BUILDING INFORMATION MODELING ADOPTION MODEL FOR ARCHITECTURE, ENGINEERING AND CONSTRUCTION INDUSTRY IN MALAYSIA

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DEDICATION

Specially Dedicated to…

My Parent and Parents in Law
My lovely Wife
My Brothers
My Friends

My love to you will always remain and thank you for your Support, Guidance, Patience, and Joyfulness to make this experience.

I wish to express my deepest gratitude and love for my beloved family members. My father, who taught me that the best kind of knowledge to have which is learned for its own sake. To my mother who taught me love and kindness, my brothers, brothers in law and sister in law for their limitless support, encouragement and love, and to the person who make this thesis a reality and ease my PhD study, my Wife, my partner in marriage, and life. You are my everything.

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ABSTRACT

Building Information Modeling (BIM) is a modelling technology and an associated set of processes to produce, communicate, analyze, and use information models for the construction project life cycle. The BIM application developers provide a suite of BIM software that facilitates project delivery from early-stage design through to construction. The construction industry in Malaysia suffers productivity deficiency due to a lack of modern technologies such as BIM. The Malaysian construction sector is now implementing level one BIM (3D modelling with Revit and Sketch up), whereas the rest of the world is aiming towards level four or higher (4D Scheduling, 5D Costing, 6D Sustainability, and 7D Maintenance & Operation). In Malaysia, BIM adoption has been relatively unexplored, especially in Architecture, Engineering and Construction (AEC) organizations. Meanwhile, the lack of a theoretical framework is recognized as the central gap, as there are limited studies that used technology acceptance theories. Moreover, the influence of organizational, environmental, and interoperability factors on BIM adoption got limited attention in existing studies. Therefore, the purpose of this research was to empirically examine the factors that influence BIM adoption in the Malaysian AEC industry. A quantitative approach was adopted with data collection from AEC decision-makers. The survey instrument was distributed to 1,200 AEC organizations, with 552 responses obtained. After the data screening process, 279 valid answers for further analysis of the data were utilized. The proposed model's theoretical foundations were based on technology, organization, environment framework, Diffusion of Innovation theory, and European Interoperability framework. The model was tested and validated using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS software. The findings indicated that relative advantage, top management support, government support, organizational readiness, and regulation support were the drivers of BIM adoption. Financial constraints, complexity, lack of technical interoperability, semantic interoperability, and organizational interoperability were barriers to BIM adoption. Finally, this study provides implications of the essential technological, organizational, environmental, and interoperability factors that AEC stakeholders can address to enhance BIM adoption in Malaysia.

