MULTI-CRITERIA DECISION-MAKING PROTOTYPE FOR THE 4TH CONSTRUCTION REVOLUTION IMPLEMENTATION READINESS USING INTELLECTUAL CAPITAL PERSPECTIVE

HUSAM TAHSEEN MANSOUR MANSOUR

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

MAY 2022

DEDICATION

To my beloved parents:

My father and role model, Prof. Tahseen Mansour, who has supported me financially, emotionally, and spiritually through this journey.

Who instilled in me the notion that sky is the limit, and anything is possible with hard work and passion.

My mother, Arch. Naila Santarisi, whose unshakeable belief in me and my ability to achieve success in anything I engage in, have always ignited me to do more and keep trying to be better every day.

To my dear wife, Dr. Majd Al-Najjar, whose endless love, support, and compassion allowed me to overcome all the challenges I faced throughout my Ph.D. journey.

To my kids, Mariam, Teya, and Tahseen, who are the stars of my life.

To all my dear siblings, Dr. Wesam, M.D., Dr. Anmar, and Arch. Bayan, who believed in me, encouraged me, and do not avoid providing any kind of help.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Eeydzah Aminudin, it would not have been possible to reach where I am today without her guidance, mentoring, endless support, and friendship. She is one of the best and brightest minds in the construction management discipline, and I am privileged to be one of her students.

My sincerest appreciation also goes to my all-time supervisor, My father, Prof. Tahseen Mansour, for convincing me to continue my studies at the doctoral level. His endless encouragement, guidance, and supervision helped me through the PhD process.

I would also like to express my deepest appreciation to my co-supervisor, Dr. Nur Iziediana Abidin. I am grateful to all the time, effort, advice, and encouragement she offered me while doing my dissertation.

I am also indebted to Universiti Teknologi Malaysia (UTM) for providing my PhD study with many facilities.

Moreover, I would like to extend my sincere thanks to all the experts who participated in my subject matter-expert panels, their time, feedback, and insights were critical for my research to move forward.

ABSTRACT

The fourth industrial revolution, so-called Industry 4.0 has transformed the decision-making process by increasing the use of information and digitisation technologies, which resulted in improving the performance and structuring the management process to the industry. Thus, in recent years, the implementation level of information and digitisation technologies in the construction industry, termed as 'Construction 4.0 (CR4.0)', has increased rapidly. However, the construction industry has been unable to translate its acquired knowledge into actionable, transformational and strategic goals towards CR4.0. CR4.0 has changed the nature of competitive resources by reshaping the structure and way construction firms work. Construction firms face various technological, human, and process-related challenges. The starting point for this research was based on exploring the potentials in reskilling and upskilling knowledge through the development of Intellectual Capital (IC) of the construction firms. As a result, based on the Resource-based View theory, CR4.0 implementation process has been approached as a knowledge-based innovation which occurred with the development of three IC capitals: Human Capital (HC), Relationship Capital (RC) and Structure Capital (SC). Hence, this research aims to develop a Multi-Criteria Decision-Making (MCDM) prototype, used to support decision-making in CR4.0 readiness, named as the 'Construction Firm's Industry 4.0 Readiness MCDM (ConFIRM)'. The first objective is to identify the critical criteria of IC that may affect the CR4.0 implementation readiness. The process involved Systematic Literature review and semi-structured interviews. The second objective is to investigate the significant level of IC affecting CR4.0 implementation readiness through Analytical Hierarchy Process (AHP) technique. The third objective is to derive the weightage of criteria and sub-criteria of ConFIRM through Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP). The fourth objective is to develop a prototype called as ConFIRM that comprising of 3 main criteria, 16 sub-criteria and 92 super sub-criteria according to their significance weightage in achieving CR4.0 implementation readiness. The MCDM results indicated HC (37%) to be the most critical CR4.0 main criteria, followed by SC (34%), and RC (29%) respectively. The HC represented the cumulative tacit knowledge within the organisation, and it would be the main generator of intangibles. For the sub-criteria level, the results indicated that "Management Capital (12%)" has been considered the most critical CR4.0 sub-criteria. The second most critical sub-criteria would be the "Experience Capital (10%)", followed by "Process Capital (8%)". On the other hand, the "Sustainable Capital (2%)" was the least critical sub-criteria. Then, the weightages were formulated into automated MCDM prototype, where the scores were calculated using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), indicating the CR4.0 implementation readiness. As for the fourth objective, ConFIRM was adopted in real case studies and evaluated based on the judgement of five experts to determine its applicability and validity in evaluating CR4.0 readiness of contracting firms in Malaysia. In the case studies, the experts recognised the performance and effectiveness of ConFIRM as the novel method for CR4.0 readiness evaluation. ConFIRM would be able to add value to the development of CR4.0 strategies by identifying the corrective/preventive actions needed, based on the readiness assessment, before the start of the implementation process.

ABSTRAK

Revolusi perindustrian ke-4, yang dipanggil Industri 4.0, mengubah proses membuat keputusan melalui peningkatan penggunaan teknologi maklumat dan pendigitalan yang mengakibatkan meningkatkan prestasi dan menyusun semula proses pengurusan kepada industri. Dengan demikian, sejak kebelakangan ini, tahap pelaksanaan teknologi maklumat dan pendigitalandalam industri pembinaan, yang disebut sebagai 'Pembinaan 4.0 (CR4.0)', sebahagian besar peningkatan. Walau bagaimanapun, industri pembinaan tidak dapat menterjemahkan pengetahuan yang diperolehi kepada strategi transformasi yang dapat dilaksanakan ke arah CR4.0. CR4.0 telah mengubah sifat sumber daya saing dengan membentuk semula struktur dan cara kerja firma pembinaan. Firma pembinaan menghadapi pelbagai cabaran berkaitan teknologi, manusia dan proses. Titik permulaan kajian ini didasarkan ke penerokaan potensi dalam kemahiran semula dan meningkatkan pengetahuan melalui pengembangan Modal Intelektual (IC) firma pembinaan. Akibatnya, berdasarkan teori Pandangan Berasaskan Sumber, proses pelaksanaan CR4.0 dikenali sebagai inovasi berasaskan pengetahuan yang terjadi dengan pengembangan tiga modal IC: Modal Manusia (HC), Modal Hubungan (RC) dan Modal Struktur (SC). Justeru, penyelidikan ini bertujuan untuk membangunkan prototaip Multi-Criteria Decision-Making (MCDM), yang digunakan untuk mendukung pengambilan keputusan dalam strategi CR4.0, yang dinamakan sebagai 'Construction Firm's Indusry 4.0 Readiness MCDM (ConFIRM)'. Objektif pertama adalah untuk mengenal pasti elemen IC kritikal yang boleh mempengaruhi kesediaan pelaksanaan CR4.0. Proses yang terlibat kajian literatur bersistematik dan temu bual separa berstruktur. Objektif kedua adalah untuk menyiasat tahap kepentingan IC yang mempengaruhi pelaksanaan CR4.0 melalui teknik Analytical Hierarchy Process (AHP). Objektif ketiga adalah untuk mendapatkan wajaran kriteria dan sub-kriteria ConFIRM melalui Decision-Making Trial and Evaluation Laboratory (DEMATEL) dan Analytic Network Process (ANP). Objektif keempat adalah untuk membangunkan prototaip yang dipanggil ConFIRM yang terdiri daripada 3 kriteria utama, 16 sub-kriteria dan 92 super sub-kriteria mengikut wajaran kepentingannya dalam mencapai kesediaan pelaksanaan CR4.0. Keputusan MCDM menunjukkan HC (37%) sebagai kriteria utama CR4.0 yang paling kritikal, diikuti oleh SC (34%), dan RC (29%). HC mewakili kumulatif pengetahuan tersirat dalam organisasi dan ia adalah penjana utama yang tidak ketara. Untuk tahap sub-kriteria, keputusan menunjukkan bahawa "Modal Pengurusan (12%)" dianggap sebagai sub-kriteria CR4.0 yang paling kritikal. Sub-kriteria CR4.0 yang kedua paling kritikal adalah "Modal Pengalaman (10%)", diikuti oleh "Modal Proses (8%)". Sebaliknya, "Modal Lestari (2%)" adalah Sub-kriteria paling tidak kritikal. Kemudian, pemberat dirumuskan menjadi prototaip MCDM automatik, di mana skor - dikira menggunakan Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) - menunjukkan kesediaan strategik CR4.0. Dalam objektif keempat, ConFIRM dilaksanakan dalam kajian kes sebenar dan dinilai melalui penilaian lima pakar untuk menentukan kebolehlaksanaan dan kesahihannya dalam menilai kesediaan CR4.0 oleh syarikat kontraktor di Malaysia. Dalam kajian kes, para pakar mengiktiraf prestasi dan keberkesanan ConFIRM sebagai kaedah baru untuk penilaian CR4.0. ConFIRM menambah nilai untuk pengembangan strategi CR4.0 dengan menunjukkan di mana tindakan pembetulan/ pencegahan diperlukan, berdasarkan penilaian, sebelum memulakan pelaksanaannya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
ANP	-	Analytic Network Process
BIM	-	Building Information Modelling
CIDB	-	Construction Industry Development Board
ConFIRM	-	Construction Firm's Industry 4.0 MCDM
CPS	-	Cyber-Physical Systems
CR4.0	-	Construction 4.0
DANP	-	Hybrid DEMATEL-ANP
DEMATEL	-	Decision Making Trial and Evaluation Laboratory
DMF	-	Decision Making Factor
HC	-	Human Capital
IA	-	Intangible Assets
IC	-	Intellectual Capital
ICBV	-	Intellectual Capital-Based View
ICC	-	Interclass Correlation Coefficient
IoT	-	Internet of Things
IR4.0	-	Industry 4.0
IS	-	Information System
IT	-	Information Technology
KBI	-	Knowledge-Based Innovation
KBV	-	Knowledge-Based View
MCDM	-	Multi-Criteria Decision-Making
MCO	-	Movement Control Order
MCr	-	Main Criteria
MM	-	Maturity Model
MVF	-	Model Validation Form
NIS	-	Neagtive Ideal Solution
PC	-	Pairwise Comparison
PIS	-	Positive Ideal Solution
PS	-	Preliminary Study

PW	-	Pair-Wiser
RBV	-	Resource-Based View
RC	-	Relational Capital
RFID	-	Radio Frequency Identification
RWV	-	Relative Weightage Value
SC	-	Structural Capital
SCr	-	Sub-Criteria
SE	-	Self Evaluator
SME	-	Subject Matter Expert
SPSS	-	Statistical Package for the Social Sciences
SSCr	-	Super Sub-Criteria
TOPSIS	-	Technique for Order of Preference by Similarity to Ideal Solution
UI	-	User Interface
UTM	-	Universiti Teknologi Malaysia
VC	-	Value Creation
WSM	-	Weighted Sum Method

LIST OF SYMBOLS

%	-	Percentage
N	-	Total number of respondents
M	-	Mean
Σ	-	Sum
A+	-	Positive Ideal Solution
A-	-	Negative Ideal Solution
S+	-	Separation form the Positive Solution
S-	-	Separation from the Negative Solution
C*	-	Closeness to Ideal solution
w	-	Weight

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

The world has experienced three major industrial revolutions in its history and is currently undergoing its fourth revolution; in which every change has promoted optimal performance, output and benefits. The first revolution was the "Steam Revolution" at the end of the eighteenth century; the second revolution, the "Electric Revolution" at the beginning of the twentieth century; and the third revolution, the "Information Revolution'' in the 1970s (Li and Yang, 2017). Currently, the fourth revolution is coming into view directed by cyber-physical systems (CPS), the internet of things (IoT), cloud computing, and mobile computing, among others, termed Industry 4.0 (Alaloul *et al.*, 2018; Kozlovska *et al.*, 2021). The term Industry 4.0 (IR4.0) was proposed by Germany in 2011, then was formally put forward as a concept at the Hannover Industrial Expo in April 2013 (Li and Yang, 2017). Since then, myriad research efforts to examine IR4.0 technologies, applications, benefits, and challenges have started. Such efforts have reached all industries, including the construction industry, termed the fourth construction revolution.

Recently, several governments have launched local programs to accelerate the development and deployment of IR4.0 technologies. The "High-Tech Strategy 2020" programme was established in Germany, where this concept was born; "Advanced Manufacturing Partnership" in the United States, "Made in China 2025" in China, and "La Nouvelle France Industrielle" in France (Dalenogare *et al.*, 2018). In Malaysia, "Industry4WRD" (National Policy on Industry 4.0) was launched in 2018 in response to IR4.0 in order to drive the digital transformation in Malaysia's manufacturing and related services sectors (Lau *et al.*, 2019b). In both developed and emerging countries, these programs aimed to disseminate IR4.0 concepts and technologies in across all industries and businesses. Malaysia has been categorised as a technologically developing country (Ibrahim *et al.*, 2021). The Malaysian Government focused significant efforts to encourage construction industry members to implement IR4.0 as a transformative innovation to improve productivity and efficiency throughout the industry (Hussain *et al.*, 2019). More specifically, following the pace towards the fourth construction revolution, Malaysia has been considered as one of the leading countries to develop the "Construction 4.0 strategic plan" (CIDB, 2021), following Hong Kong "Construction 2.0" and UK "Construction 2025". Moreover, according to Forcael *et al.* (2020), Malaysia was among the countries to lead IR4.0 digital revolution, with the highest number of publications.

The visionary idea of the fourth construction revolution or other synonyms such as Smart construction, Smart site, or Construction 4.0, have been put forward steadily by different actors to describe the trend towards IR4.0 implementation in the construction industry. Multiple scholars have brought diverse definitions in the term "Construction 4.0" (CR4.0). In the context, it has been defined as various IR4.0 related technologies to enable the digitisation, automation and integration of the construction process at all stages of the construction value chain (Lau *et al.*, 2019b). Based on this definition, the implementation of IR4.0 within the construction industry will affect the business process and practices (Adepoju and Aigbavboa, 2020b). Nevertheless, while most industries have moved to IR4.0 implementation, the construction industry has not fully integrated IR4.0 (Oesterreich and Teuteberg, 2016; Turk, 2021).

