address before starting the I4.0 transformation.

Lack of labor force is a serious concern for the construction companies aiming to invest in new technologies and use digitizaliton confidently. Hewage et al. (2008) investigated the IT usage in the building projects in Alberta, Canada. They emphasized that a shortage of labor force leads managers to doubt whether the available labor force is confident in utilizing modern information technologies. They further explained that construction companies are unwilling to welcome the change driven by new technologies when the labor force is not sufficient. Doloi et al. (2012) mentioned that lack of skilled labor leads to poor labor productivity, which often times result in delays in Indian construction projects. Hence, it becomes troublesome for construction companies to start a transformation process for I4.0 where the labor foce is unstable and lacking.

Unclear benefits and gains from I4.0 are a major cause for the unwillingness towards welcoming change and investing in innovative technologies. Hence, the construction companies are reluctant to adopt new technologies due to uncertainties in benefits and gains to be brought by this adoption (Davies and Sharp, 2014; Oesterreich and Teuteberg, 2016). Luthra and Mangla (2018) futher mentioned that most industries are hesitant in adopting I4.0 due to ignorance of the potential benefits. Therefore, it is a serious concern for the construction companies not to have a definite plan for the unknown benefits and gains. This necessitates the construction companies to develop strategies,after thoroughly evaluating the potential gains and losses after the I4.0 adoption.

The budget spared for research and development (R&D) in the construction industry is relatively low compared to other industries (Zhang et al. 2010). Ofori (2003) mentioned that Singapore's construction industry invests in construction R&D less than other developed countries and other sectors. In another study conducted by Ling et al. (2006), it was emphasized that Architecture-Engineering-Construction (AEC) firms investing in R&D are more likely to experience budget overruns for the fact that the R&D investment generates cost increases in the short term and does not yield returns fast. On the other hand, Kim et al. (2009) implied that interdisciplinary R&D programs conducted by academia and other entities are promising for promoting the use of adavanced technologies in construction. This indicates that the construction companies are still struggling with the decision of investing in R&D and have not become yet sure whether the investment cost will be compensated with the exclusive benefits in the long term. This leads to the discussion that the lack of investment in R&D is still a challenge for the industry aiming to increase benefits with the adoption of I4.0.

The fragmented and project-based nature of the construction industry hinders many companies from investing in digitalisation and welcoming innovations (Elmualim and Gilder, 2014; Chowdhury et al., 2019). Lavikka et al. (2018) mentioned that the fragmented nature of the industry creates knowledge boundaries leading to challenges in communication and collaboration. This in results in poor adoption of new technologies and unperceived benefits of the I4.0 implementation. Yap et al. (2019) explored the criticality of the construction industry problems in Malaysian construction projects. They concluded that the fragmentation in projects leads to poor project performance, low productivity, and reluctance towards implementing innovative solutions. One might assert that construction companies are less likely to change their focus towards becoming more technological organizations adopting the innovative solutions driven by I4.0. Hence, the fragmentation and project-based nature of construction projects are major challenges in terms of the I4.0 adoption.

Lack of standardization is a major problem in construction projects. Wang et al. (2016) mentioned that engineering construction standards have not been succesfully adopted in the Chinese construction industry due to lack of standardization talents. Moreover, Thunberg and Fredriksson (2018) implied that temporary organizations suffer from lack of standardization in processes and lack of information sharing. The temporary nature of construction projects is therefore leading to unstandardized processes hindering construction companies from setting up standard procedures for operations. Gamil and Rahman (2019) listed lack of standardization as a challenge for the BIM implementation in the Yemenese construction industry. It is apparent that the construction companies struggle with stadardizing processes and this leads to unwillingness for adoptiong I4.0. Therefore, lack of standardization is listed as an important challenge for the I4.0 adoption at construction companies.

Data protection and cybersecurity is a major concern for the construction companies. Mantha and de Soto (2019) implied that the Architecture-Engineering-Construction (AEC) industry has already been experiencing cyberattacks such as stealing private information, accessing unauthrozied files, and remove records. The expansion of digital platforms on construction sites and transformation towards I4.0 are also expected to increase the risk of cyberattacks in the construction industry (Patel and Patel, 2020). Therefore, the construction companies must work towards developing their infrastructure and organizational structure in terms of handling the cybersecurity risks.. However, there is not yet an avaiable standard to develop a procedure for identifying such risks in the construction industry (Mantha and de Soto, 2019). Hence, data protection and cybersecurity is listed as an essential challenge for the I4.0 implementation in the construction industry due to the fact that the construction companies do not still have a definite plan or procedure to follow for protecting digital assets.

Legal and contractual procedures might be problematic for some construction projects for the fact that contracts either do not explicity indicate project terms and clauses or there are vague statements in terms of legal aspects. For example, Oesterreich and Teuteberg (2016) emphasized that there are several legal and contractual uncertainties in regards to the use of BIM indicating that legal ownership of the BIM model and legal responsibility of errors with the model remain unanswered. In another study, Abubakar et al. (2014) implied that legal and contractual constraints lead to reluctance towards BIM adoption in the Nigerian construction industry. Jo et al. (2018) further revealed that legal and contractual issues are among the critical barriers for BIM implementation in the Malaysian construction industry. Li et al. (2019) stated that there are several aspects associated with untested legal issues and clear contract terms in the construction industry to reduce the likelihood of risks leading to unintended obligations and disputes. This reveals that the construction companies must first work on strategies and sound plans for removing the conflicts in terms of legal and contractual issues for the I4.0 adoption. This would lead to a more successful transformation process and digitizalition within the organization.

Given this background, Table 1 summarizes the challenges identified for the I4.0 adoption in the construction industry.