ABSTRAK

Pemodelan Maklumat Bangunan (BIM) adalah teknologi pemodelan dan satu set proses yang berkaitan untuk menghasilkan, berkomunikasi, menganalisis dan menggunakan model maklumat untuk kitaran hayat projek pembinaan. Pembangun aplikasi BIM menyediakan rangkaian perisian BIM yang memudahkan penyampaian projek dari reka bentuk peringkat awal hingga pembinaan. Industri pembinaan di Malaysia mengalami kekurangan produktiviti kerana kekurangan teknologi moden seperti BIM. Sektor pembinaan Malaysia kini melaksanakan BIM tahap satu (pemodelan 3D dengan Revit dan Sketch up), manakala seluruh dunia menyasarkan ke tahap empat atau lebih tinggi (Penjadualan 4D, kos 5D, Kelestarian 6D dan Penyelenggaraan & Operasi 7D). Di Malaysia, penggunaan BIM masih belum diterokai, terutamanya dalam organisasi Seni Bina, Kejuruteraan, dan Pembinaan (AEC). Sementara itu, kekurangan rangka kerja teori diiktiraf sebagai jurang utama, kerana terdapat kajian terhad yang menggunakan teori penerimaan teknologi. Selain itu, pengaruh faktor organisasi, persekitaran dan kesalingoperasian terhadap penggunaan BIM mendapat perhatian terhad dalam kajian sedia ada. Oleh itu, tujuan kajian ini adalah untuk mengkaji secara empirikal faktor-faktor yang mempengaruhi penggunaan BIM dalam industri AEC Malaysia. Pendekatan kuantitatif telah diterima pakai dengan pengumpulan data daripada pembuat keputusan AEC. Instrumen soal selidik ini diedarkan kepada 1200 organisasi AEC, dengan 552 maklum balas diperoleh. Selepas proses saringan data, 279 jawapan yang sah untuk analisis lanjut data telah digunakan. Asas teori model yang dicadangkan adalah berdasarkan rangka kerja teknologi, organisasi, alam sekitar, teori penyebaran inovasi dan rangka kerja kesalingoperasian Eropah. Model ini telah diuji dan disahkan menggunakan Pemodelan Persamaan Struktur Separa Kuasa Dua (PLS-SEM) dalam perisian SmartPLS. Dapatan kajian menunjukkan bahawa kelebihan relatif, sokongan pengurusan atasan, sokongan kerajaan, kesediaan organisasi, dan sokongan peraturan adalah pemacu penerimaan BIM. Kekangan kewangan, kerumitan, kekurangan kebolehoperasian teknikal, kebolehoperasian semantik dan kebolehoperasian organisasi merupakan penghalang kepada penggunaan BIM. Akhirnya, kajian ini memberi implikasi kepada faktor-faktor teknologi, organisasi, alam sekitar dan kebolehoperasian yang boleh ditangani oleh pihak berkepentingan AEC untuk meningkatkan penggunaan BIM di Malaysia.

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LIST OF ABBREVIATIONS

AEC	-	Architecture, Engineering, and Construction
BIM	-	Building Information Modelling
DOI	-	Diffusion of Innovation Theory
EIF	-	European Union Interoperability Framework
INT	-	Institutional theory
IS	-	Information System
TAM	-	Technology Acceptance Model
TOE	-	Technology Organization Environment
TPB	-	Theory of Planned Behavior
UTAUT	-	Unified Theory of Acceptance and Use of Technology
	-	

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CHAPTER 1

INTRODUCTION

1.1 Overview

The Architecture, Engineering, and Construction (AEC) industry is the national economy's backbone, contributing to domestic revenue (Saka and Chan, 2020). The construction industry comprises many stakeholders involved in building projects such as architects, project managers, quantity surveyors, facility managers, fabricators, mechanical and plumbing engineers (Bastan, Zarei and Ahmadvand, 2020). Construction is a complex activity due to stakeholders' involvement from diverse disciplines. The construction industry's significant challenges are lack of collaboration, poor design documents, delay in project delivery, cost overruns, frustrated clients, interoperability of construction software, change orders, and rework (Liu, *et al.*, 2020; Dao and Chen, 2021; Yang, *et al.*, 2021). These challenges caused low productivity in construction firms. The Malaysian AEC industry is a significant contributor to the national economy, with an investment of RM 36.3 billion. The government sector share is 45.3 %, and private sectors invested 54.7 % (DOSM, 2018). The increase in investment is due to the government's efforts to promote the construction industry. Despite this large investment, the construction industry's productivity is very low (MPCM, 2016).

To overcome the construction industry's challenges the use of Information and Communication Technologies (ICT) in the construction organization improved collaboration (Elshafey, *et al.*, 2020). ICT enabled coordination among project participants and provided data integration to graphically dispersed team members. Graphical tools such as Computer-Aided Design (CAD) provide Two-Dimensional (2D) capabilities for building design and parametric modeling. Several tools such as AutoCAD and Sketch-up provide the facility for designing 2D drawings. These tools replaced traditional architectural practices and tools with more sophisticated tools for

Three-Dimensional (3D) modelling, project costing and management, facility management, and project delivery.