The significance of CR4.0 would rely on its ability to create new business areas and enhance performance, termed IR4.0 value-creation (IRVC) (Nagy *et al.*, 2018; Schreiber *et al.*, 2018). For the construction industry, the positive effects of implementing IR4.0 are visible in many areas. CR4.0 resulted in value creation of 5-20% cost savings (Niu *et al.*, 2018; Rastogi, 2015). Moreover, the created value of 10-30% time-saving provided by CR4.0 (Rastogi, 2015). Similarly, CR4.0 would improve 30-50% quality of construction projects (Kelly and Ilozor, 2019; Rastogi, 2015). Decision-making within the industry would also be enhanced due to big data analytics (Dubey *et al.*, 2019). Likewise, CR4.0 would be leading in communication and collaboration enhancement through the use of the cloud computing, Building

Information Modelling (BIM) and social media apps would be high among project team members. However, a corresponding shift, focusing on technology, people, and process, would be needed to gain those benefits and achieve IRVC (Mêda *et al.*, 2020). Fundamentally, new frameworks, businesses, term of references and readiness models for CR4.0 are required for its implementation (Oesterreich and Teuteberg, 2016).

CR4.0 has changed the nature of competitive resources by reshaping the structure and way of working of construction firms. In the competitive paradigm, construction firms face various technological, human, and process-related challenges (Mêda *et al.*, 2020). To gain and hold a competitive edge, construction firms needed to enhance the performance of CR4.0 implementation. The resource-based view (RBV) theory argued that firms could attain a competitive advantage and performance could be optimised through the use of strategic assets (Barney and Hesterly, 2019). In addition, the intellectual capital-based view (ICBV) argued that the most crucial strategic asset to achieve optimal performance would be the Intellectual Capital (IC) (Martín-de-Castro *et al.*, 2011). IC has been considered the keystone in implementing innovation (such as CR4.0) and business success (Duodu and Rowlinson, 2019). Profoundly, ICBV was mainly based on the RBV and the knowledge-based view (KBV) (Khalique *et al.*, 2018).

Intellectual Capital (IC) has been a promising resource for innovation management that may help with CR4.0 implementation readiness. It was indicated that knowledge management would be the current competitive asset, and firms who wisely manage their IC will succeed (Kori, 2017). According to Li et al. (2019), IC has been defined as valuable knowledge-related resources that organisations possess and use to create value and achieve a competitive advantage. Consequently, IC development and management could be positioned as critical pillars on which construction firms could rely on to achieve successful CR4.0 implementation readiness (Li *et al.*, 2021). The success of CR4.0 implementation would depend on the industry's unique characteristics. Notably, few studies indicated that construction firms have a limited ability to manage resources for effective CR4.0 implementation. However, decision-making regarding the orientation towards a higher level of IC developments could act as catalyst for CR4.0 implementation (Cabrita *et al.*, 2019).

The Knowledge-Based Innovation framework was developed, by Lu and Sexton (2009), to examine innovation in the built environment context using IC management. Based on their framework, it was propositioned that the CR4.0 implementation process should be viewed as a knowledge-based innovation, which occurred when the three IC dimensions; Human Capital (HC), Relationship Capital (RC), and Structure Capital (SC) - to be developed to achieve successful CR4.0 implementation readiness. Additionally, the people-process-technology framework has been used by multiple scholars to conceptualise and structure the main pillars of CR4.0 (Karmakar and Delhi, 2021; Mêda *et al.*, 2020; Oesterreich and Teuteberg, 2016). Thus, based on Knowledge-based Innovation and People-Process-Technology frameworks, this research would propose and use the IC perspective, including its three dimensions, to conceptualise the CR4.0 implementation critical criteria.

However, there has been a lack of knowledge on IC identification and management in the construction firms' business environment and practical tools of deployment to achieve successful CR4.0 implementation readiness (Li *et al.*, 2021). As a result, the theoretical link between IC management and CR4.0 would be investigated in this research (Muñoz-La Rivera *et al.*, 2020). The research would seek to use ICBV theoretical link to develop a decision-making (DM) prototype for the management and development of the IC towards successful CR4.0 implementation readiness, as shown in Figure 1.1.

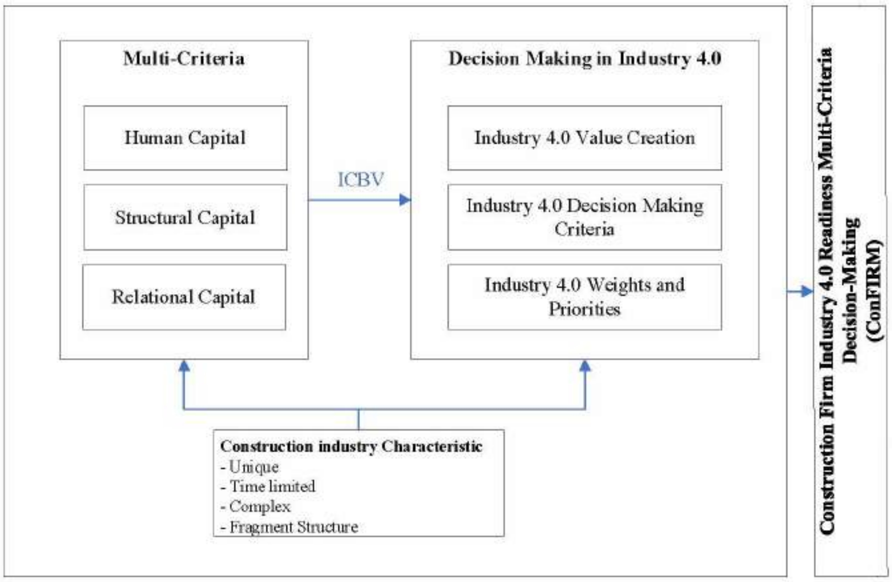

Figure 1.1 Theoretical links that guided this research

1.2 Problem Statement

IR4.0 initiatives' failure would have a severe impact on the firm due to the high cost of obtaining and running IR4.0 technologies, time-waste of personnel assigned to work on these technologies, and the competitive disadvantage of not having recent technologies, while competitors would have (Barham and Daim, 2020). In addition, a recent research found that 78% of firms were afraid of being disrupted or displaced because competitors had successfully implemented IR4.0 technologies (Davenport and Bean, 2018). Consequently firms undertake IR4.0 initiatives and step into the implementation process, firms would need to ensure that the chances of such an initiative being successful would be reasonably high (Barham, 2019). Therefore, a model, framework or prototype would be required to assist firms to be more confident and ready before IR4.0 is initiated (Sony and Naik, 2019b). In particular, a theoretically sound framework that would support decision-makers at every level of decision-making when considering whether to adopt IR4.0 and would allow decision-makers to customise the framework to a firm's requirements is obtained (Adepoju and Aigbavboa, 2020b).

Several research have been conducted into IR4.0 and its implementation readiness, particularly in the manufacturing industry (Lau *et al.*, 2019b). However, unlike the manufacturing industry, not much research regarding IR4.0 has been focused on the construction industry. Furthermore, the limited research conducted on CR4.0 did not consider the criteria that significantly impact the readiness of CR4.0 implementation or proposed prototypes to support decision-makers when considering whether to implement CR4.0, or not (Kozlovska *et al.*, 2021). Understanding the unique and specific nature of the construction projects, with specific time-limitations, complex organisations and fragmented structure must be understood before addressing the CR4.0's critical criteria which would lead to an effective implementation process (Dallasega *et al.*, 2018).

According to a recent survey in Malaysia (Alaloul *et al.*, 2019), 53% of Malaysian construction professionals were unfamiliar with applying CR4.0 technology in the industry, whereas only 34% have encountered some of the technologies during their work experience. Surprisingly, 13% of respondents were uncertain about the linkages between the technologies described and CR4.0. Only after being presented with a list of technologies connected to CR4.0, respondents changed their minds. After the shift in perspective, 47% of respondents were familiar with CR4.0 technologies.

The construction industry would be one of the most profitable sectors in the world and contributed massively to a country's economic growth (Karmakar and Delhi, 2021) with a 6% contribution of global Gross Domestic Product (GDP) (Tayurskaya *et al.*, 2020). By 2022, the industry would be expected to contribute up to 13% of global GDP (Maskuriy *et al.*, 2019b). Furthermore, the construction industry would have a significant impact on other sectors such as transportation, education, and health (Adepoju and Aigbavboa, 2020b). For Malaysia, CIDB (2015) reported that more than 120 industries relied on the construction industry, indicating the importance of the industry as an element of economic development for Malaysia. The Malaysian Ministry of Finance reported that the construction industry GDP contribution was 4.9% for 2019 (CIDB, 2021). Undoubtedly, the construction industry would be critical to any country's economic growth and development.

CR4.0 implementation resulted in multiple benefits and value creation for construction firms. Yet, as indicated by Aripin *et al.* (2019), majority of the Malaysian construction firms have not managed to implement the CR4.0 technologies to keep up with the automotive or manufacturing sectors. Notably, in a recent report by NVP (2020), 74% of manufacturing companies indicated that they had not achieved measurable results from implementing Big Data and Artificial Intelligence (AI) technologies, as presented in Figure 1.2. Value creation from CR4.0 would not be an easy task; construction industry adoption of CR4.0 and the driving of measurable results from these investments, would represent a multi-year journey. As illustrated in Figure 1.2, it is revealed that 78% of the firms failed to conduct digital implementation (Everest-Group, 2019).

Figure 1.2 IR4.0 implementation surveys and reports

Multiple factors attributed to people, process, and organisation culture (not technology) have been cited as key challenges of CR4.0 implementation (Khalifa and Daim, 2021). Similarly, the results from Everest Group Everest-Group (2019)reported organisation structure (69%), collaboration and innovation (82%), and failure to implement a change management plan (87%) as the main challenges. Interestingly, top managers now realised that the most significant barrier to IR4.0 implementations within firms was not technology but issues relating to people, culture and process, as reported by NVP (NVP, 2020), where, 91% of managers agreed that people and process-related factors represented the most significant barrier to implementing Big Data and AI.

One solution that many scholars have suggested to address those challenges would be through the management and development of IC (Asif, 2020; Cabrita *et al.*, 2019; Khalique *et al.*, 2018; Maria Serena *et al.*, 2019; Prakasa, 2018; Sengil and Duran, 2019; Stachová *et al.*, 2019; Uysal, 2019). Yet, for the Malaysian construction firms, the role of the IC has remained unclear, reflected by the relatively low level of IC management in Malaysian construction firms (Khalique and Pablos, 2015). Yitmen (2011) indicated that the IC components were essential sources of competitiveness and innovation performance within the engineering firms. Moreover, Khalique and Pablos

(2015) showed that 50.5% of the variance in the performance of Malaysian construction firms was jointly explained by the IC variables.

Consequently, the DM prototype for CR4.0 implementation readiness using IC perspective would be needed to consider the various characteristics of the construction industry. Such a model could be used to forecast the readiness of CR4.0 by addressing multiple issues in its implementation: firstly by identifying potential criteria that significantly impact the readiness of CR4.0 implementation, secondly by supporting CR4.0 decision-making by calculating the CR4.0 implementation readiness, and finally by providing guidance where corrective/preventive actions are needed, based on the assessment, before starting the implementation.

1.3 Research Gap

Several research gaps that this research aimed to fulfil were highlighted by reviewing literature. Although the literature addressed the IR4.0 importance and applications in the construction domain, they were however lacking in investigating the key influencing criteria for the successful IR4.0 implementation in the construction environment (Maskuriy *et al.*, 2019b). Previous research on CR4.0 had only focused on the applications, awareness, and challenges while frameworks, business, readiness and maturity models have not been developed (García de Soto *et al.*, 2019). There have been a lot of focus on 'why' construction firms needed to adopt digital technologies, however there has been less focus on 'how' they could realise their expected benefits and generate value simultaneously (Love and Matthews, 2019). Hossain and Nadeem (2019) conducted research to identify the state of art of CR4.0. They concluded that it would be critical to recognise the primary criteria to implement new technologies peculiar to the construction industry and to manage them appropriately. Thus, much research would still be needed to fill the gaps and to overcome the current and future challenges (Shahinmoghadam and Motamedi, 2019).

Moreover, it was revealed that the relevant literature were lacking theoretical underpinning. The current literature mainly focusing on particular technical dimensions of CR4.0 implementation process and not offering guidance on handling the whole decision-making and implementation process (Forcael *et al.*, 2020). In addition, there has been limited research about evaluating CR4.0 implementation criteria under different perspectives. It was revealed by previous reviews that only a handful of papers had even tried to group the criteria of CR4.0 (Lau *et al.*, 2019a; Muñoz-La Rivera *et al.*, 2020). The taxonomy of CR4.0 critical criteria under different perspectives could help significantly to represent the big picture and the actors around CR4.0 for better understanding and addressing of those criteria. The ICBV theory was used to fill this as a theory underpinning this research, following the suggestions of multiple scholars (Asif, 2020; Khalique *et al.*, 2018; Maria Serena *et al.*, 2019; Prakasa, 2018; Sengil and Duran, 2019; Stachová *et al.*, 2019; Uysal, 2019). For instance, Love and Matthews (2019) referred to the three dimensions of IC when they stated:

> If construction firms do not conduct a benefits management assessment before implementing digital technologies, their expected efficiencies are unlikely to materialise, as strategic (i.e. customer), organisational (i.e. structure), and cognitive (i.e. people) changes will be overlooked.
>
> (Love and Matthews, 2019)

Fundamentally, construction firms must rethink their business models and to innovate on how they manage their IC to achieve CR4.0 implementation readiness (Cerezo *et al.*, 2019; Muñoz-La Rivera *et al.*, 2020). As the ICs are promising knowledge-based resources for innovation, there has been a lack of knowledge on their identification in the construction firms' business environment and business models of deploying them to achieve CR4.0 readiness (Kori, 2017). Therefore, this research would aim to cover this gap by using IC perspectives to develop CR4.0 implementation readiness prototype; such as knowledge about the impact of IC and their sub-criteria in order to enhance the understanding of construction managers and decision-makers on when, where, and how to implement CR4.0.

Also, there has been limited empirical and statistical research about the dynamics of internal and external criteria surrounding CR4.0 (Hussain *et al.*, 2019).