Table 1. Challenges for I4.0 Adoption in the Construction Industry

Challenge	Definition	Reference
Cost of Implementation	Construction companies are prejudiced against adopting I4.0 in construction projects since they are not clear with its benefits in cost savings as well as its investment requirements. Hence, companies perceive I4.0 as costly to implement	Zhou et al., (2015); Oesterreich and Teuteberg (2016); Dallasega et al. (2018).
Resistance to Change	The construction industry is conservative in terms of embracing change. However, I4.0 requires change, which appears as a significant challenge for the I4.0 adoption by the industry.	Oesterreich and Teuteberg (2016); Trstenjak and Cosic (2017); Woodhead et al., (2018).
Lack of labor force	The construction industry is competing against the lack of skilled workforce in I4.0 due to the compexity and dynamic nature of projects. Introducing the I4.0 principles in the industry might require the utilization of new technologies and creating new departments. Therefore, lack of labor force is a serious challenge for the successful adoption of I4.0 in the construction industry.	Allmon et al., (2000); Schneider (2018).
Unclear Benefits and Gains	Technology investment and innovation adoption require a complete understanding of value generation for construction projects. Presently, the I4.0 benefits and gains are not clear for the construction industry. This vagueness poses a serious challenge for the I4.0 investment.	Barlish and Sullivan (2012); Lee et al., (2015); Oesterreich and Teuteberg (2016).

Lack of investment in research & development (R&D)	The construction industry has traditionally lacked commitment to R&D activities and investment. This also puts a barrier before the R&D necessary for I4.0 in the industry.	Dulaimi (1995); Blayse and Manley (2004); Oesterreich and Teuteberg (2016).
Fragmentated and project-based nature of the industry	The construction industry is fragmented and project-based. Therefore, the conditions are dynamic and variable in every project, which hinders construction practitioners from developing structures to enable technology innovation and adoption. This eventually leads to reluctance for the I4.0 adoption. Hence, the fragmentation and project based nature are key challenges for I4.0.	Ofori (1994); Nitithamyong et al. (2004); Golizadeh et al. (2014).
Lack of standardization	It is essential for construction companies to keep up with global dynamics. However, several companies are still struggling with the the lack of standardization, which results in serious time losses and increased costs. Even though there are efforts towards creating standardized processes, there is still need for setting up the standards.	Goodrum et al. (2006); Li and Yang (2017); Axelsson et al. (2018).
Data protection and cybersecurity	Construction companies suffer from data protection and adaptation issues for new techologies. These cause serious challenges for the majority of companies while implementing I4.0. Hence, the companies are seeking ways to improve their data protection policies.	Love et al. (2001); Patel and Patel (2020).

Legal and contractual issues	The legal and contractual processes are often troublesome for construction companies due to unclear statements in the contracts and the difficulties in contract management. This leads to vulnerability in adopting new technologies and innovation within companies. Hence, legal and contractual issues are major barriers hindering construction companies from adopting the I4.0 principles.	Chan and Suen (2005); Eadie et al. (2015).

3. Research Methodology

In this study, a mixed method of research was assessed to collect both qualitative and quantitave data. Figure 1 summarized the research process developed for this study.