Building Information Modeling (BIM) is modelling technology and associated set of process to produce, communicate, analyze and use of information models for construction project life cycle" (CIDB, 2018). The BIM application developers provide designers, engineers, and contractors a set of BIM and CAD tools supported by a cloud-based common data environment that facilitates project delivery from early-stage design through to construction. This software creates high-quality, high-performing building and infrastructure designs with conceptual and detailed design. BIM is the recent development of paradigm shift from traditional AEC delivery processes, cost reduction capabilities, increased quality, enhanced productivity, and on-time delivery. BIM facilitates managing digital representations of data throughout the whole life cycle of the building, starting from design to the building's final delivery to the stakeholders. BIM uses a shared digital representation of built environment data to facilitate the whole construction activity from design to modelling, modelling to scheduling, scheduling to estimating, and construction to deliver the project. BIM generates a methodology to manage project data in digital format throughout the building's lifecycle (ISO, 2016). The use of BIM in building projects has opened up new avenues for AEC research.

BIM is a paradigm shift from traditional 2D to 3D and provides Multi-Dimension modeling (ND). ND capabilities of BIM provide life cycle management of a construction project. BIM benefits include construction productivity, information availability and delivery, improved decision making, better risk management, competitive advantage, and market accessibility (Cemesova, Hopfe and Mcleod, 2015). However, the actual benefits of BIM are not yet realized due to the low adoption of professionals. Technology diffusion in AEC is reported low compared to other industries (Prashant, Somesh and Sree, 2016).

Current BIM adoption studies addressed the adoption barriers and drivers in the AEC industry (Chen, *et al.*, 2019; Georgiadou, 2019; Gong, *et al.*, 2019; Ma, *et al.*, 2019; Mohammad, *et al.*, 2019; Park, Kwon and Han, 2019; Akdogan, 2020; Al-

Hammadi and Tian, 2020). A study by Ahmed and Kassem (2018) developed a taxonomy of BIM drivers in the UK. Cao *et al.* (2017) discuss motivations at the individual level to adopt BIM in China's architects and identify motives in adopting BIM. However, this study is culturally specific and supports only the Chinese architectural context. Another survey by Howard, Restrepo, and Chang (2017) identified individual perceptions about BIM prevailing among UK architects. However, perceptions of small and medium design organizations are not covered. A few studies discuss BIM readiness and acceptance in design organizations and identify BIM adoption inhibitors that hinder BIM adoption at a broader scale (Ahuja, *et al.*, 2016; Juan, Lai, and Shih, 2017). Similarly, most of the studies discussed BIM adoption at the project level such as BIM implementation in a single construction project (Cao, *et al.*, 2016; Merschbrock and Nordahl-Rolfsen, 2016) and individual level such as BIM adoption by architects and engineers in individual capacity not at organizational capacity (Song, *et al.*, 2017; Hong and Yu, 2018). However, organizational-level BIM adoption studies are limited.

1.2 Problem Background

Existing studies show that technology factors influence the adoption of innovation, but also many organisational factors influence the adoption of technology (Chen, *et al.*, 2019). Organizational factors are related to inter-organizational processes, practices, and policies that affect BIM adoption. A study tested the organizational adoption of digital technologies and found that organizational culture directly influences its intention to use technologies (Yoon and George, 2013). In the implementation of BIM, organizational issues such as evolving work processes and inter-organizational relations should be considered (Gao, Li and Tan, 2013; Merschbrock and Nordahl-Rolfsen, 2016; Ahuja, *et al.*, 2018a). Although these studies offer valuable insight into organizational issues, research that explores specific organizational challenges such as organizational interoperability also remains to be accomplished.

Existing research on innovation in the building industry demonstrates that the use of technology is not only driven by the need for productivity to solve internal process problems efficiently and effectively (Toinpre, Mackee and Gajendran, 2018). It could also be impacted by external environmental pressures too. Furthermore, research on innovations in many other sectors indicates that how organizations react to external challenges is highly dependent on the characteristics of innovation and the attributes of the industry (Cao, Li and Wang, 2014). Since the construction industry relies on many external bodies, such as government and industry associations, it can affect BIM adoption (Takim, Harris and Nawawi, 2013; Ramanayaka and Venkatachalam, 2015; Babič and Rebolj, 2016; Mohammad, *et al.*, 2019). Therefore, it is vital to test the impact of environmental factors on BIM adoption.