According to Maskuriy *et al.* (2019b), most of the publications reviewed used systematic and scoping review methodologies to demonstrate the value of CR4.0. Thus, Patrucco *et al.* (2020) recommended that future research to use survey studies to statistically test the links between CR4.0 technology, organisation, and performance. Similarly, Maskuriy *et al.* (2019a) asserted that qualitative research would be required in order to have in-depth knowledge of the theories that drive CR4.0. Consequently, a structured framework would be needed for successful technology adoption and digitalisation in the construction industry (Muñoz-La Rivera *et al.*, 2020). According to Karmakar and Delhi (2021), quantitative research would be needed to better understand the interactions between various CR4.0 technologies and the dynamics of implementation.

Moreover, Lau *et al.* (2019b) indicated that most IR4.0 roadmaps or strategic plans focused on the manufacturing sectors instead of the construction industry. This would increase the need to construct a prototype to assess IR4.0 implementation readiness, focusing on the construction sector (Bai *et al.*, 2020; Dallasega, 2018). Moreover, while IR4.0 related studies used single-criteria models, the construction industry required an MCDM because its characteristics were unique, time-limited, complex, and having a fragmented structure rather than the existing manufacturing-focused tools (Adepoju and Aigbavboa, 2020a). A recent review of CR4.0 in construction management research concluded that there were many research gaps in research that were mainly looking at new technology in construction projects (Schönbeck *et al.*, 2020). The gap between IR4.0 and the construction industry would continue to widen as long as there is a lack of models for technological adoption and new construction techniques (Kozlovska *et al.*, 2021). Thus, realising the specific nature of the construction industry while addressing the CR4.0 critical criteria would essentially lead to an effective implementation readiness (Aghimien *et al.*, 2021).

Subsequently, the identified research gaps very well implied the need to integrate the ICBV theory and CR4.0 readiness. Also, it demonstrated the need to develop the MCDM prototype to account the multiple dimensions of CR4.0 implementation readiness. However, a speedy decision-making system would be required, which can be built via a digitalised automation system. This digitalised automation system was developed using MS Excel because of its convenience, efficiency, and effectiveness. Figure 1.3 showed the multiple research gaps in this research, contributing significantly to the body of knowledge with novelty.

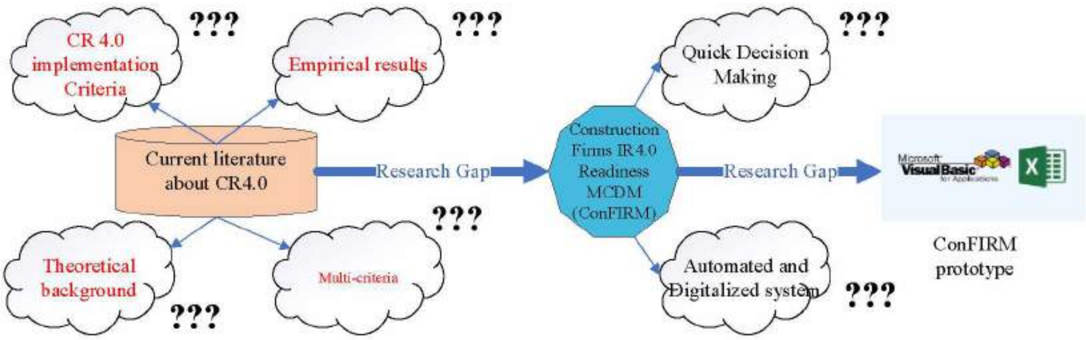

Figure 1.3 Research Gap

1.4 Aim and Objectives of the Research

This research would aim to develop a prototype, that could be used by construction firms planning to implement CR4.0 to support their decision-making process, named as 'Construction Firm's Industry 4.0 Readiness MCDM (ConFIRM)'. This would integrate the experts' judgement with MCDM techniques to develop a convenient, computer-aided prototype for construction industry practitioners. Therefore, to achieve this aim, four objectives have been drawn up, including:

i. To identify the critical criteria of IC that affect CR4.0 implementation readiness.

ii. To investigate the level of significance of IC that affect CR4.0 implementation readiness.

iii. To analyse the scoring and weightage factor for Construction Firm's Industry 4.0 Readiness MCDM (ConFIRM).

iv. To develop the automated MCDM prototype that would be able to assess CR4.0 implementation readiness.

1.5 Scope of the Research

This research would focus solely on implementing IR4.0 in construction firms in Malaysia. It was conducted following a thorough examination of relevant technology implementation readiness evaluation techniques utilised in the construction sector.

The scope of the research has been limited to construction firms, sometimes known as Architecture, Engineering and Construction firms. In terms of IR4.0 coverage, the research debated the business side of the implementation process, referred to as IR4.0 Value Creation. Next, the relationship between IC management and CR4.0 implementation readiness was elaborated. However, the relationship was established based on findings from previous literature and the judgement of class A contractors in Malaysia. Class A contractors are registered as grade 7 (G7) contractors with the Construction Industry Development Board (CIDB) in Malaysia and are granted permission to handle construction projects with no bidding limit. As such, their opinions would matter because of the large number and size of construction projects they have undertaken and executed. Also, class A contractors would have sufficient awareness on CR4.0 practices as opined by Muthusamy and Chew (2020) and Onubi and Hassan (2020), which justified the need to seek for their judgement. For instance, contractors who participate in tenders are required to have practical knowledge of BIM usage. In Malaysia, contractors with government projects valued at RM100 million and above would have the legal responsibility and obligation to adopt BIM starting from the year 2019.

In terms of context, this research would mainly focus on construction industry in Malaysia, although it was reduced to a few specific regional boundaries within the country. Prior research indicated that, in Malaysia BIM is 78% adopted by construction firms in the central region (Rafindadi *et al.*, 2020). The research selected Kuala Lumpur and Selangor as the States and Federal Territories to focus on when collecting data for the research fieldwork. As a result, 75% of data was collected from those states. Finally, this research was carried out at the level of the firm rather than the individual, to gather details of firms' operations.

The researcher encountered several challenges during data collection due to Movement Control Order (MCO) being implemented in response to the coronavirus disease of 2019 (COVID-19) outbreak, resulting in difficulties locating respondents, miscommunication, limited access to high-ranking personnel, time constraints, financial issues, and limited access to the construction sites. As a result, after considering various data collection techniques, the experts' panel technique was chosen as an alternative research approach that did not require a large sample size (Barham and Daim, 2020). In addition, as a response to social distancing, meetings were conducted online using video conferencing tools, and the statistical data were obtained via online surveys.

1.6 Significance of the Research

This research would explore and presented a new innovative computer-based automation prototype for the CR4.0 implementation readiness and IC management. Mostly the concept indicated that CR4.0 initiatives would incur a higher cost during the initial stage and this has been considered as one of the major issues. For that drawback, investors, developers, and other major stakeholders involved in construction projects were reluctant to deal with the unwanted financial critical situation. Therefore, most of the investors would have minimal interest to undertake the CR4.0 implementation and less effort being put forward to justify the worth of future and value creation. As a contribution to the body of knowledge, the findings from this research would provide a basis to CR4.0 critical criteria and their relative weighted values to serve as a tool for developers and investors within the construction industry. Likewise, the findings would serve as the foundation for government to achieve their targets and goals set for 2025 (CIDB, 2021).

The construction investors and managers are welcoming the automation solution which would be workable on the computer-based system and could easily assess CR4.0 implementation readiness by managing their IC more effectively and efficiently. The integrated approach of IC management and CR4.0 would be able to provide an easy, quick responsive prototype of decision-making for the construction firms. Needless to say, there have been lots of tools available to carry out the IR4.0 for manufacturing firms, somehow innovative integrated approach focusing on the construction sector is still very much lacking behind.

Furthermore, the research would also present the automation of ConFIRM in the industry and would provide feedback on the prototype. Project managers and other skilled stakeholders are still lacking behind due to the unavailability of the integrated computer-based automated MCDM prototypes for CR4.0. Therefore, this computer-based automation of CR4.0 implementation readiness which integrated IC and CR4.0 would be a massive helping prototype for the investors, developers and other stakeholders as a new innovative solution to a high CR4.0 implementation readiness.

Moreover, In Malaysia, Industry4WRD Readiness Assessment (Industry4WRD-RA) is a comprehensive programme to help firms assess their capabilities and readiness to adopt IR4.0 technologies and processes. The assessment uses a pre-determined set of indicators to understand their present capabilities and gaps, from which will enable firms to prepare feasible strategies and plans to move towards IR4.0 (MITI, 2018). Since Industry4WRD-RA targets the manufacturing segment, ConFIRM prototype could serve as the readiness assessment programme to target the construction segment. In addition, ConFIRM could be integrated with "Construction 4.0 strategic plan (2021-2025) (CIDB, 2021)

1.7 Research Framework of Thesis

Qualitative and quantitative research methods were included in the development of the research framework to attain the outlined objectives. The research framework would be divided into three phases: Variables Development, Variables Analysis, and DM Model Development.

As shown in Figure 1.4, Phase 1 entailed a systematic review of relevant literature to obtain research topics. In Chapter 2 and Chapter 3, the literature review and research methodology were presented. In addition, semi-structured interviews with construction engineers were undertaken throughout Phase 1 and shown in Chapter 4.

The online interviews with the expert panel were covered in Phase 2. A set of questionnaires was designed and validated by professionals to collect data in this phase, then was employed during the online interviews. Then, the collected data was analysed using The Analytical Hierarchy Process (AHP), Decision making trial and evaluation laboratory (DEMATEL), and Analytic Network Process (ANP).

The rapid prototyping approach was used to construct the self-assessment automated MCDM prototype in Phase 3. MS Excel's Userform was used as the environment to build the prototype. Desirability curves were used to assign values for each metric, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to calculate the CR4.0 implementation readiness. Finally, the case study method was used to validate the prototype.

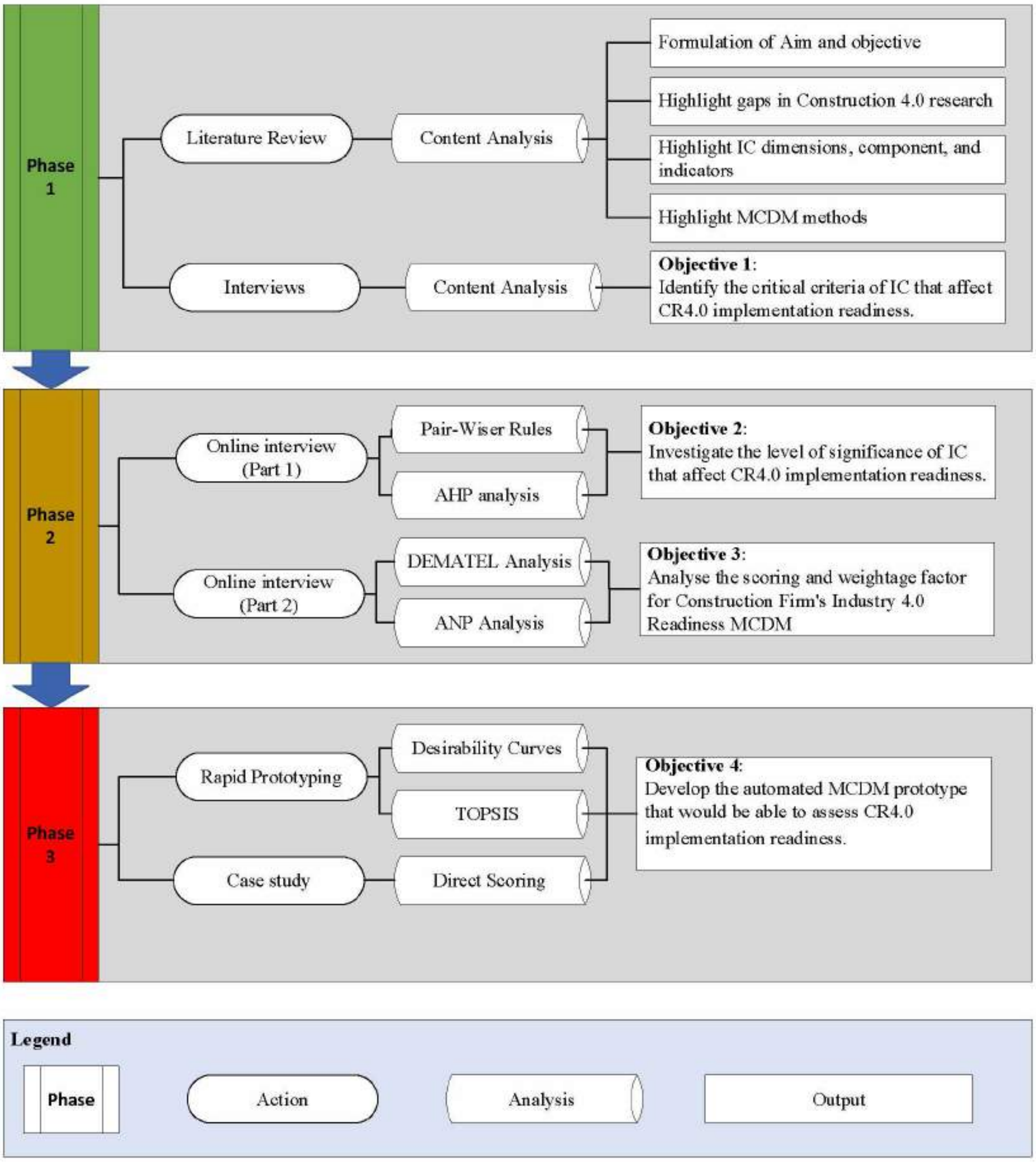

Figure 1.4 Research framework

1.8 Structure of the Research

Chapter 1 (Introduction), Chapter 2 (Literature Review), Chapter 3 (Methodology), Chapter 4 (Data Analysis and Discussions), Chapter 5 (Model Development), and Chapter 6 (Conclusion) would make up this research. The contents of each chapter are explained in the following paragraphs.

Chapter 1 would outline the introduction and background of the research, as well as the problem statement and research significance. In addition, this chapter would provide the research's aim and objectives as well as the research gaps. This chapter would also include the research framework, scope, and chapter summary.

Chapter 2 would cover the literature review of the theoretical underpinning of CR4.0 and IC management and criteria. In addition, MCDM techniques would also be discussed in this chapter. As a result, the IC meta-model affecting CR4.0 implementation readiness is established in this chapter.

Chapter 3 would explain the research methodology used in this research. It also would discuss the research phases, questionnaires development, data collection procedures, data analysis methods, and the overall research design. The automated prototype development, including methods, analysis, and validation through case studies, would also be covered in this chapter.