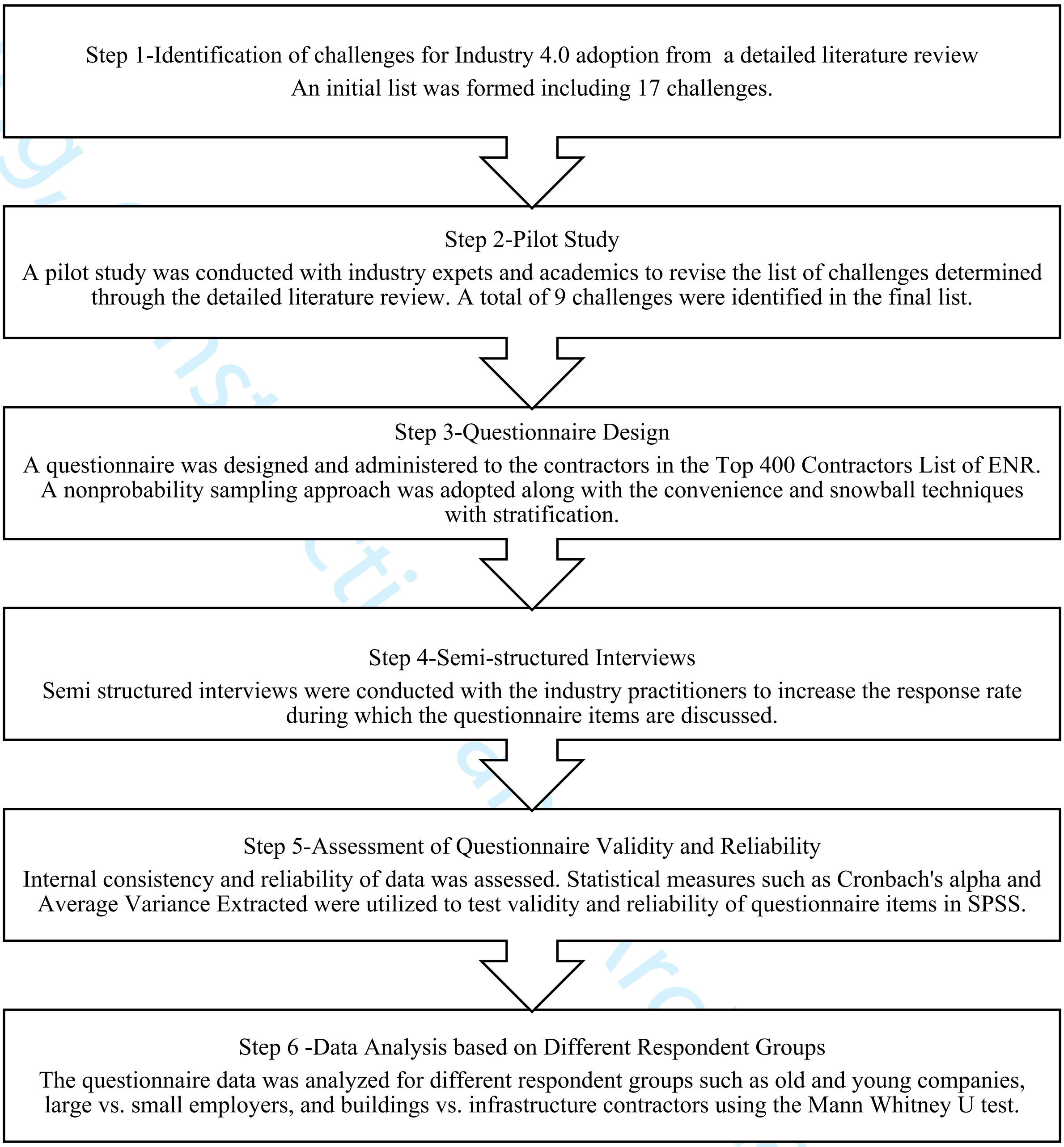

Figure 1. Research Process

As the first step, the study identified major challenges for the I4.0 adoption in the construction industry. In the first stage, a total of 17 challenges for I4.0 in construction were identified from literature. However, after conducting a pilot study with experts from the industry, some of the challenges were either merged or removed as they represent similar challenges. The final list consists of 9 major challenges (as seen in Table 1). The specified challenges are evaluated through a questionnaire designed and administered to industry practitioners. The results are presented and discussed in the sections below. In the first stage, a questionnaire was developed and administrated to construction professionals operating in the U.S. construction industry. Before designing the final questionnaire, a pilot study was conducted with five practitioners from the construction industry, who have experience with the I4.0 adoption within their organizations and three university professors working on the I4.0 transformation at construction companies. Based on the analysis of the pilot studies, the questionnaire items were redesigned, where some of the questions were either deleted or revised as per the feedback provided by the experts. This exploratory approached led to an explanatory questionnaire design. In the second part, semi-structured interviews were conducted with industry practitioners, who are experienced in the I4.0 adoption in the construction industry. The basis for utilizing the mixed method approach is to guarantee participant enrichment, ensuring instrument fidelity, assessing treatment integrity, and enhancing significance (Collins et al., 2006).

The sampling entails the general contractors listed in the 400 Top Contractors by Engineering News-Record (ENR) in 2019. There are different construction groups operating in the U.S. having different roles in the projects such as clients, consultants, independent contractors, general contractors, and subcontractors. Among these, ENR presents a Top Owners, Top Contractors and Top Design Firms list every year. ENR is a weekly news magazine published in the US covering the news and data regarding the construction industry worldwide (Jones et al., 2010). The reason why the 400 Top Contractors list was selected as the sampling is that ENR lists the contractors based on their contracting revenue. According to data presented in ENR website, the companies listed in the 400 Top Contractors in 2018 generated a revenue of $405 billion in 2018, where this was $373.98 billion in 2017 (ENR, 2020). This indicates that these companies on the list generate most of the national construction value and shows their extensive presence in the industry. The Global Powers of Construction report also listed 13 companies from the U.S. in 2019 in the Top 100 ranking emphasizing the largest contractors' increase in sales, which were also listed in the ENR's list (Deloitte, 2020). Moreover, Lu (2014) assessed the reliability of ENR data in his research and concluded that the ENR data might be confidently used in international construction research for the fact that there are no systemic errors in the data.

A nonprobability sampling approach was adopted along with the convenience and snowball techniques with stratification as mentioned in various studies (Bagaya and Song, 2016; Ling and Khoo, 2016; Yap et al., 2019). These techniques are commonly utilized in construction research to obtain significant responses from industry practitioners (Bagaya and Song, 2016; Abowitz and Toole, 2010; Yap et al., 2019). Semi structured interviews were conducted with the industry practitioners to increase the response rate. Initially, a total of 111 responses were received but it was detected later that there were some nonresponse items in the returned questionnaires. Therefore, the questionnaires having nonresponse items were eliminated for a more reliable analysis. A two cycled data collection was conducted. In the first cycle, a total of 59 responses were collected by the cut off date of December 17th, 2019. However, the response rate was not evaluated to be satisfactory for analysis and generalizability. Therefore, a second cycle was commenced. Finally, 89 reponses were collected by the final cut off date of January 17th, 2020 out of the 400 surveys sent out, resulting in a response rate of 22%. This response rate was found to be satisfactory after a careful review of the questionnaire data since mostly high revenue generating companies had responded to the questionnaire without nonresponse items. Considering the high volume of work undertaken by high revenue generating companies, the results could be generalizable for the U.S. contractors since low revenue generating companies generally adapt their strategies through benchmarking large companies. Moreover, similar studies reported approximately similar response rates emphasizing that the response rateis acceptable and satisfactory for a reliable analysis (Chen et al., 2010; Demirkesen and Arditi, 2015).

A 1 to 5-point Likert scale (1=not important, 2= slightly important, 3= moderately important, 4= very important, 5= extremely important) was adopted for the assessment of the challenges in terms of evaulating their level of importance. Moreover, the level of success in tackling those challenges was also assessed based on a 1 to 5-point Likert scale, where 1 represents "poor" and 5 represents "excellent". To assess the reliability of the survey, the Cronbach's alpha value was investigated as the most common measure used for internal consistency and reliability (Litwin, 1995). Values of Cronbach's alpha greater than 0.7 represent acceptable reliability in SPSS (Bolarinwa, 2015). The Cronbach's alpha value was calculated as 0.911 utilizing SPSS leading to the conclusion that the questionnaire is reliable. A pilot study was also employed before distributing the survey to reinforce the reliability. Content validity was assessed by examining the skewness of the distributions. The skewness ranged between -0.11 and +0.02 indicating that the frequency distribution of scores is quite symmetrical and not considerably skewed. The values of kurtosis were also assessed and it was observed that the kurtosis values ranged between -1.03 and 2.13. Skewness and kurtosis values are calculated to observe the non-normality of a data distribution and it was revealed that the data is normally distributed since the values of skewness and kurtosis lying between -2 and +2 are acceptable to prove an univariate normal distribution (George and Mallery, 2003). Convergent and discriminant validity were also assessed. The Average Variance Extracted (AVE) values were all above 0.7 indicating the questionnaire items were adequately convergent valid measures (Fornell and Larcker, 1981).