Chapter 4 would present the results, data analysis, and discussions. This chapter would provide a comprehensive picture of the data acquired from expert panel' responses to interviews and questionnaires.

Chapter 5 would discuss the development of a self-assessment prototype for assessing CR4.0 implementation readiness. It would depict the application's user interface. In addition, as a metric development, this chapter describing the creation of the desirability curves for each IC criteria. Furthermore, the case studies were analysed and discussed in this chapter.

Chapter 6 would present the conclusions and recommendations for future research. This chapter would sum up the key findings and results of the research. In addition, the research's limitations would also be discussed in this chapter. It would provide several recommendations for future research. The references and appendices can be found near the end of this research.

REFERENCES

Abdelmegid, M., González, V., Poshdar, M., O'Sullivan, M., Walker, C., and Ying, F. (2020). Barriers to adopting simulation modelling in construction industry. *Automation in Construction, 111*, 103046.

Abdin, N. I. B. (2019). *Decision Making Tool in Building Retrofitting for Energy Reduction in Higher Learning Institution.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Abotah, R. (2015). *Evaluation of energy policy instruments for the adoption of renewable energy: Case of wind energy in the Pacific Northwest US.* (Ph.D Thesis). Portland State University, Portland, OR.

Adepoju, O. O., and Aigbavboa, C. O. (2020a). Assessing knowledge and skills gap for construction 4.0 in a developing economy. *Journal of Public Affairs, 21*(3), e2264.

Adepoju, O. O., and Aigbavboa, C. O. (2020b). Implementation of Construction 4.0 in Nigeria: Evaluating the Opportunities and Threats on the Workforce. *Academic Journal of Interdisciplinary Studies, 9*(5), 254-264.

Aghimien, D., Aigbavboa, C., and Matabane, K. (2021). Impediments of the Fourth Industrial Revolution in the South African Construction Industry. In A. S.M., H. P. and D. S. A. Azhar S. (Eds.), *Collaboration and Integration in Construction, Engineering, Management and Technology* (pp. 223-227). Cham: Springer.

Aghimien, D. O., Aigbavboa, C. O., and Oke, A. E. (2020). Critical success factors for digital partnering of construction organisations–A Delphi study. *Engineering, Construction and Architectural Management, 27*(10), 3171-3188.

Agostini, L., Nosella, A., and Filippini, R. (2017). Does intellectual capital allow improving innovation performance? A quantitative analysis in the SME context. *Journal of Intellectual Capital, 18*(2), 400-418.

Akdil, K. Y., Ustundag, A., and Cevikcan, E. (2018). Maturity and Readiness Model for Industry 4.0 Strategy. In *Industry 4.0: Managing The Digital Transformation* (pp. 61-94). Cham: Springer.

Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A., and Kennedy, I. B. (2019). Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain Shams Engineering Journal, 11*(1), 225-230.

Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A., and Mohammed, B. S. (2018). Industry revolution IR 4.0: future opportunities and challenges in construction industry. *MATEC Web of Conferences, 203*, 02010.

Alexander, S. (2018). *A Correlation Between Intellectual Capital and Organizational Performance In The U.S. Airline Industry.* (Ph.D Thesis). University of Phoenix, Phoenix,AZ.

Almanasreh, E., Moles, R., and Chen, T. F. (2019). Evaluation of methods used for estimating content validity. *Research in Social and Administrative Pharmacy, 15*(2), 214-221.

Aloulou, W. J. (2019). Impacts of strategic orientations on new product development and firm performances: Insights from Saudi industrial firms. *European Journal of Innovation Management, 22*(2), 257-280.
AlRyalat, S., Malkawi, L. W., and Momani, S. M. (2019). Comparing bibliometric analysis using PubMed, Scopus, and Web of Science databases. *Journal of Visualized Experiments, 152*, e58494.
Amade, B., and Nwakanma, C. I. (2021). Identifying Challenges of Internet of Things on Construction Projects Using Fuzzy Approach. *Journal of Engineering, Project & Production Management, 11*(3), 215-227.
Ames, H., Glenton, C., and Lewin, S. (2019). Purposive sampling in a qualitative evidence synthesis: A worked example from a synthesis on parental perceptions of vaccination communication. *BMC medical research methodology, 19*(1), 1-9.
Andrew, D. P., Pedersen, P. M., and McEvoy, C. D. (2019). *Research methods and design in sport management* (Second ed.). Champaign, IL: Human Kinetics.
Anwar, N., Izhar, M. A., and Najam, F. A. (2018). Construction monitoring and reporting using drones and unmanned aerial vehicles (UAVs). In *The Tenth International Conference on Construction in the 21st Century (CITC-10)* (Vol. 1, pp. 325-332). Colombo, Sri Lanka.
Aripin, I. D. M., Zawawi, E. M. A., and Ismail, Z. (2019). Factors Influencing the Implementation of Technologies Behind Industry 4.0 in the Malaysian Construction Industry. *MATEC Web of Conferences, 266*, 01006.
Asif, M. (2020). Are QM Models Aligned with Industry 4.0? A Perspective on Current Practices. *Journal of Cleaner Production, 258*, 1208202.
Automation, R. (2014). *The Connected Enterprise Maturity Model*: Rockwell Automationo. Document Number)
Azimifard, A., Moosavirad, S. H., and Ariafar, S. (2018). Selecting sustainable supplier countries for Iran's steel industry at three levels by using AHP and TOPSIS methods. *Resources Policy, 57*, 30-44.
Babatunde, S. O., Udeaja, C., and Adekunle, A. O. (2020). Barriers to BIM implementation and ways forward to improve its adoption in the Nigerian AEC firms. *International Journal of Building Pathology and Adaptation, 39*(1), 48-71.
Babbie, E. R. (2020). *The practice of social research* (15th ed.). Boston, MA: Cengage learning.
Bai, C., Dallasega, P., Orzes, G., and Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics, 229*, 107776.
Bakar, K. A., Ibrahim, R., and Yunus, Y. (2020). Digital Government Evolution and Maturity Models: A Review. *Open International Journal of Informatics, 8*(2), 70-87.
Balubaid, S. O. (2017). *Decision Making Model for The Selection of Energy Efficient Building Structural Systems.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.
Bamgbade, J. A., Kamaruddeen, A. M., Nawi, M. N. M., and Aziz, Z. (2015). Preliminary Study on Antecedents of Sustainable Construction Among Contracting Companies Operating in Malaysia. *Jurnal Teknologi, 77*(4), 119-125.

Barham, H. (2019). *Development of a Readiness Assessment Model for Evaluating Big Data Projects: Case Study of Smart City in Oregon, USA.* (Ph.D Thesis). Portland State University, Portland, OR.

Barham, H., and Daim, T. (2018). Identifying Critical Issues in Smart City Big Data Project Implementation. In *Proceedings of the 1st ACM/EIGSCC Symposium on Smart Cities and Communities* (Vol. 1, pp. 1-9). Portland, OR: Association for Computing Machiner.

Barham, H., and Daim, T. (2020). The use of readiness assessment for big data projects. *Sustainable Cities and Society, 60*, 102233.

Barham, H., Giadedi, A., Gibson, E., Eljayar, A., and Daim, T. (2018). EVALUATING FIRM'S READINESS FOR BIG DATA ADOPTION: A HIERARCHICAL DECISION MODEL. In *Proceedings of the American Society for Engineering Management 2018 International Annual Conference* (Vol. `, pp. 1-10). Idaho, USA.: American Society for Engineering Management.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management, 17*(1), 99-120.

Barney, J. B., and Hesterly, W. S. (2019). *Strategic management and competitive advantage: Concept an cases* (5th ed.). New York, NY: Pearson

Barney, J. B., Ketchen Jr, D. J., and Wright, M. (2011). The future of resource-based theory: revitalization or decline? *Journal of management, 37*(5), 1299-1315.

Baur, C., and Wee, D. (2015). *Manufacturing's next act* o. Document Number)

Bavafa, A., Mahdiyar, A., and Marsono, A. K. (2018). Identifying and assessing the critical factors for effective implementation of safety programs in construction projects. *Safety Science, 106*, 47-56.

Bavafa, A. A. (2017). *Developing a Generic Safety Performance Evaluation Prototype for Construction Projects In Malaysia.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Beattie, V., and Thomson, S. J. (2007). Lifting the lid on the use of content analysis to investigate intellectual capital disclosures. *Accounting Forum, 31*(2), 129-163.

Berraies, S. (2019). The effect of enterprise social networks use on exploitative and exploratory innovations. *Journal of Intellectual Capital, 20*(3), 426-452.

Bertram, D. (2007). Likert Scales are the meaning of life. University of Calagary, Department of Computer Science. *Recuperado de: http://poincare. matf. bg. ac. rs/~ kristina/topic-dane-likert. pdf. Di Martino, P. y Gregorio, F.(2017). The role of affect in failure in mathematics at the university level: the tertiary crisis. Cerme, 10*, 1050-1057.

Bian, T. B. (2018). *Building A Big Data Community For Construction in Malaysia.* Paper presented at the Statistics, Indices in Construction and Automation (SICA), Kuala Lumpur, 1-10.

Boateng, P. (2014). *A dynamic systems approach to risk assessment in megaprojects.* (Ph.D Thesis). Heriot-Watt University, UK.

Bonilla-Enriquez, G., and Caballero-Morales, S.-O. (2020). The Opportunities of Industry 4.0 in the Post-COVID-19 Era. *The International Journal of Business Management and Technolog, 4*(3), 243-247.

Brush, C. G., Edelman, L. F., and Manolova, T. S. (2012). Ready to launch? Growth-oriented ventures and the pursuit of angel financing. *Venture Capital, 14*(2), 1-19.

Buenechea-Elberdin, M. (2017). Structured literature review about intellectual capital and innovation. *Journal of Intellectual Capital, 18*(2), 262-285.
Buszko, A., and Mroziewski, M. (2009). The intellectual capital impact on Polish construction companies during the transformation period. *Journal of Human Resource Costing & Accounting, 13*(3), 206-220.
Cabrita, M. R., Cruz-Machado, V., and Duarte, S. (2019). Enhancing the Benefits of Industry 4.0 from Intellectual Capital: A Theoretical Approach. In C. F. Xu J., Gen M., Ahmed S. (Ed.), *Proceedings of the Twelfth International Conference on Management Science and Engineering Management* (pp. 1581-1591). Cham: Springer.
Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., et al. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing, 25*(8), 652-661.
Cárdenas, L. J. A., Ramírez, W. F. T., and Rodríguez Molano, J. I. (2018). Model for the Incorporation of Big Data in Knowledge Management Oriented to Industry 4.0. In S. Y. Tan Y., Tang Q. (Ed.), *Data Mining and Big Data* (pp. 683-693). Cham: Springer.
Cerezo, A., Pastor, A., Otero, M., and Portela, J. (2019). Predictive Tools for Project Performance Management in the Construction Industry. In Y. B. J. Ayuso Muñoz J., Capuz-Rizo S. (Ed.), *Project Management and Engineering Research* (pp. 3-18). Cham: Springer.
Chalekaee, A., Turskis, Z., Khanzadi, M., Ghodrati Amiri, G., and Keršulienė, V. (2019). A new hybrid MCDM model with grey numbers for the construction delay change response problem. *Sustainability, 11*(3), 776.
Chan, D. W., Olawumi, T. O., and Ho, A. M. (2019). Critical success factors for building information modelling (BIM) implementation in Hong Kong. *Engineering, Construction and Architectural Management, 26*(9), 1838-1854.
Chang, S.-C., Chang, H.-H., and Lu, M.-T. (2021). Evaluating Industry 4.0 Technology Application in SMEs: Using a Hybrid MCDM Approach. *Mathematics, 9*(4), 414.
Chauhan, C., Singh, A., and Luthra, S. (2021). Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. *Journal of Cleaner Production, 285*, 124809.
Chen, J., Zhu, Z., and Yuan Xie, H. (2004). Measuring intellectual capital: a new model and empirical study. *Journal of Intellectual Capital, 5*(1), 195-212.
Chen, Z. (2010). *A cybernetic model for analytic network process.* Paper presented at the 2010 International Conference on Machine Learning and Cybernetics, China, 1914-1919.
Chen, Z., Boateng, P., and Ogunlana, S. O. (2019). A dynamic system approach to risk analysis for megaproject delivery. In *Proceedings of the Institution of Civil Engineers-Management, Procurement and Law* (Vol. 172, pp. 232-252): ICE Publishing.
Chowdhury, T., Adafin, J., and Wilkinson, S. (2019). Review of digital technologies to improve productivity of New Zealand construction industry. *Journal of Information Technology in Construction, 24*(Special issue: 'Virtual, Augmented and Mixed: New Realities in Construction'), 569-587.
CIDB. (2015). *Construction Industry Transformation Programme 2016–2020*. Retrieved. from http://www.citp.my/.
CIDB. (2021). *Construction 4.0 Strategic Plan (2021-2025): Next Revolution of the Malaysian Construction Industry*. Retrieved. from

https://cream.my/my/publication/construction-4-0-strategic-plan-2021-2025/construction-4-0-strategic-plan-2021-2025.

Cleary, P., and Quinn, M. (2016). Intellectual capital and business performance. *Journal of Intellectual Capital, 17*(2), 255-278.

Contreras-Masse, R., Ochoa-Zezzatti, A., García, V., Perez-Dominguez, L., and Elizondo, M. (2020). Implementing a Novel Use of Multicriteria Decision Analysis to Select IIoT Platforms for Smart Manufacturing. *Symmetry, 12*(3), 368.

Cooper, M., Levy, Y., Wang, L., and Dringus, L. (2020). Subject matter experts' feedback on a prototype development of an audio, visual, and haptic phishing email alert system. *Online Journal of Applied Knowledge Management (OJAKM), 8*(2), 107-121.

Costa, R. V., and Ramos, A. P. (2015). Designing an AHP methodology to prioritize critical elements for product innovation: An intellectual capital perspective. *International Journal of Business Science & Applied Management 10*, 15-34.

Craveiro, F., Duarte, J. P., Bartolo, H., and Bartolo, P. J. (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. *Automation in Construction, 103*, 251-267.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., and Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics, 204*, 383-394.

Dallasega, P. (2018). Industry 4.0 Fostering Construction Supply Chain Management: Lessons Learned From Engineer-to-Order Suppliers. *IEEE Engineering Management Review, 46*(3), 49-55.

Dallasega, P., Rauch, E., and Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in industry, 99*, 205-225.

Davenport, T. H., and Bean, R. (2018). Big companies are embracing analytics, but most still don't have a data-driven culture. *Harvard Business Review, 6*, 1-4.

De Groote, M., and Lefever, M. (2016). *Driving transformational change in the construction value chain: reaching the untapped potential*. (B. P. I. Europe o. Document Number)

Dehdasht, G., Mohamad Zin, R., Ferwati, M. S., Abdullahi, M., Keyvanfar, A., and McCaffer, R. (2017). DEMATEL-ANP risk assessment in oil and gas construction projects. *Sustainability, 9*(8), 1420.

Demircan Keskin, F., Kabasakal, İ., Kaymaz, Y., and Soyuer, H. (2019). An Assessment Model for Organizational Adoption of Industry 4.0 Based on Multi-criteria Decision Techniques. In G. M. Durakbasa N. (Ed.), *Proceedings of the International Symposium for Production Research 2018* (pp. 85-100). Cham: Springer.

Demirkesen, S., and Tezel, A. (2021). Investigating major challenges for industry 4.0 adoption among construction companies. *Engineering, Construction and Architectural Management, ahead-of-print*.

Drescher, M., and Edwards, R. C. (2019). A systematic review of transparency in the methods of expert knowledge use. *Journal of applied ecology, 56*(2), 436-449.

Dubey, R., Gunasekaran, A., Childe, S. J., Blome, C., and Papadopoulos, T. (2019). Big Data and Predictive Analytics and Manufacturing Performance: Integrating Institutional Theory, Resource-Based View and Big Data Culture. *British Journal of Management, 30*(2), 341-361.

Duodu, B., and Rowlinson, S. (2019). Intellectual capital for exploratory and exploitative innovation: Exploring linear and quadratic effects in construction contractor firms. *Journal of Intellectual Capital, 20*(3), 382-405.

Ebrahimi, S. (2019). *Awareness of the Turkish Construction Industry Towards Industry 4.0 Technologies and Concepts.* (Master's thesis). Middle East Technical University, Turkey.

Ecem Yildiz, A., Dikmen, I., and Talat Birgonul, M. (2020). Using System Dynamics for Strategic Performance Management in Construction. *Journal of Management in Engineering, 36*(2), 04019051.

Erdogan, M., Ozkan, B., Karasan, A., and Kaya, I. (2018). Selecting the best strategy for industry 4.0 applications with a case study. In C. A. H. Calisir F. (Ed.), *Industrial engineering in the industry 4.0 era* (pp. 109-119). Cham: Springer.

Erdogan, S. A., Šaparauskas, J., and Turskis, Z. (2019). A Multi-Criteria Decision-Making Model to Choose the Best Option for Sustainable Construction Management. *Sustainability, 11*(8), 2239.

Estep, J. (2017). *Development of a technology transfer score for evaluating research proposals: Case study of demand response technologies in the Pacific Northwest.* (Ph.D Thesis). Portland State University, Portland, OR.

Etikan, I., Musa, S. A., and Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics, 5*(1), 1-4.

Everest-Group. (2019, Feb 5, 2020). Digital Services – Annual Report 2018: Future Operating Model to Scale Digital. 2020, from https://www2.everestgrp.com/Files/previews/Everest%20Group%20-%20Digital%20Services%20Annual%20Report%202018%20-%20CA.pdf

Fan, C.-L. (2020). Application of the ANP and fuzzy set to develop a construction quality index: A case study of Taiwan construction inspection. *Journal of Intelligent & Fuzzy Systems, 38*(3), 3011-3026.

Fargnoli, M., and Lombardi, M. (2020). Building information modelling (BIM) to enhance occupational safety in construction activities: Research trends emerging from one decade of studies. *Buildings, 10*(6), 98.

Farish, K., Anil, A. P., and Satish, K. (2017). Effect of TQM practices on financial performance through innovation performance-in Indian manufacturing context. *International Research Journal of Engineering and Technology, 4*(7), 2649-2655.

Fayek, A. R. (2020). Fuzzy logic and fuzzy hybrid techniques for construction engineering and management. *Journal of Construction Engineering and Management, 146*(7), 04020064.

Fayek, A. R., and Lourenzutti, R. (2018). Introduction to fuzzy logic in construction engineering and management. In A. R. Fayek (Ed.), *Fuzzy Hybrid Computing in Construction Engineering and Management* (pp. 3-35). Bingley: Emerald Publishing Limited.

Ferenhof, H. A., Durst, S., Zaniboni Bialecki, M., and Selig, P. M. (2015). Intellectual capital dimensions: state of the art in 2014. *Journal of Intellectual Capital, 16*(1), 58-100.

FIEC. (2017). Safeguarding in the next industrial revolution. *Construction Europe*.

Finkbeiner, P. (2017). Qualitative Research: Semi-structured Expert Interview. In *Social Media for Knowledge Sharing in Automotive Repair* (pp. 141-181). Cham: Springer.

Forcael, E., Ferrari, I., Opazo-Vega, A., and Pulido-Arcas, J. A. (2020). Construction 4.0: A Literature Review. *Sustainability, 12*(22).

Forgues, D., Rivest, L., Danjou, C., and Meyer, J. (2019). *De l'Industrie 4.0 à la Construction 4.0: Des exemples concrets!* Paper presented at the Congrès 2019 : influencez l'avenir.

Garcia-Perez, A., Ghio, A., Occhipinti, Z., and Verona, R. (2020). Knowledge management and intellectual capital in knowledge-based organisations: a review and theoretical perspectives. *Journal of Knowledge Management, ahead-of-print.*

García de Soto, B., Agustí-Juan, I., Joss, S., and Hunhevicz, J. (2019). Implications of Construction 4.0 to the workforce and organizational structures. *International Journal of Construction Management*, 1-13.

García, N. M. (2019). Multi-agent system for anomaly detection in Industry 4.0 using Machine Learning techniques. *ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal, 8*(4), 33-40.

Giannakis, M., Dubey, R., Vlachos, I., and Ju, Y. (2020). Supplier sustainability performance evaluation using the analytic network process. *Journal of cleaner production, 247*, 119439.

Gibson, E. (2016). *A measurement system for science and engineering research center performance evaluation.* (Ph.D Thesis). Portland State University Portland, OR.

Goebel, V. (2015). Is the literature on content analysis of intellectual capital reporting heading towards a dead end? *Journal of Intellectual Capital, 16*(3), 681-699.

Goepel, K. D. (2013). Implementing The Analytic Hierarchy Process As a Standard Method For Multi-Criteria Decision Making In Corporate Enterprises – A New AHP Excel Template With Multiple Inputs. In *Proceedings of the International Symposium on the Analytic Hierarchy Process* (Vol. 2, pp. 1-10). Kuala Lumpur: Creative Decisions Foundation.

Gökalp, E., Şener, U., and Eren, P. E. (2017). Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In M. A. Mas A., O'Connor R., Rout T., Dorling A. (Ed.), *Software Process Improvement and Capability Determination* (Vol. 770, pp. 128-142). Cham: Springer.

Golizadeh, H., Hosseini, M. R., Martek, I., Edwards, D., Gheisari, M., Banihashemi, S., et al. (2019). Scientometric analysis of research on "remotely piloted aircraft": A research agenda for the construction industry. *Engineering, Construction and Architectural Management, 27*(3), 634-657.

Grant, R. M. (2002). The knowledge-based view of the firm. In C. W. Choo and N. Bontis (Eds.), *The strategic management of intellectual capital and organizational knowledge* (Vol. 17, pp. 133-148). New York: Oxford University Press.

Groves, R. M., Fowler Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., and Tourangeau, R. (2011). *Survey methodology* (Vol. 561). Hoboken, NJ: John Wiley & Sons.

Gunduz, M., and Alfar, M. (2019). Integration of Innovation through Analytical Hierarchy Process (Ahp) in Project Management and Planning. *Technological and Economic Development of Economy, 25*(2), 258-276.

Gupta, S., Kumar, S., Singh, S. K., Foropon, C., and Chandra, C. (2018). Role of cloud ERP on the performance of an organization: Contingent resource-based view perspective. *International Journal of Logistics Management, 29*(2), 659-675.

Gursev, S. (2019). *Generating an Assessment Model for Industry 4.0.* (Ph.D Thesis). Marmara University, Turkey.

Hair, J. F., Babin, B. J., Anderson, R. E., and Black, W. C. (2019). *Multivariate Data Analysis* (8th ed.). U.K.: Cengage.

Hallowell, M. R., and Gambatese, J. A. (2010). Qualitative research: Application of the Delphi method to CEM research. *Journal of construction engineering and management, 136*(1), 99-107.

Hapsari, I., and Hartikasari, A. I. (2019). Role of Knowledge Sharing in Intellectual Capital and Company Performance: Challenges in Industry 4.0 Era. *Jurnal Ekonomi dan Bisnis Kontemporer, 5*(1), 1-16.

Hasnain, M., Thaheem, M. J., and Ullah, F. (2018). Best value contractor selection in road construction projects: ANP-based decision support system. *International Journal of Civil Engineering, 16*(6), 695-714.

Hatefi, S. M., and Tamošaitienė, J. (2019). An integrated fuzzy DEMATEL-fuzzy ANP model for evaluating construction projects by considering interrelationships among risk factors. *Journal of Civil Engineering and Management, 25*(2), 114-131.

Herdiawan, D., Setiadji, A., and Bastari, A. (2020). Analysis and Determination of Position Battalion Commander AAL Method with Personality and Methods DEMATEL PAPI Kostick Analytic Network Process (DFANP). *International Journal of Asro, 11*(1), 10-20.

Hill, R. (1998). What sample size is “enough” in internet survey research. *Interpersonal Computing and Technology: An electronic journal for the 21st century, 6*(3-4), 1-12.

Hongjun, G., and Chang-long, W. (2009). *The application of unascertained measurement model in intellectual capital management of construction enterprises.* Paper presented at the ISECS International Colloquium on Computing, Communication, Control, and Management. , China, 295-298.

Hossain, M. A., and Nadeem, A. (2019). Towards Digitizing the Construction Industry: State of the Art of Construction 4.0. In D. Ozevin, Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A. (Ed.), *Proceedings of the ISEC* (Vol. 10, pp. 13-11-13-16). Chicago, IL: ISEC Press.

Huang, C.-J., Talla Chicoma, E., and Huang, Y.-H. (2019). Evaluating the Factors that are Affecting the Implementation of Industry 4.0 Technologies in Manufacturing MSMEs, the Case of Peru. *Processes, 7*(3), 161.

Hung, W.-H., Wang, T.-H., Wu, M.-F., Tong, Y., and Su, S.-H. (2019). Analysis of Key Success Factors for Industry 4.0 Development. In *Proceedings of the 2019 5th International Conference on E-business and Mobile Commerce - ICEMC 2019* (Vol. 1, pp. 51-56). Taiwan: Association for Computing Machinery.

Hussain, A. H., Husain2, M. K. A., Roslan, A. F., Fadzil, F., and Ani, A. I. C. (2019). The Fourth Industrial Revolution and Organisations' Propensity Towards Building Information Modelling (BIM) Adoption. *Malaysian Construction Research Journal, 27*(1), 79-92.

Hwang, B.-G., Shan, M., and Looi, K.-Y. (2018). Knowledge-based decision support system for prefabricated prefinished volumetric construction. *Automation in Construction, 94*, 168-178.

Ibrahim, F. S. B., Esa, M. B., and Kamal, E. B. M. (2019). Towards Construction 4.0: Empowering BIM Skilled Talents in Malaysia. *International Journal of Scientific & Technology Research, 8*(10), 1694-1700.

Ibrahim, F. S. B., Esa, M. B., and Rahman, R. A. (2021). The Adoption of IOT in the Malaysian Construction Industry: Towards Construction 4.0. *International Journal of Sustainable Construction Engineering and Technology, 12*(1), 56-67.

Inkinen, H. (2015). Review of empirical research on intellectual capital and firm performance. *Journal of Intellectual Capital, 16*(3), 518-565.

Irizarry, J. (2020). *Construction 4.0: An innovation platform for the built environment* (1st ed.). London: Routledge.

Isaac, S., and Michael, W. B. (1995). *Handbook in research and evaluation: A collection of principles, methods, and strategies useful in the planning, design, and evaluation of studies in education and the behavioral sciences* (3rd ed.). Washington, DC: EdITS Publishers.

Ishak, A. R. (2021). Selangor CIDB uses drone to detect MCO violations at construction site. *Selangor Journal, June 2021*.

Islam, M. S., Nepal, M. P., Skitmore, M., and Kabir, G. (2019). A knowledge-based expert system to assess power plant project cost overrun risks. *Expert Systems with Applications, 136*, 12-32.

ITRC. (2013). *Groundwater Statistics and Monitoring Compliance*. from https://www.itrcweb.org/gsmc-1/Content/Resources/GSMCPDF.pdf

James, M. (2018). Strategic Readiness. In *The International Encyclopedia of Strategic Communication* (pp. 1-5). USA: John Wiley & Sons.

Jamwal, A., Agrawal, R., Sharma, M., Kumar, V., and Kumar, S. (2021). Developing A sustainability framework for Industry 4.0. *Procedia CIRP, 98*, 430-435.

Jia, M., Xu, Y., He, P., and Zhao, L. (2020). Identifying critical factors that affect the application of information technology in construction management: A case study of China. *Frontiers of Engineering Management*, 1-16.

Jin, R., Wang, F., and Liu, D. (2020). Dynamic probabilistic analysis of accidents in construction projects by combining precursor data and expert judgments. *Advanced Engineering Informatics, 44*, 101062.

Jin, R., Zou, P. X. W., Piroozfar, P., Wood, H., Yang, Y., Yan, L., et al. (2019). A science mapping approach based review of construction safety research. *Safety Science, 113*, 285-297.

Johanson, G. A., and Brooks, G. P. (2010). Initial scale development: sample size for pilot studies. *Educational and psychological measurement, 70*(3), 394-400.

Jung, K., Kulvatunyou, B., Choi, S., and Brundage, M. P. (2016). An Overview of a Smart Manufacturing System Readiness Assessment. In N. I. e. al. (Ed.), *Advances in Production Management Systems. Initiatives for a Sustainable World* (pp. 705-715). Cham: Springer.

Kagermann, H., Helbig, J., Hellinger, A., and Wahlster, W. (2013). *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group.* Berlin, Germany: Forschungsunion.