Furthermore, the questionnaire data was analyzed based on different response groups utilizing the Mann Whitney U test in SPSS. The Mann–Whitney U test was preferred over a parametric test such as analysis of variance (ANOVA) since the parametric tests consider that the observations in the samples follow a normal distribution. Since the sample of 89 observations in this study is divided into smaller sub-samples (i.e., old vs. young, building vs.

infrastructure contractors, and small and large employers) for comparison purposes, it is safer to assume that the fewer observations in the smaller sub-samples are not normally distributed. Therefore, the Mann–Whitney U test, which is conducted when samples are not normally distributed,was utilized in this study as a non-parametric test,. Moreover, the sub-samples might provide justification as to why small employers or large employers struggle more with the I4.0 adoption in case there are significant differences in responses. The age of the companies and their main business area might also be considered as significant parameters in terms of comparing either the perceptions of these firms about the I4.0 adoption or detecting the different approaches in terms of handling the I4.0 challenges. A sample questionnaire can be found in Appendix 1.

The respondent characteristics were analysed to better interpret the results. Figure 2 presents the percentages of respondents by their positions and Figure 3 presents the companys' main business activity. According to Figure 2, the majority of the respondents are project managers working at large-size companies. According to Figure 3, a major portion of the responding companies are executing building projects.

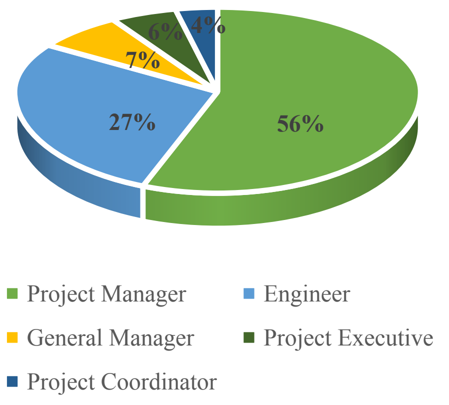

Figure 2. Respondents by Position

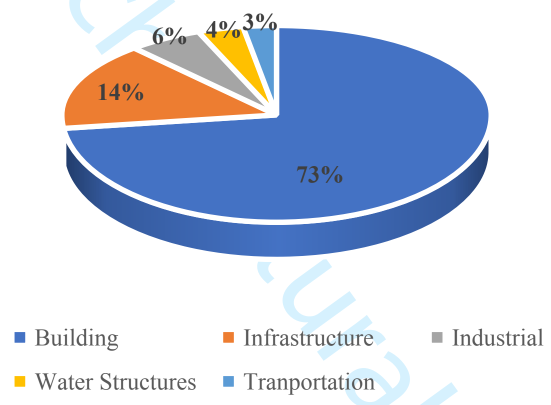

Figure 3. Companys' main business activity

More respondent characteristics were sought such as the companys' years of experience in construction, annual turnover, and number of employees. Table 2 reflects the respondent and company characteristics.

Table 2. Respondent Characteristics

	Mean	Median	Minimum	Maximum
Company's years of experience in the construction industry	26	40	7	80
Annual Turnover (million USD)	403	79	4	12,127
Number of employees	3703	790	53	17,000
Respondent's Age	34	29	26	71
Respondent's years of experience in the construction industry	7.4	9	2	36

The responses were grouped according to the companys' years of experience in the construction industry, annual turnover, company employment size (number of employees), respondents' age, and respondents' years of experience in the construction industry. The average years of experience of the responding companies was found to be 26 years, which is a significant amount of time in terms of operating in the industry. Years of experience is also a key factor for the growth of a construction company. The average annual turnover of the companies was found to be $403 million. This is not suprising because the companies selected for the questionnaire are in the ENR Top 400 Contractors list, which is an indication of high returns. The average number of employees was found to be 3703, representing a high employee volume. The respondents' average age and years of experience in the construction industry were found to be 34 and 7.4 years, respectively. The type of construction projects undertaken by the companies was also considered to be an essential variable for investigating the companies' Industry 4.0 adoption. It was found that 57% of the responding companies are undertaking building construction projects, whereas 39% are pursuing infrastructure facilities. The remaining 4% indicated that they mostly construct water structures.

4. Data Analysis and Results

The first section of the questionnaire administred in the study was intended to collect information regarding the importance level of each challenge identified for the I4.0 adoption. To rank the challenges, the relative importance index (RII) method was used to quantify the relative importance of the I4.0 challenges in the U.S. construction industry. This method has already been applied in several construction research studies to determine the relative importance of different items (Kometa et al., 1994; Sambasivan and Soon, 2007; Gündüz et al., 2012). The RIIs for the I4.0 challenges were calculated following the equation (1) presented below.

$$RII = \frac{\sum W}{(A * N)} \quad (1)$$

In Eq. (1), RII repsents the relative importance index, where W = weighting given to each challenge by the respondents (from 1 to 5; 1 refers to the lowest and 5 refers to the highest); A = highest weight and N = total number of respondents.

The RII values ranged between 0 and 1, where the values approaching 1 represent more importance. The RIIs were then ranked and the results are presented in Table 3.

Table 3. Relative Importance Indices for Challenges for I4.0 Adoption

Challenge	RII	Rank
Resistance to change	0.892	1
Unclear benefits and gains	0.878	2
Cost of implementation	0.792	3
Lack of standardization	0.695	4

Fragmentated and project-based nature of the industry	0.688	5
Lack of labor force	0.658	6
Lack of investment in research & development	0.641	7
Data protection and cybersecurity	0.627	8
Legal and contractual problems	0.599	9

According to Table 3, ‘resistance to change’ is ranked as the most important challenge hindering the I4.0 adoption. Moreover, ‘unclear benefits and gains’ and ‘cost of implementation’ are also ranked as very important challenges for the I4.0 adoption by the respondent companies. ‘Lack of standardization’, ‘Fragmentated and project-based nature of the industry’, and ‘lack of labor force’ are ranked as important and moderately important challenges based on the responses. Finally, ‘lack of investment in research & development’ is ranked as moderately important, whereas ‘data protection and cybersecurity’ and ‘Legal and contractual problems’ are ranked as less important, compared to the other challenges based on the assessment of relative important indices.

The questionnaire also assessed the level of success in terms of tackling the above listed challenges. This assessment was done by considering the success level index using the mean score approach. Similar methodological approaches were adopted in various studies in construction research before (Yeung et al., 2009; Ahadzie et al., 2008; Osei-Kyei et al., 2018). To compute the success indices, the “mean score” method was utilized as perceived by the contractors. The five-point Likert scale (1 = unsuccessful and 5 =very successful) was used to calculate the mean scores for each challenge, which were then used to determine its success ranking in descending order. The mean score (MS) for the challenges was computed by Eq. (2), where s=score given to each challenge by the respondents, ranging from 1 to 5 (1 = unsuccessful and 5 =very successful);f=frequency of each rating (1–5) for each challenge ; and N=total number of responses concerning a particular challenge.

$$MS = \frac{\Sigma(f \times s)}{\mathrm{N}} \quad , (1 \leq \mathrm{MS} \leq 5) \tag{2}$$

The success level indices of the challenges are presented in Table 4, reflecting the contractors' success level in handling each challenge based on the responses provided.

Table 4. Success Level Indices of Challenges for I4.0 Adoption

Challenge	Success Level Index
Lack of standardization	3.46
Legal and contractual problems	3.35
Cost of implementation	2.94
Data protection and cybersecurity	2.84
Lack of investment in research & development	2.77
Unclear benefits and gains	2.64
Resistance to change	2.14
Lack of labor force	1.74
Fragmentated and project-based nature of the industry	1.34

An evaluation scale of 1 to 5 was used to comment on the responses. According to the research conducted by Ahadzie et al. (2008), a success criterion is critical if it has a mean score of 3.5 or more. The research also implied that when two or more criteria have the same mean, the one having the lowest standard deviation must be assigned the highest importance ranking. Based on the results, Table 4 indicates that the responding companies are relatively more successful in handling the lack of standardization challenge for their I4.0 adoption. Moreover, the companies also reported that they are succesful in overcoming the legal and contractual problems, where that challenge is not as critical as lack of standardization. The companies responded that they are fairly succesful in tackling the cost of implementation, data protection and cybersecurity, lack of investment in research & development, and unclear benefits and gains challenges for the I4.0 adoption. On the other hand, they reported that they are unsuccessful in handling the resistance to change and lack of labor force. Even though the fragmented and project based nature of the industry was found to be an important challenge for the I4.0 adoption based on the RIIs, the companies are reported to be least successful in handling this challenge by the success index.

The respondents and companies were grouped into smaller sub samples such as old vs. young, building vs. infrastructure contractors, and small and large employers to test the differences between the groups.The differences in ratings were analyzed using SPSS. The Mann Whitney U test was applied to test whether the differences between the groups are statistically significant at $\alpha = 0.05$. The Mann Whitney U test was selected as the statistical testing tool for the fact that it is a non-parametric test (Rees, 2011). Considering the parametric tests' limitation in assuming the observations in samples follow a normal distribution, the non-parametric Mann-Whitney U test was determined to be the most appropriate test to compare the groups. Hence, it is safer to assume that the fewer observations in the smaller sub-samples are not normally distributed. The companies were also grouped by their level of experience/years of operation (old vs. young), by their operational area (building vs. infrastructure), and by their size (small vs. large) and turnover (high annual turnover vs. low annual turnover) to test whether there are statistically significant differences among the identified groups by the Mann-Whitney U test. Table 5 shows the results of the Mann-Whitney U test based on the response groups set.

Table 5 shows the companies' success level in tackling those challenges by the analysis of the groups. According to the table, there is a significant difference between the younger and older companies in terms of handling the lack of standardization. Moreover, a significant difference in the responses is observed between the companies having higher and lower annual turnover for the cost of implementation challenge. The cut off value for dividing the old and young companies into two groups was determined to be 50 years in operation with the analysis of average values for company age. Since there was no threshold proposed in the literature for such categorization, the average age was calculated for the respondents which resulted in 50.36 years. Hence, the responding companies having an age of less then 50 were evaluated as young companies, whereas the responding companies having an age of higher than 50 were evaluated as old. On the other hand, young companies were further grouped into ages of 0-10, 10-20, 20-30, 30-40, and 40-50 for a more rigorous analysis and accurate evaluation of different age groups' experience towards I4.0 adoption due to dynamic nature of the industry. A similar division criterion was applied for the other groups identified. Finally, the success in tacking the resistance to change challenge is responded differently by the younger and older companies, where the younger companies report that they better handle this challenge than the older companies. A detailed discussion regarding the significant differences among the different response groups is provided in the findings and discussion section.

Table 5. Average Ratings for "What is your success level for overcoming I4.0 adoption challenges in the construction industry?" by Control Variables (1=poor, 5=excellent)

Questionnaire Items	Young companies <50 years	Old companies >50 years	Large Contractor >500	Small Contractor <500	Building	Infrastructure	High Annual Turnover >$200 million	Low Annual Turnover < $200 million
Lack of standardization	4.2*	2.5*	3.6	3.2	3.4	3.4	3.6	3.2
Legal and contractual problems	3.2	3.4	3.4	3.2	3.3	3.3	3.4	3.2
Cost of implementation	2.6	3.2	3.3	2.5	3.1	2.7	3.7*	2.1*
Data protection and cybersecurity	2.9	2.8	2.8	2.8	2.8	2.8	2.9	2.8
Lack of investment in research & development	2.8	2.7	2.7	2.7	2.7	2.7	2.8	2.7
Unclear benefits and gains	2.6	2.6	2.6	2.6	2.7	2.6	2.7	2.6
Resistance to change	2.8*	1.4*	2.3	1.9	2.1	2.1	2.4	1.8
Lack of labor force	1.8	1.7	1.7	1.8	1.7	1.7	1.8	1.7
Fragmentated and project-based nature of the industry	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.3