Kale, S. (2009). Fuzzy Intellectual Capital Index for Construction Firms *Journal of Construction Engineering and Management, 135*(6), 508-517.

Kannan, G. (2004). Intellectual capital: Measurement effectiveness. *Journal of Intellectual Capital, 5*(3), 389-413.

Kanniyapan, G., Nesan, L. J., Mohammad, I. S., Tan, S. K., and Ponniah, V. (2019). Selection criteria of building material for optimising maintainability. *Construction and Building Materials, 221*, 651-660.

Kaplan, R. S., and Norton, D. P. (2004). Measuring the strategic readiness of intangible assets. *Harvard business review, 82*(2), 52-63.

Kaplan, S., Schenkel, A., Krogh, G. v., and Weber, C. M. (2001). Knowledge-based theories of the firm in strategic management : a review and extension. *International Journal of Project Management, 25*(56), 143-158.

Karamoozian, A., Wu, D., Chen, C. P., and Luo, C. (2019). An approach for risk prioritization in construction projects using analytic network process and decision making trial and evaluation laboratory. *IEEE Access, 7*, 159842-159854.

Karmakar, A., and Delhi, V. S. K. (2021). Construction 4.0: what we know and where we are headed. *Journal of Information Technology in Construction (ITcon), 26*(28), 526-545.

Kasim, N., Sarpin, N., Noh, H. M., Zainal, R., Mohamed, S., Manap, N., et al. (2019). Automatic materials tracking practices through RFID implementation in construction projects. *MATEC Web of Conferences, 266*, 05001.

Kaya, I., Erdoğan, M., Karaşan, A., and Özkan, B. (2020). Creating a road map for industry 4.0 by using an integrated fuzzy multicriteria decision-making methodology. *Soft Computing, 24*, 17931-17956.

Kelly, D., and Ilozor, B. (2019). A quantitative study of the relationship between project performance and BIM use on commercial construction projects in the USA. *International Journal of Construction Education and Research, 15*(1), 3-18.

Khalid, L. S., and Rahman, I. A. (2019). Measuring the Effect of the External Factors on Iraqi Construction Projects Performance Using PESTLE Technique. *TEST Engineering & Management, 81*, 2206-2213.

Khalifa, R. I., and Daim, T. U. (2021). Project Assessment Tools Evaluation and Selection Using the Hierarchical Decision Modeling: Case of State Departments of Transportation in the United States. *Journal of Management in Engineering, 37*(1), 05020015.

Khalique, M., Bontis, N., Abdul Nassir bin Shaari, J., and Hassan Md. Isa, A. (2015). Intellectual capital in small and medium enterprises in Pakistan. *Journal of Intellectual Capital, 16*(1), 224-238.

Khalique, M., and Pablos, P. O. d. (2015). Intellectual capital and performance of electrical and electronics SMEs in Malaysia. *International Journal Learning and Intellectual Capital, 12*(3), 251-269.

Khalique, M., Shah, M. T. A., and Hina, K. (2018). Towards a Better Understanding of Intellectual Capital in Small and Medium Enterprises (SMEs) Operating in Service Sector. *Global Management Journal for Academic & Corporate Studies, 8*(1), 78-85.

Khan, J. S. (2019). *Automation of Integrated System on MyCREST and Lıfe Cycle Costing.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Khanra, S., and Joseph, R. P. (2019). E-governance maturity models: a meta-ethnographic study. *The International Technology Management Review, 8*(1), 1-9.

Kheybari, S., Rezaie, F. M., and Farazmand, H. (2020). Analytic network process: An overview of applications. *Applied mathematics and Computation, 367*, 124780.

Kianto, A., Sáenz, J., and Aramburu, N. (2017). Knowledge-based human resource management practices, intellectual capital and innovation. *Journal of Business Research, 81*, 11-20.
Kim, D. Y., and Kumar, V. (2009). A framework for prioritization of intellectual capital indicators in R&D. *Journal of Intellectual Capital, 10*(2), 277-293.
Klinc, R., and Turk, Ž. (2019). Construction 4.0 – Digital Transformation of one of the oldest Industries. *Economic and Business Review, 21*(3), 393-410.
Korayem, I. M. (2017). *The" water-specific PPP Risk Model.".* (Ph.D Thesis). Heriot-Watt University, U.K.
Kori, S. i. A. (2017). *BIM business value creation for SME architectural firms in Nigeria using intellectual capital development.* (Ph.D Thesis). University of Liverpool, Liverpool, England.
Kostis, A., and Näsholm, M. H. (2019). Balancing Trust and Distrust in Strategic Alliances. In *Managing Trust in Strategic Alliances* (pp. 103-127). Charlotte, NC: Information Age Publishing.
Kozlovska, M., Klosova, D., and Strukova, Z. (2021). Impact of Industry 4.0 Platform on the Formation of Construction 4.0 Concept: A Literature Review. *Sustainability, 13*(5), 2683.
Kumar, R. (2019). *Research methodology: A step-by-step guide for beginners.* London: Sage Publication Limited.
Kurki, S. (2019). The Long-Waves and the Evolution of Futures Practice and Theory. *World Futures Review, 11*(2), 122-140.
Kutlu Gündoğdu, F., and Kahraman, C. (2019). Spherical fuzzy sets and spherical fuzzy TOPSIS method. *Journal of intelligent & fuzzy systems, 36*(1), 337-352.
Kvale, S., and Brinkmann, S. (2009). *Interviews: Learning the craft of qualitative research interviewing.* London: Sage Publication Limited.
Lataś, R., and Walasek, D. (2016). Intellectual Capital within the Project Management. *Procedia Engineering, 153*, 384-391.
Lau, S., Aminudin, E., Zakaria, R., Saar, C. C., Abidin, N. I., Roslan, A. F., et al. (2019a). Revolutionizing the Future of the Construction Industry: Strategizing and Redefining Challenges. *WIT Transactions on the Built Environment, 192*, 105-115.
Lau, S., Zakaria, R., Aminudin, E., Chang Saar, C., Abidin, N. I. A., Roslan, A. F., et al. (2019b). Review: Identification of roadmap of fourth construction industrial revolution. *IOP Conference Series: Materials Science and Engineering, 615*, 012029.
Lee, J., Jun, S., Chang, T.-W., and Park, J. (2017). A Smartness Assessment Framework for Smart Factories Using Analytic Network Process. *Sustainability, 9*(5), 794.
Lekan, A., Clinton, A., and James, O. (2021). The Disruptive Adaptations of Construction 4.0 and Industry 4.0 as a Pathway to a Sustainable Innovation and Inclusive Industrial Technological Development. *Buildings, 11*(3), 79.
Leyh, C., Schäffer, T., Bley, K., and Forstenhäusler, S. (2016). SIMMI 4.0 – A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0. In *Proceedings of the 2016 Federated Conference on Computer Science and Information Systems* (Vol. 1, pp. 1297-1302). Gdansk, Poland: IEEE.

Li, J., and Yang, H. (2017). A research on development of construction industrialization based on BIM technology under the background of Industry 4.0. *MATEC Web of Conferences, 100*, 02046.
Li, X., Nosheen, S., Haq, N. U., and Gao, X. (2021). Value creation during fourth industrial revolution: Use of intellectual capital by most innovative companies of the world. *Technological Forecasting and Social Change, 163*, 120479.
Li, Y., Song, Y., Wang, J., and Li, C. (2019). Intellectual Capital, Knowledge Sharing, and Innovation Performance: Evidence from the Chinese Construction Industry. *Sustainability, 11*(9).
Liao, Y., Deschamps, F., Loures, E. d. F. R., and Ramos, L. F. P. (2017). Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. *International journal of production research, 55*(12), 3609-3629.
Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., et al. (2015). *IMPULS.-Industrie 4.0-Readiness*. Germany: VDMA.
Ligen, Y., and Yanjuan, Z. (2009). *Study on Evaluation Model of Construction Enterprise's Core Competence Based on Value Chain and Intellectual Capital.* Paper presented at the 2009 Second International Conference on Intelligent Computation Technology and Automation, China, 434-437.
Liu, H., Xie, D., and Wu, S. (2009). *Research Approach Measuring the Strategic Readiness of Intangible Assets.* Paper presented at the Second International Conference on Future Information Technology and Management Engineering, China, 99-103.
Liu, Y., van Nederveen, S., and Hertogh, M. (2017). Understanding effects of BIM on collaborative design and construction: An empirical study in China. *International Journal of Project Management, 35*(4), 686-698.
Love, P. E. D., and Matthews, J. (2019). The 'how' of benefits management for digital technology: From engineering to asset management. *Automation in Construction, 107*, 102930.
Lu, S.-L., and Sexton, M. (2009). *Innovation in Small Professional Practices in the Built Environment* Singapore: Wiley-Blackwell.
Luthy, D. H. (1998). Intellectual capital and its measurement. In *Proceedings of the Asian Pacific Interdisciplinary Research in Accounting Conference (APIRA)* (Vol. 1, pp. 16-17). Osaka, Japan.
Mahdiyar, A., Tabatabaee, S., Durdyev, S., Ismail, S., Abdullah, A., and Rani, W. N. M. W. M. (2019). A prototype decision support system for green roof type selection: A cybernetic fuzzy ANP method. *Sustainable cities and society, 48*, 101532.
Mahmoudkelaye, S., Azari, K. T., Pourvaziri, M., and Asadian, E. (2018). Sustainable material selection for building enclosure through ANP method. *Case Studies in Construction Materials, 9*, e00200.
Mahmud, S. H., Assan, L., and Islam, R. (2018). Potentials of internet of things (IoT) in malaysian construction industry. *Annals of Emerging Technologies in Computing, 2*(1), 44-52.
Maijanen, P. (2020). 3 Approaches from strategic management: Resource-based view, knowledge-based view, and dynamic capability view. In *Management and Economics of Communication* (Vol. 30, pp. 47-68). Berlin: De Gruyter Mouton.

Manzari, M., Kazemi, M., Nazemi, S., and Pooya, A. (2012). Intellectual capital: Concepts, components and indicators: A literature review. *Management Science Letters, 2*(7), 2255-2270.
Mardani, A., Zavadskas, E. K., Khalifah, Z., Zakuan, N., Jusoh, A., Nor, K. M., et al. (2017). A review of multi-criteria decision-making applications to solve energy management problems: Two decades from 1995 to 2015. *Renewable and Sustainable Energy Reviews, 71*, 216-256.
Maria Serena, A., Alessandro, G., and Simone, L. (2019). Disclosure on Intellectual Capital in the Age of Industry 4.0: Evidence From Italian Capital Market. *Management Studies, 7*(1), 1-14.
Martín-de-Castro, G., Delgado-Verde, M., López-Sáez, P., and Navas-López, J. E. (2011). Towards 'an intellectual capital-based view of the firm': origins and nature. *Journal of Business Ethics, 98*(4), 649-662.
Martin, B., Linick, M. E., Fraade-Blanar, L., Burns, J. G., Foran, C., Grocholski, K. R., et al. (2021). *Measuring Strategic Readiness*. Santa Monica, Calif: RAND Corporation.
Maskuriy, R., Selamat, A., Ali, K. N., Maresova, P., and Krejcar, O. (2019a). Industry 4.0 for the Construction Industry—How Ready Is the Industry? *Applied Sciences, 9*(14), 2819.
Maskuriy, R., Selamat, A., Maresova, P., Krejcar, O., and David, O. O. (2019b). Industry 4.0 for the construction industry: Review of management perspective. *Economies, 7*(3).
Mavi, R. K., and Standing, C. (2018). Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach. *Journal of cleaner production, 194*, 751-765.
McCreary, D. R. (2009). Cambridge Academic Content Dictionary. *Dictionaries: Journal of the Dictionary Society of North America, 30*(1), 151-155.
McIntosh, C. (2013). *Cambridge advanced learner's dictionary* (4th ed.). England: Cambridge University Press.
Mêda, P., Sousa, H., Gonçalves, M., Calvetti, D., Dias, P., and Camargo, F. (2020). People, Process, Technology in Construction 4.0-Balancing Knowledge, Distrust and Motivations. In *Proceeding of 37th CIB W78 Information Technology for Construction Conference (CIB W78* (pp. 1-13). São Paulo, Brazil: EasyChair.
Meng, L., Wen, K.-H., Brewin, R., and Wu, Q. (2020). Knowledge Atlas on the Relationship between Urban Street Space and Residents' Health—A Bibliometric Analysis Based on VOSviewer and CiteSpace. *Sustainability, 12*(6), 2384.
MITI. (2018). *Industry4WRD Readiness Assessment*. Retrieved. from https://www.miti.gov.my/miti/resources/National%20Policy%20on%20Industry%204.0/Industry4WRD_Booklet.pdf.
Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., and Eburdy, R. (2019). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research, 58*(5), 1384-1400.
Mohammad, H. S., Bujang, I., and Hakim, T. A. (2018). The Impact of Intellectual Capital on Financial Performance of Malaysian Construction Firms. *International Journal of Academic Research in Business and Social Sciences, 8*(5), 173-186.

Mohammadi, F. (2016). *A Decision Support System for Demolition Safety Risk Assessment.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Mohammadi, F., Nateghi, F., Pourhejazi, S. P., Abdullah, A., Gandomi, N., and Sadi, M. K. (2014a). Part deployment model using combined quality function deployment and cybernetic fuzzy analytic network process. *Indian Journal of Science & Technology, 7*(1), 53-62.

Mohammadi, F., Sadi, M. K., Nateghi, F., Abdullah, A., and Skitmore, M. (2014b). A hybrid quality function deployment and cybernetic analytic network process model for project manager selection. *Journal of Civil Engineering and Management, 20*(6), 795-809.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., and Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLOS Medicine, 6*(7), e1000097.

Momade, M. H. (2020). *Modelling Construction Labour Productivity from Labour's Characteristics.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Morkunaite, Z., Podvezko, V., Zavadskas, E. K., and Bausys, R. (2019). Contractor selection for renovation of cultural heritage buildings by PROMETHEE method. *Archives of Civil and Mechanical Engineering, 19*(4), 1056-1071.

Mousavi-Nasab, S. H., and Sotoudeh-Anvari, A. (2017). A comprehensive MCDM-based approach using TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems. *Materials & Design, 121*, 237-253.