*Statistically significant difference at α=0.05

5. Findings and Discussion

The analysis of the questionnaire revealed interesting results worth further discussion. The respondents reported that the resistance to change is the most serious concern for the adoption of I4.0 with a RII of 0.892. Several studies have already reported that resistance to change is a critical barrier for technology adoption specifically for BIM tools, digitalisation and automation in the construction industry (Stewart et al., 2004; Khosrowshahi and Arayici, 2012; Oesterreich and Teuteberg, 2016; Matarneh and Hamed, 2017). Moreover, the respondents indicated that they cannot effecitvely tackle the resistance to change at their organizations (success level index: 2.14). Especially, the resistance for change has been reported to be a common significant challenge for different construction industries such as Hong Kong and Sweden. For example, Chan et al. (2019) implied that the resistance to change is heavily observed in the Hong Kong construction industry in terms of BIM adoption by construction stakeholders emphasizing that proper standards are lacking for a successful adoption. Hemström et al. (2017) implied that the resistance to change exists in the Swedish construction industry for the fact that companies are reluctant towards adopting the change brought by the technology for staying competitive within the market with a traditional structure. Hence, it is apparent that the resistance to change is also a critical barrier for the U.S. construction companies. Therefore, the companies first need to address this barrier to prepare their organization for a successful I4.0 transformation (Ozumba and Shakantu, 2018). To resolve this issue, the companies might work towards developing a change culture or offer trainings so as to prepare themselves for a smooth transition. The analysis of the statistical tests indicated that the responses for the resistance to change differed between the younger and older companies. The younger companies indicated that they perform better while tackling the resistance to change than the older companies. This might stem from the fact that the young individuals in an organizations might better respond to changes and adopt process of change more easily than olders do (Neiva et al., 2005). Moreover, the companies were further divided into subgroups in terms of their age since younger companies might perceive I4.0 differently than older companies. The companies were grouped based on their ages for the intervals of 0-10, 10-20, 20-30, 30-40, and 40-50. Some significant differences were observed in responses between companies having an age of between 0 and 10, and 30 and 40. The younger companies (age of 0 to 10) reported that they better handle the resistance for change, lack of standardization, and fragmented and project based nature of the industry, which hinder the I4.0 adoption. This may be due to the fact that younger companies are more open to change in terms of innovating their practices when they are aiming for high growth (Czarnitzki and Delanote, 2013). Hence, younger companies resist to changes lesser than older companies, which in return results in relatively easier change management for I4.0 at younger companies. On the other hand, Hemström et al.'s (2017) study revealed that Swedish contractors are not willing to adopt I4.0 regardless of the firm age, where the industry is dominated by a few contractors.

Unclear benefits and gains was listed as another important challenge for I4.0 by the respondents with an RII of 0.878. The companies are unwilling to invest in new technologies and welcome change unless they are certain or better informed about the benefits and gains brought by the potential investment (Davies and Sharp, 2014; Lee and Lee, 2015). As revealed by Luhtra and Mangla (2018), ignorance of the potential benefits brought by the adoption of I4.0 is a serious problem not only for the construction industry but also for several other industries. However, the construction industry itself has a project-based nature, which is rendering this even more challenging for a careful consideration of the benefits and gains achieved through the I4.0 adoption since project teams and project characteristics are dynamic. Hence, the I4.0 adoption becomes challenging when the companies are not capable of foreseeing or forecasting its benefits and gains. Moreover, the respondents reported that they are not quite successful in handling the unclear benefits and gains in terms of the I4.0 adoption (success level index: 2.64). The uncertaintinies and changes in construction projects hinder the practitioners' capability of estimating those potential benefits and gains (Lechler et al., 2012). Therefore, the companies and researchers first need to develop ways for eliminating the uncertainties and better estimating the benefits and gains from the I4.0 adoption. A successful forecast of the benefits and gains towards the I4.0 transformation could help construction companies devise new strategies in time, cost, or quality management practices. This would in turn result in enhanced performance in processes and experience less wasteful activities.

Cost of implementation is rated as another important challenge for the I4.0 adoption by the construction companies with an RII of 0.792. Since the construction industry is dynamic and complex in nature, the cost of implementing a new technology is a risk for the majority of companies. Hence, the companies approach innovative technologies with caution due to the cost burden that the technology may cause. The cost of implementation as a barrier for the I4.0 adoption has already been highlighted in various studies (Oesterreich and Teuteberg, 2016; Uhlemann et al., 2017). Even though the study of Alaoul et al. (2020) indicated that innovative technology causes a significant cost burden for organizations, the return on investment is often times disregarded. However, the adoption of I4.0 in the construction industry, also called as Construction 4.0, is estimated to generate significant cost and time savings (Hofmann and Rüsch, 2017; Osunsami et al., 2018). Khosrowshahi and Arayici (2012) stated that the UK construction industry is experiencing slow progressive changes in the BIM implementation due to the belief that adoption of BIM might cause higher additional project cost. Hence, it is essential that construction organizations be ware that the cost of implementation for I4.0 technologies might compensate the costs with a high revenue generated through utilizing new technologies. The results of the success level analysis by the respondents indicated that the companies are ready to undertake the implementation costs, hoping to realize the I4.0 benefits and gains (success level index: 2.94). Contrary to the reluctance towards investing in new technologies as highlighted in the past studies (Ruikar et al., 2007; Henderson and Ruikar, 2010; Sköld et al., 2018), the U.S. contractors reported that they are successful in terms of investing in new technologies considering the potential benefits and gains. This may stem from the fact that U.S. firms are willing to involve in research and development activites, where they perceive the potential benefits and gains easier than other contractors operating in other countries. Godin (2004) highlighted that U.S. constitutes a high proportion of R&D activity compared to other countries, which makes it competitive in science-based industries. The Mann Whitney U test results revealed that there is a significant difference between the responding companies having high and low annual turnover. The results show that the companies generating higher revenues are more welcoming in terms of the I4.0 implementation costs. This finding also highlights that the companies having larger revenues are more successful in handling the cost of implementation challenge for the I4.0 adoption. This might stem from the fact that larger employers are more able to spare a seizable budget for new technologies and adopt those within their organizations.

Lack of standardization is ranked as another important challenge with an RII of 0.695. The respondents stated that they are quite successful in standardizing their I4.0 adoption with a success index of 3.46. Standardization is critical to create an effective workflow and production environment (Akbar et al., 2015). However, various research studies conducted in different regions have already highlighted that the construction companies fail to adopt standardization and lack the information sharing due to lack of standardization (Wang et al., 2016; Thunberg and Fredriksson, 2018; Gamil and Rahman, 2019). Lack of standardization was also shown to be a critical challenge for I4.0 by the U.S. contractors. On the other hand, the contractors reported that they are wisely handling this challenge in their projects. Since lack of standardization leads to low project performance and inefficient processes, firms should create efforts towards developing standardized workflows and processes in order to benefit more from the I4.0 transformation. Hence, creating stardardized workflows at the organizations strongly contributes to the adoption of a new technology, which in return leads to a higher I4.0 awareness (Trappey et al., 2017). Moreover, the Mann Whitney U test results show that there are significant differences in responses between the younger and older companies. According to these results, the younger companies are better at handling the lack of standardization challenge for the I4.0 adoption than the older companies. The younger companies aim to grow their business as a primary objective and target being one of the well recognized industry leaders. Hence, they may be more welcoming towards the utilization of new technologies or adoption of new concepts and methods (Premkumar and Roberts, 1999). The reason behind the younger companies' higher success for the standardization may stem from the fact that they consider the stardization in that regard as a more important matter than the older companies do because of the stronger growth desire and motivation.

Fragmentated and project-based nature of the industry is ranked as another important challenge in terms of the I4.0 adoption with a RII of 0.688. The fragmented and project-based nature of construction projects render the adoption of new technologies or stardardized work harder due to the changing conditions and dynamic environment (Jacobsson and Linderoth, 2010). The fragmented nature of the industry was also reported to result in serious problems such as low performance, low productivity, and unwillingness towards developing innovative solutions as in the Malaysian case (Yap et al., 2019). The responding companies in the U.S. construction industry reported that they mostly fail to overcome the challenge associated with the fragmented and project-based nature of the industry for their I4.0 adoption with a success level rating of 1.34. This is the lowest rated success level item of all the other challenges, indicating that the companies are struggling with the industry conditions, and temporary nature of construction projects and their complexity. It is apparent that fragmented nature of the industry is a serious concern for the construction industry in general in terms of welcoming change and innovation. Shen et al. (2010) further underlined that structuring a collaborative environment and interoperability in practice is a serious concern due to the fragmented nature of the industry. This leads to a low awareness of the innovative approaches and adoption of new technologies. Hence, the temporary nature of construction projects is a major problem in terms of preparing the construction companies to adapt to new technologies or concepts.

Even though not ranked very high in terms of importance with respect to the other challenges, the lack of labor force is also listed among important challenges for the I4.0 adoption in the construction industry (RII: 0.658). In Hewage et al.'s (2008) study, it was implied that lack of labor force renders managers concerned about whether the available labor force is sufficient to adopt innovative technologies. Doloi et al. (2012) revealed that it is likely to experience low productivity when there is labor shortage. This eventually leads to poor performance and reluctance towards adopting change and developing innovative solutions. Moreover, the respondents reported that they fail to overcome the labor force barrier to facilitate the I4.0 adoption in their organizations (success level index: 1.74). On the other hand, the I4.0 adoption is expected to remove some problems in the industry such as material, labor, and longer set-up times (Dalenogare et al., 2018). Therefore, companies succeeding in handling the labor force problem in their organizations are likely to better promote the I4.0 adoption.

Lack of investment in research & development (R&D), data protection and cybersecurity, and legal and contractual issues are rated as the relatively less important challenges in terms of the I4.0 adoption in the construction industry with the RIIs of 0.641, 0.627, 0.599, respectively. This may stem from the fact that the responding companies reported that they are relatively successful in dealing with the legal and contractural problems (success level index: 3.35), data protection and cybersecurity (2.84), and the lack of investment in research & development (2.77), compared to the other challenges listed. Oesterreich and Teuteberg (2016) implied that the research and development investments in the construction industry are relatively low when compared to other industries. As emphasized by several studies, R&D expenditures are proven to provide long term benefits than short term gains (Ling et al., 2006; Kim et al., 2009). However, the companies should be aware of the potential of setting up collaborations with academia and in order to benefit from R&D to the fullest. This might explain the fact that the responding companies may find it as a less important challenge in terms of implementing I4.0 as the I4.0 adoption is thought to have more important challenges such as resistance to change and lack of standardization.

Moreover, data protection and cybersecurity is of utmost importance if I4.0 is to be fully adopted at an organization. As implied by Mantha and de Soto (2019), the AEC industry is vulnerable to cyberattacks such as stealing private information, accessing to unauthorizied files, and remove records, which makes the industry open to threats. The increase in the number of digital platforms used in the industry is also increasing the risk of cyberattacks in construction (Patel and Patel, 2020). Hence, the construction companies are advised to reinforce their infrastructure for handling the cyber attacks and risks of cybersecurity. Even though data protection and cybersecurity was perceived to be a less important challenge among the I4.0 adoption challenges, it is essential that the companies develop ways to set up secure digital structures to ensure the protection of data. Although there is no standard procedure available to identify cybersecurity risks in the construction industry (Mantha and de Soto, 2019), the companies might work towards developing their own procedures for data protection and cybersecurity, where the responding companies inficated that they are not quite succesfully handling such attacks and risks.

Finally, the legal and contractual issues pose serious challenges not specifically for the I4.0 adoption only, but more generally, for the adoption of new technologies and innovative ways of work. Various studies have already showed that legal and contractual problems lead to poor adoption of new technologies and digitalisation (Abubakar et al., 2014; Jo et al., 2018; Li et al., 2019). Even though this challenge was ranked as the least important among other challenges, the responding companies reported that they successfully handle this barrier for their I4.0 adoption. The relatively low ranking of importance for the legal and contractual issues might stem from the fact that the companies are mostly struggling with the resistance to change and implementation costs for I4.0 than legal and contractual concerns. On the other hand, the responding companies indicated that they are relatively successful in handling the problems arisen due to the legal and contractual issues. The reason behind the high rating for success may be for the the fact that the companies have already developed ways to deal with the legal and contractual challenges since this appears to be a common concern for almost all construction projects.