MRT-Corp. (2019). MRT LINE 2 (SSP) UNDERGROUND WORKS. *Construction Plus, June 2019.*

Muñoz-La Rivera, F., Mora-Serrano, J., Valero, I., and Oñate, E. (2020). Methodological-Technological Framework for Construction 4.0. *Archives of Computational Methods in Engineering, 28*(2), 689-711.

Murad, M. H., Katabi, A., Benkhadra, R., and Montori, V. M. (2018). External validity, generalisability, applicability and directness: a brief primer. *BMJ evidence-based medicine, 23*(1), 17.

Muthusamy, K., and Chew, L. (2020). Critical Success Factors for the Implementation of Building Information Modeling (BIM) among Construction Industry Development Board (CIDB) G7 Contractors in the Klang Valley, Malaysia. In *2020 IEEE European Technology and Engineering Management Summit (E-TEMS)* (pp. 1-6). Dortmund, Germany: IEEE.

Nagy, J., Oláh, J., Erdei, E., Máté, D., and Popp, J. (2018). The Role and Impact of Industry 4.0 and the Internet of Things on the Business Strategy of the Value Chain—The Case of Hungary. *Sustainability, 10*(10), 3491.

Ng, S. T., Cheng, K. P., and Skitmore, R. M. (2005). A framework for evaluating the safety performance of construction contractors. *Building and environment, 40*(10), 1347-1355.

Nguyen, T. N. Q., Ngo, L. V., Northey, G., and Siaw, C. A. (2019). Realising the value of knowledge resources and capabilities: an empirical study. *Journal of Knowledge Management, 23*(2), 374-395.

Nilashi, M., Zakaria, R., Ibrahim, O., Majid, M. Z. A., Zin, R. M., and Farahmand, M. (2015). MCPCM: a DEMATEL-ANP-based multi-criteria decision-making approach to evaluate the critical success factors in construction projects. *Arabian Journal for Science and Engineering, 40*(2), 343-361.

Nimawat, D., and Gidwani, B. (2020). Prioritization of important factors towards the status of industry 4.0 implementation utilizing AHP and ANP techniques. *Benchmarking: An International Journal, 28*(2), 695-720.
Nimawat, D., and Gidwani, B. (2021). Identification of cause and effect relationships among barriers of Industry 4.0 using decision-making trial and evaluation laboratory method. *Benchmarking: An International Journal, 28*(8), 2407-2431.
Niu, Y., Lu, W., and Liu, D. (2018). RFID-Enabled Management System Adoption and Use in Construction: Passing Through the Labyrinth with an Improved Technology Acceptance Model. In *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate* (pp. 1251-1258). Singapore: Springer.
Noori, A., Bonakdari, H., Morovati, K., and Gharabaghi, B. (2018). The optimal dam site selection using a group decision-making method through fuzzy TOPSIS model. *Environment Systems and Decisions, 38*(4), 471-488.
Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in health sciences education, 15*(5), 625-632.
NVP. (2020). *Big Data and AI Executive Survey 2020: Executive Summary of Findings* o. Document Number)
Ocak, and Fındık. (2019). The Impact of Intangible Assets and Sub-Components of Intangible Assets on Sustainable Growth and Firm Value: Evidence from Turkish Listed Firms. *Sustainability, 11*(19).
Oesterreich, T. D., and Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry, 83*, 121-139.
Ogbeifun, E., Mbohwa, C., and Pretorius, J. (2016). Developing Key Performance Indicators using the Delphi technique. *FUTY Journal of the Environment, 10*(1), 27-38.
Okoli, C., and Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information & management, 42*(1), 15-29.
Okudan, O., and Budayan, C. (2020). Assessment of Project Characteristics Affecting Risk Occurrences on Construction Projects Using Fuzzy AHP. *Sigma Journal of Engineering & Natural Sciences/Mühendislik ve Fen Bilimleri Dergisi, 38*(3), 1447-1462.
Olawumi, T. O., and Chan, D. W. (2018). Critical success factors (CSFs) for amplifying the integration of BIM and sustainability principles in construction projects: a Delphi study. In *Proceedings of the RICS COBRA, Conference 2018* (Vol. 1, pp. 23-25). London, UK: RICS.
Olawumi, T. O., and Chan, D. W. (2019a). Critical success factors for implementing building information modeling and sustainability practices in construction projects: A Delphi survey. *Sustainable Development, 27*(4), 587-602.
Olawumi, T. O., and Chan, D. W. (2019b). Development of a benchmarking model for BIM implementation in developing countries. *Benchmarking: An International Journal, 26*(4), 1210-1232.
Onubi, H. O., and Hassan, A. S. (2020). Effects of green construction on project's economic performance. *Journal of Financial Management of Property and Construction, 25*(3), 331-346.

Orji, I. J., Kusi-Sarpong, S., Huang, S., and Vazquez-Brust, D. (2020). Evaluating the factors that influence blockchain adoption in the freight logistics industry. *Transportation Research Part E: Logistics and Transportation Review, 141*(102025).

Osunsanmi, T. O., Aigbavboa, C., and Oke, A. (2018a). Construction 4.0: The Future of the Construction Industry in South Africa. *International Journal of Civil and Environmental Engineering, 12*(3), 206-2012.

Osunsanmi, T. O., Aigbavboa, C., Oke, A., and Ohiomah, I. (2018b). *Construction 4.0: Towards Delivering of Sustainable Houses in South Africa.* Paper presented at the The Creative Construction Conference, Ljubljana, Slovenia.

Ozkaya, G., and Erdin, C. (2020). Evaluation of smart and sustainable cities through a hybrid MCDM approach based on ANP and TOPSIS technique. *Heliyon, 6*(10), e05052.

Ozorhon, B., and Karahan, U. (2017). Critical success factors of building information modeling implementation. *Journal of management in engineering, 33*(3), 04016054.

Oztemel, E., and Gursev, S. (2018). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing, 31*, 127-182.

Ozturk, G. B. (2007). *Managing Intellectual Capital Strategically: A Core Competence for Architectural Design Firms in Turkish Construction Sector.* Paper presented at the CIB2007.

Pacchini, A. P. T., Lucato, W. C., Facchini, F., and Mummolo, G. (2019). The degree of readiness for the implementation of Industry 4.0. *Computers in Industry, 113*, 103125.

Pallant, J. (2013). *SPSS survival manual* (5th ed.). UK: McGraw-Hill Education.

Pallant, J. (2020). *SPSS survival manual: A step by step guide to data analysis using IBM SPSS.* New York, NY: Routledge.

Patel, T., Bapat, H., Patel, D., and van der Walt, J. D. (2021). Identification of Critical Success Factors (CSFs) of BIM Software Selection: A Combined Approach of FCM and Fuzzy DEMATEL. *Buildings, 11*(7), 311.

Patrucco, A., Ciccullo, F., and Pero, M. (2020). Industry 4.0 and supply chain process re-engineering. *Business Process Management Journal, 26*(5), 1093-1119.

Perera, S., Nanayakkara, S., Rodrigo, M. N. N., Senaratne, S., and Weinand, R. (2020). Blockchain technology: Is it hype or real in the construction industry? *Journal of Industrial Information Integration, 17*, 100125.

Perrier, N., Bled, A., Bourgault, M., Cousin, N., Danjou, C., Pellerin, R., et al. (2020). Construction 4.0: a survey of research trends. *Journal of Information Technology in Construction, 25*, 416-437.

Phan, K. (2013). *Innovation measurement: A decision framework to determine innovativeness of a company.* (Ph.D Thesis). Portland state university, Portland, OR.

Poh, S. (2020). *Adoption of Drones Technology in Monitoring the Construction Progress in Malaysia.* (Final Year Project). Tunku Abdul Rahman University College, Malaysia.

Poplawska, J., Labib, A., and Reed, D. M. (2015). A hybrid multiple-criteria decision analysis framework for corporate social responsibility implementation applied to an extractive industry case study. *Journal of the Operational Research Society, 66*(9), 1491-1505.

Prakasa, Y. (2018). Influence of Intellectual Capital toward Micro Small and Medium Enterprises' (MSMEs') Performance in Malang City. *Advances in Economics, Business and Management Research, 93*, 260-263.

PwC. (2016). Industry 4.0: Building the digital enterprise. Retrieved 12/10/2019, from https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

Qin, J., Liu, Y., and Grosvenor, R. (2016). A categorical framework of manufacturing for industry 4.0 and beyond. *Procedia Cirp, 52*, 173-178.

Rabionet, S. E. (2011). How I learned to design and conduct semi-structured interviews: an ongoing and continuous journey. *Qualitative Report, 16*(2), 563-566.

Rafindadi, A. D. u., Napiah, M., Othman, I., Mikić, M., and Al-Ashmori, Y. Y. (2020). Rate of occurrence of fatal accidents in Malaysian construction industry after BIM implementation. *International Journal of Engineering and Management Research, 10*(2).

Rahimian, F. P., Seyedzadeh, S., Oliver, S., Rodriguez, S., and Dawood, N. (2020). On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning. *Automation in Construction, 110*, 103012.

Rahmandad, H., Denrell, J., and Prelec, D. (2021). What makes dynamic strategic problems difficult? Evidence from an experimental study. *Strategic Management Journal, 42*(5), 865-897.

Rakshanifar, M. (2018). *A Decision Support Model for Demolition Waste Management.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Rastogi, S. (2015). *CONSTRUCTION 4.0: New Generation Construction in a Hyper-Connected World.* Paper presented at the Indian Lean Construction Conference, India, 1-11.

Rastogi, S. (2017). *CONSTRUCTION 4.0: THE 4th GENERATION REVOLUTION.* Paper presented at the Indian Lean Construction Conference, indea.

Raval, S. J., Kant, R., and Shankar, R. (2021). Analyzing the critical success factors influencing Lean Six Sigma implementation: fuzzy DEMATEL approach. *Journal of Modelling in Management, 16*(2), 728-764.

Razi, P., Ramli, N., Ali, M., and Ramadhansyah, P. (2020). Selection of Contractor by Using Analytical Hierarchy Process (AHP). *IOP Conference Series: Materials Science and Engineering, 712*(1), 012014.

Ridgely, M. S., Ahluwalia, S. C., Tom, A., Vaiana, M. E., Motala, A., Silverman, M., et al. (2020). What Are the Determinants of Health System Performance? Findings from the Literature and a Technical Expert Panel. *The Joint Commission Journal on Quality and Patient Safety, 46*(2), 87-98.

Sa'id Kori, Itanola, M., Saka, A. B., and (2019). The Capability and Support of Structure Capital on BIM Innovation in SME. *Information and Knowledge Management, 9*(20).

Saaty, T. L. (2007). Time dependent decision-making; dynamic priorities in the AHP/ANP: Generalizing from points to functions and from real to complex variables. *Mathematical and Computer Modelling, 46*(7-8), 860-891.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences, 1*(1), 83-98.

Saaty, T. L. (2020). The SuperDecisions. Retrieved 1/8/2020, from https://www.superdecisions.com/

Sadeghi-Niaraki, A. (2020). Industry 4.0 development multi-criteria assessment: an integrated fuzzy DEMATEL, ANP and VIKOR methodology. *IEEE Access, 8*, 23689-23704.
Sadi, M. K. (2015). *A Hybrid Model for Assessing the Quality Performance of Demolition Contractors.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.
Sajesh, V. (2018). Forecasting using Delphi method: an Overview. In A. Suresh, Sajeev, M.V. and Rejula, K (Ed.), *Extension management techniques for up-scaling technology dissemination in fisheries* (pp. 188-193). Cochin: ICAR - Central Institute of Fisheries Technology.
Saka, A. B., Chan, D. W., and Siu, F. M. (2020). Drivers of sustainable adoption of building information modelling (BIM) in the Nigerian construction small and medium-sized enterprises (SMEs). *Sustainability, 12*(9), 3710.
Saldaña, J. (2021). *The coding manual for qualitative researchers* (4th ed.). London: Sage Publication Limited.
Saleh, R. M., and Al-Swidi, A. (2019). The adoption of green building practices in construction projects in Qatar: a preliminary study. *Management of Environmental Quality: An International Journal, 30*(6), 1238-1255.
Saunders, M. N. (2012). Choosing research participants. In *The Practice of Qualitative Organizational Research: Core Methods and Current Challenges.* (pp. 35-52). London: Sage.
Saunders, M. N., and Townsend, K. (2018). Choosing participants. In *The SAGE Handbook of Qualitative Business and*

Management Research Methods: History and Traditions (pp. 1-19). London: SAGE Publications Ltd
Sayyadi, R., and Awasthi, A. (2020). An integrated approach based on system dynamics and ANP for evaluating sustainable transportation policies. *International Journal of Systems Science: Operations & Logistics, 7*(2), 182-191.
Schmidt, F. L. (2012). Cognitive tests used in selection can have content validity as well as criterion validity: A broader research review and implications for practice. *International Journal of Selection and Assessment, 20*(1), 1-13.
Schönbeck, P., Löfsjögård, M., and Ansell, A. (2020). Quantitative Review of Construction 4.0 Technology Presence in Construction Project Research. *Buildings, 10*(10).
Schönberger, M., and Vasiljeva, T. (2018). Impact of the computer system validation on the firm performance of small and medium enterprises in the medical device industry. In *Proceedings of the 31st International Business Information Management Association Conference, IBIMA 2018: Innovation Management and Education Excellence through Vision 2020* (pp. 1353-1359). Milan, Italy: RISEBA.
Schreiber, R., yavar, E., and Alger, C. (2018). The Middle Market Manufacturer's Roadmap to Industry 4.0. Retrieved 26th Feb 2020, from https://www.bdo.com/insights/industries/manufacturing-distribution/the-middle-market-manufacturer-s-roadmap-to-in-(1)/the-middle-market-manufacturer-s-roadmap-to-indust
Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., and Wahlster, W. (Eds.). (2017). *Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies (acatech STUDY)*. Munich: Herbert Utz Verlag.

Schumacher, A., Erol, S., and Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia Cirp, 52*, 161-166.

Seker, S., and Zavadskas, E. K. (2017). Application of fuzzy DEMATEL method for analyzing occupational risks on construction sites. *Sustainability, 9*(11), 2083.

Sekhar, C., Patwardhan, M., and Vyas, V. (2015). A Delphi-AHP-TOPSIS Based Framework for the Prioritization of Intellectual Capital Indicators: A SMEs Perspective. *Procedia - Social and Behavioral Sciences, 189*, 275-284.