This study aimed to reveal the challenges for the I4.0 adoption for the construction companies in the U.S. since a major portion of studies have focused mostly on the opportunities for I4.0 instead of determining and discussing the challenges. One of the main objectives of the study was to provide the construction companies with what challenges that they need to handle before starting their I4.0 transformations. In this context, a comprehensive list of challenges was identified, and the challenges identified were ranked based on thire order of importance as per the responses from the construction companies participating in a questionnaire study. The study showed that the construction companies are still struggling with instilling a change culture towards the I4.0 adoption as the most important challenge. Moreover, it was found that the construction companies operating in the U.S. are not still fully aware of the benefits and gains for the I4.0 adoption and implementation. One other important finding is that the companies participating in the survey are doubtful about the cost of implementing I4.0, which hinders the adoption of I4.0. The companies also indicated that they are not quite successful in handling these challenges in terms of transforming for I4.0. Contrary to a significant portion of studies indicating that the construction companies are welcoming towards digitalisation and implementing innovative technologies, this study revealed that the construction companies in the U.S. are still not ready for the full implementation of I4.0 due to the challenges listed. Hence, this study has potential to be used as a reference guide for the companies aiming to start their I4.0 transformation to understand the I4.0 challenges and to develop strategies how to handle them. A concrete plan would help them achieve greater performance and benefit from the I4.0 implementation Moreover, the study encourages researchers in terms of developing strategies for handling the challenges listed for I4.0 and conducting similar studies in different regions, where the results could differ enabling comparative discussions. Finally, the study can be used in practice by considering the challenges and preparing action plans for handling each challenge

6. Conclusions

This study investigated the challenges for the I4.0 adoption at the construction companies in the U.S.. To reveal these challenges, an extensive review of the previous studies and pilot studies with experts were conducted. As a result, a total of 9 major challenges for the I4.0 adoption for the construction companies were listed. Then, a questionnaire was designed and administered to construction professionals to observe how these challenges are perceived by their importance and how the contractors are performing in terms of handling those challenges. The questionnaire yielded a high response rate, revealing notable results. The analysis of the questionnaire data indicated that the majority of the responding companies see resistance to change, unclear benefits and gains, and cost of implementation as the major challenges for the adoption of I4.0 at the construction companies. The companies' level of success in handling the identified challenges was also assessed. According to data analysis, the respondents think that they are successful in overcoming the lack of standardization, legal and contractual problems, and cost of implementing challenges for their I4.0 adoption. The results of the questionnaire were further analyzed by the different responding groups;old and young companies, large and small contractors, heavy focus of contractors on building vs. civil works, and high and low revenue generating contractors. Some significant differences were observed for the lack of standardization, cost of implementing, and resistance to change challenges based on the level of success achieved in handling them by the responding companies. The younger companies were found to be more successful in handling the lack of standardization than the older companies. Companies having higher annual turnover seem to be dealing better with the cost of implement challenge for the I4.0 adoption. Finally, the younger companies seem to be better coping with the resistance to change challenge in terms of the I4.0 adoption.

The main limitation of this study is that it is based on data gathered from a portion of the ENR Top 400 Contracting companies, which reflects the thoughts and opinions of a relatively small study group. The results may differ by sample groups but considering there are top companies in the list and the results are deemed to be generalizable mostly for the companies aiming to start an I4.0 transformation. To validate the questionnaire results, studies in construction sites might be conducted to observe the experience level of respondents in terms of the I4.0 adoption. Future work can be conducted to reveal the enablers for the I4.0 adoption and the results can be compared alongside the challenges. A generic list of key enablers and barriers for I4.0 would help contractors revise their strategies and better align their organizations towards adopting I4.0 Moreover, case studies might be conducted to observe the practical implementation of I4.0 to better evaluate the challenges, opportunties, and enablers for I4.0.

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APPENDIX I

QUESTIONNAIRE FOR I4.0 ADOPTION AMONG CONSTRUCTION COMPANIES

PART 1: GENERAL INFORMATION ABOUT THE COMPANY AND THE RESPONDENT

1) Field of operation of your company

☐ Engineerin ☐ Architecture ☐ Construction

2) Number of years that your company has been operating in the construction industry

☐ 0-10 years ☐ 10-20 years ☐ 20-30 years ☐ 30-40 years ☐ >50 years

3) Areas of expertise of your company

☐ Infrastructure ☐ Transportation ☐ Building ☐ Industrial ☐ Water Structures ☐ Other

4) Annual turnover of your company ....

5) Total number of employees in your company ....

6) Your position at the company

☐ Owner ☐ Board Member ☐ Director ☐ Manager ☐ Engineer ☐ Other.......

7) Your experience in the construction industry

☐ 0-5 years ☐ 5-10 years ☐ 10-15 years ☐ 15-20 years ☐ >20 years

8) Please indicate your age..

PART 2: IMPORTANCE AND SUCCESS LEVEL RATINGS

IMPORTANCE LEVEL		Please rate the challenges based on the importance level.				
		Not important 1	**Slightly important 2**	**Moderately important 3**	**Very important 4**	**Extremely important 5**
CHALLENGES OF INDUSTRY 4.0	Resistance to Change					
	Unclear Benefits and Gains					
	Lack of standardization					
	Cost of Implementing					

	Legal and contractual problems					
	Data protection and cybersecurity					
	Lack of investment in research & development					
	Lack of labor force					
	Fragmentated and project-based nature of the industry					

SUCCESS LEVEL		**Please rate the challenges based on the success level.**				
		Poor 1	**Fair 2**	**Good 3**	**Very good 4**	**Excellent 5**
CHALLENGES OF INDUSTRY 4.0 ADOPTION	Resistance to Change					
	Unclear Benefits and Gains					
	Lack of standardization					
	Cost of Implementing					
	Legal and contractual problems					
	Data protection and cybersecurity					
	Lack of investment in research & development					
	Lack of labor force					

	Fragmentated and project-based nature of the industry					