Seng, F. K. (2018). *Development of a Computer Based Green Highway Energy Efficiency Index Assessment for Malaysia.* (Ph.D Thesis). Universiti Teknologi Malaysia, Malaysia.

Sengil, G., and Duran, S. (2019). Integrated technologies, advances and benefits in Industry 4.0. *International Journal of Business Ecosystem & Strategy (2687-2293), 1*(2), 31-38.

Sevinç, A., Gür, Ş., and Eren, T. (2018). Analysis of the Difficulties of SMEs in Industry 4.0 Applications by Analytical Hierarchy Process and Analytical Network Process. *Processes, 6*(12).

Shahinmoghadam, M., and Motamedi, A. (2019). Review of BIM-centered IoT deployment: State of the Art, Opportunities, and Challenges. In *Proceedings of the 36th International Symposium on Automation and Robotics in Construction (ISARC)*. Canada.

Shahpari, M., Saradj, F. M., Pishvaee, M. S., and Piri, S. (2020). Assessing the productivity of prefabricated and in-situ construction systems using hybrid multi-criteria decision making method. *Journal of Building Engineering, 27*, 100979.

Shaik, M. N., and Abdul-Kader, W. (2014). Comprehensive performance measurement and causal-effect decision making model for reverse logistics enterprise. *Computers & Industrial Engineering, 68*, 87-103.

Sherratt, F., Dowsett, R., and Sherratt, S. (2020). Construction 4.0 and its potential impact on people working in the construction industry. In *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law* (Vol. 173, pp. 145-152). UK: ICE Publishing.

Si, S.-L., You, X.-Y., Liu, H.-C., and Zhang, P. (2018). DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. *Mathematical Problems in Engineering, 2018*, 3696457.

Singh, J., Garg, D., and Luthra, S. (2018). An Analysis of Critical Success Factors for Industry 4.0: An Application of Analytical Hierarchy Process. *Industrial Engineering Journal, 11*(9), 1-15.

Singh, R., and Bhanot, N. (2020). An integrated DEMATEL-MMDE-ISM based approach for analysing the barriers of IoT implementation in the manufacturing industry. *International Journal of Production Research, 58*(8), 2454-2476.

Sinoh, S. S., Othman, F., and Ibrahim, Z. (2020). Critical success factors for BIM implementation: a Malaysian case study. *Engineering, Construction and Architectural Management, 27*(9), 2737-2765.

Solís-Carcaño, R., Cabrera-Pérez, A., Zaragoza-Grifé, J., and González-Fajardo, J. (2018). Construction Firms' Intellectual Capital in Southeast Mexico. *Journal of Economics, Management and Trade, 21*(1), 1-11.

Son, H., Kim, C., Kim, H., Han, S. H., and Kim, M. K. (2010). Trend analysis of research and development on automation and robotics technology in the construction industry. *KSCE Journal of Civil Engineering, 14*(2), 131-139.

Sony, M., and Naik, S. (2019a). Critical factors for the successful implementation of Industry 4.0: a review and future research direction. *Production Planning & Control, 31*(10), 799-815.

Sony, M., and Naik, S. (2019b). Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking: An International Journal*.

Stachová, K., Papula, J., Stacho, Z., and Kohnová, L. (2019). External Partnerships in Employee Education and Development as the Key to Facing Industry 4.0 Challenges. *Sustainability, 11*(2), 345.

Supartono, S., Purnomo, J., Sumantri, S. H., and Krestiawan, W. (2020). Selection of Surface to Surface Rudal Kri-Kerambit Class Using DEMATEL And Analytic Network Process Methods. *International Journal of ASRO, 11*(1), 162-173.

SuperDesicions. (2020). About SuperDecisions. Retrieved 3/4/2020, from https://www.superdecisions.com/

Susanty, A., Puspitasari, N. B., Prastawa, H., and Renaldi, S. V. (2020). Exploring the best policy scenario plan for the dairy supply chain: a DEMATEL approach. *Journal of Modelling in Management, 16*(1), 240-266.

Tan, T., Chen, K., Xue, F., and Lu, W. (2019). Barriers to Building Information Modeling (BIM) implementation in China's prefabricated construction: An interpretive structural modeling (ISM) approach. *Journal of Cleaner Production, 219*, 949-959.

Tan, T., Mills, G., Papadonikolaki, E., and Liu, Z. (2021). Combining multi-criteria decision making (MCDM) methods with building information modelling (BIM): A review. *Automation in Construction, 121*, 103451.

Tavakol, M., and Dennick, R. (2011). Making sense of Cronbach's alpha. *Internationa Journal of Medical Education, 2*, 53-55.

Tayurskaya, O., Okladnikova, D., and Bibarsov, K. (2020). The factors that influence the dynamic development of the construction industry in a remote region. *IOP Conference Series: Materials Science and Engineering, 880*(1), 012104.

Tonial, G., Cassol, A., Selig, P. M., and Giugliani, E. (2019). Intellectual capital management and sustainability activities in Brazilian organizations: A case study. In *Intellectual Capital Management as a Driver of Sustainability* (pp. 119-138). Cham: Springer.

Trstenjak, M., Lisjak, D., and Opetuk, T. (2019). *Application of multi criteria decision making methods for readiness factor calculation.* Paper presented at the IEEE EUROCON 2019-18th International Conference on Smart Technologies, Novi Sad, Serbia.

Tukiainen, J. (2020). *Neural network-based framework for intelligent systems design in the context of a for-profit organization.* (Master's Thesis). LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT, Finland.

Turk, Ž. (2021). Structured analysis of ICT adoption in the European construction industry. *International Journal of Construction Management, Latest Article*, 1-7.

Tzeng, G.-H., and Huang, J.-J. (2011). *Multiple attribute decision making: methods and applications*. Boca Raton, FL: Chapman and Hall/CRC.

Ujwary-Gil, A. (2012). Intellectual Capital Statement (ICS) as a Method of a Measurement and Management of Knowledge Assets. In *Proceedings of the 13th European Conference on Knowledge Management* (pp. 1211-1222). Spain: Universidad Politécnica de Cartagena.

Ullah, F., Sepasgozar, S. M., Thaheem, M. J., Wang, C. C., and Imran, M. (2021). It's all about perceptions: A DEMATEL approach to exploring user perceptions of real estate online platforms. *Ain Shams Engineering Journal, 12*(4), 4297-4317.

Utama, D. M., Maharani, B., and Amallynda, I. (2021). Integration Dematel and ANP for The Supplier Selection in The Textile Industry: A Case Study. *Jurnal Ilmiah Teknik Industri, 20*(1), 119-130.

Uysal, G. (2019). Wealth of Nations and Intellectual Capitals: Adam Smith Approach. *Journal of Modern Accounting and Auditing, 5*(8), 411-414.

Vacek, J. (2017). On The Road: From Industry 4.0 to Society 4.0. *Západočeská univerzita v Plzni, 4*, 43-50.

Van Eck, N. J., and Waltman, L. (2013). VOSviewer manual. *Leiden: Univeristeit Leiden, 1*(1), 1-53.

Van Eck, N. J., and Waltman, L. (2014). Visualizing bibliometric networks. In *Measuring scholarly impact* (pp. 285-320). Cham: Springer.

Vásquez, J., Aguirre, S., Puertas, E., Bruno, G., Priarone, P. C., and Settineri, L. (2021). A sustainability maturity model for micro, small and medium-sized enterprises (MSMEs) based on a data analytics evaluation approach. *Journal of Cleaner Production, 311*, 127692.

Vaz, C. R., Selig, P. M., and Viegas, C. V. (2019). A proposal of intellectual capital maturity model (ICMM) evaluation. *Journal of Intellectual Capital, 20*(2), 208-234.

Viana, V. L. B., and Carvalho, M. T. M. (2021). Prioritization of risks related to BIM implementation in brazilian public agencies using fuzzy logic. *Journal of Building Engineering, 36*, 102104.

Vyas, G. S., Jha, K. N., and Patel, D. A. (2019). Development of green building rating system using AHP and fuzzy integrals: A case of India. *Journal of Architectural Engineering, 25*(2), 04019004.

Walker, A. R. (2020). How to approach shared decision making when determining consolidation, maintenance therapy, and transplantation in acute myeloid leukemia. *Hematology 2014, the American Society of Hematology Education Program Book, 2020*(1), 51-56.

Wang, C.-N., Dang, T.-T., Tibo, H., and Duong, D.-H. (2021). Assessing renewable energy production capabilities using DEA window and fuzzy TOPSIS model. *Symmetry, 13*(2), 334.

Wang, L., Yang, M., Pathan, Z. H., Salam, S., Shahzad, K., and Zeng, J. (2018). Analysis of influencing factors of big data adoption in Chinese enterprises using DANP technique. *Sustainability, 10*(11), 3956.

Wang, X., and Duan, Q. (2019). Improved AHP–TOPSIS model for the comprehensive risk evaluation of oil and gas pipelines. *Petroleum Science, 16*(6), 1479-1492.

Wątróbski, J., Jankowski, J., Ziemba, P., Karczmarczyk, A., and Zioło, M. (2019). Generalised framework for multi-criteria method selection. *Omega, 86*, 107-124.

Wheeler, S., and Cline, H. F. (2020). Research Design and Methods. In *The Scandinavian Prison Study* (pp. 19-40). Cham: Springer.

Whiting, R., and Pritchard, K. (2020). *Collecting qualitative data using digital methods*. London: Sage Publication Limited.

Wong, J. K. W., Ge, J., and He, S. X. (2018). Digitisation in facilities management: A literature review and future research directions. *Automation in Construction, 92*, 312-326.

Yanming, Q., and Weihua, F. (2009). *On AHP Model and Fuzzy Judgement in Evaluation of Construction Enterprises' Intellectual Capital.* Paper presented at the 2009 Third International Symposium on Intelligent Information Technology Application Workshops, Nanchang, China, 427-430.

Yeoh, J. K., and Jiao, R. (2019). Ontology-Based Framework for Checking the Constructability of Concrete Volumetric Construction Submodules from BIM. In *Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation* (pp. 279-285). Atlanta, Georgia: American Society of Civil Engineers Reston, VA.

Yıldızbaşı, A., and Ünlü, V. (2020). Performance evaluation of SMEs towards Industry 4.0 using fuzzy group decision making methods. *SN Applied Sciences, 2*(3), 1-13.

Yitmen, I. (2011). Intellectual Capital: A Competitive Asset for Driving Innovation In Engineering Design Firms. *Engineering Management Journal, 23*(2), 3-19.

Yoon, K., and Hwang, C.-L. (1985). Manufacturing plant location analysis by multiple attribute decision making: Part I—single-plant strategy. *International Journal of Production Research, 23*(2), 345-359.

Yoon, K. P., and Kim, W. K. (2017). The behavioral TOPSIS. *Expert Systems with Applications, 89*, 266-272.

Zhai, Y., Chen, K., Zhou, J. X., Cao, J., Lyu, Z., Jin, X., et al. (2019). An Internet of Things-enabled BIM platform for modular integrated construction: A case study in Hong Kong. *Advanced Engineering Informatics, 42*, 100997.

Zhu, X., Meng, X., and Zhang, M. (2021). Application of multiple criteria decision making methods in construction: a systematic literature review. *Journal of Civil Engineering and Management, 27*(6), 372-403.

LIST OF PUBLICATIONS

Indexed Journal

1. **Mansour, H**., Aminudin, E., & Mansour, T. (2021). Implementing industry 4.0 in the construction industry-strategic readiness perspective. *International Journal of Construction Management*,DOI: 10.1080/15623599.2021.1975351 **(WoS: ESCI, SCOPUS: Q2)**

2. **Mansour, H.**, Aminudin, E., Omar, B., Zakaria, R., Lau, S. E. N., & Al-Sarayreh, A. (2021). Industry 4.0 and construction performance: From literature review to conceptual framework. *Malaysian Construction Research Journal, Specialissue13*(2), 53-67. **(SCOPUS: Q4)**

3. **Mansour, H.**, Aminudin, E., Omar, B., Zakaria, R., & Abidin, N. I. A. (2021). Planning impact and mediations on the quality of construction projects: Case study in jordan. *Malaysian Construction Research Journal, Specialissue13*(2) , 212-228. **(SCOPUS: Q4)**

4. **Mansour, H.**, Aminudin, E., Omar, B., & Al-Sarayreh, A. (2020). Development of an impact-on-performance index (IPI) for construction projects in Malaysia: A Delphi study. *International Journal of Construction Management*. DOI:10.1080/15623599.2020.1762036. **(WoS: ESCI, SCOPUS: Q2)**

5. Alsarayreh, A. I. M., Othman, M. L. B., Abdullah, R. B., Sulaiman, A. B., Poi-Ngian, S., & **Mansour, H.** (2020). Experimental investigation on structural lightweight aggregate concrete using palm-oil clinker and expanded perlite aggregates. *Journal of Engineering Science and Technology, 15*(6), 3741-3756 **(WoS: ESCI, SCOPUS: Q3)**

Non-Indexed Journal

1. **Mansour, H.**, Aminuddin, E., Omar, B., & Zakaria, R. (2019). A Conceptual Model on Industry 4.0 and Construction Performance: Resource-Based View. *Research Journal of Applied Sciences*, 14: 454-461. DOI: 10.36478/rjasci.2019.454.461.

Indexed Conference Proceedings

1. **Mansour, H**., Aminudin, E., Mansour, T., Abdin, N.I, & Lou, E., (2021). Researce-Based View in Construction Project Management Research: A Meta-Analysis. *IOP Conference Series: Earth and Environmental Science* **(Presented in ICRMBEE20201)**

2. **Mansour, H**., Aminudin, E., Mansour, T., Abdin, N.I, & Roslan, A.F., (2021). A bibliometric Study of Industry 4.0 in Construction Industry Using Oesterriech and Teuteberg (2016) As A Key Marker. . *IOP Conference Series: Earth and Environmental Science* **(Presented in ICRMBEE20201).**

Patent & Copyright

1. "MULTI-CRITERIA DECISION-MAKING FOR 4TH CONSTRUCTION REVOLUTION USING INTELLECTUAL CAPITAL PERSPECTIVE", Team: Eeydzah Aminudin, Husam Mansour, Nur Izieadiana Abidin, Santi Lau, Fatimah Zakaria, Patent filing: LY2021E07054.