Interoperability implies ICT systems' ability and the business processes they support to exchange data and share information and knowledge. The interoperability of BIM influences collaborative project delivery systems (Olawumi, *et al.*, 2018; Pishdad-Bozorgi, *et al.*, 2018). Such systems' information processing nature requires a broader conceptualization of interoperability to make more effective and efficient project delivery. The main barriers to adopting BIM by the market are the difficulties in interoperability among platforms (Grilo and Jardim-Goncalves, 2010; Muller, Loures and Junior, 2015). The study by Liu, Zhang and Zhang (2016) points to the interoperability problem since many engineers often adopt computational and structural modeling software with different formats from BIM and IFC standards. Existing research in the BIM domain mostly focuses on technical interoperability, such as data validation with Industry Foundation Class (IFC) (Lee, Eastman and Lee, 2015) and data integration with IFC (Matějka, *et al.*, 2016). Other studies define ontologies for mapping cross-discipline data (Lee, Eastman and Lee, 2015), use of the semantic web for enhancing data interoperability (Pauwels, Zhang and Lee, 2017), and integration of data objects in different fields (Karam, *et al.*, 2018). Few studies are addressing organizational interoperability (Zhang, *et al.*, 2017). There are limited studies conducted to find technical interoperability issues (Poirier, Forgues and Staub-French, 2014; Xu, Feng and Li, 2014; Muller, *et al.*, 2017). Similarly, organizational interoperability, semantic interoperability, and legal interoperability are yet to be explored. Therefore, it is necessary to understand interoperability factors influencing BIM adoption (Karam, *et al.*, 2018; Wong, Ge, and He, 2018; Zhu, *et al.*, 2018).

Malaysia's construction industry has a productivity deficit (CIDB, 2017). It is owing to a lack of modern methods for managing building information throughout the life cycle of construction projects (Prashant, Somesh and Sree, 2016). The Malaysian construction sector is now implementing level one BIM (3D modelling with Revit and Sketch up), whereas the rest of the world is aiming towards level four or higher. However, the current adoption rate of BIM is very low, and only 17% of design firms have adopted BIM. Other AEC firms such as engineering firms, and construction firms have yet to adopt BIM applications such as 4D Scheduling, 5D Costing, 6D Sustainability, and 7D Maintenance &Operation (Hanafi, et al., 2016). Despite the numerous benefits of BIM for construction professionals and businesses, Malaysia's adoption faces challenges. It is merely a method and technology in the eyes of construction professionals (Latiffi, Brahim and Fathi, 2017). Because of the high cost of BIM deployment, they are hesitant to invest in BIM applications (Latiffi and Tai, 2017). They're also unsure about the return on investment in BIM. BIM implementation in medium-sized businesses is easier than in small businesses. To facilitate collaboration among all project participants, self-innovation, up-to-date BIM applications, and efficient use of ICT technologies are required (Sinoh, Othman and Ibrahim, 2018).

Common adoption theories such as the Technology Acceptance Model (TAM) (Acquah, Eyiah and Oteng, 2018; Dong-Gun, Ji-Young and Song, 2018; Liu, Lu and Niu, 2018; Okakpu, *et al.*, 2019; Qi, Liu and Jupp, 2019), Institutional theory (Cao, Li and Wang, 2014; Fareed, *et al.*, 2015; Succar and Kassem, 2015; Cao, *et al.*, 2016; Ahmed, Kawalek and Kassem, 2017), and Unified Theory of Acceptance and Use of Technology (UTAUT) (Harty and Laing, 2013; Mahamadu, Mahdjoubi and Booth, 2014; Oduyemi, Okoroh and Fajana, 2017) are used in existing research to discuss individual adoption issues. The DOI and TOE are used for organizational adoption assessment. However, there are some limitations of DOI. The first limitation is that DOI does not support environmental context in adoption assessment. It does not investigate social systems according to their complexity (Parker and Castleman, 2009). Therefore there is a need for another theory for this research study. Similarly, the DOI and TOE do not cover technology adoption interoperability; therefore, EIF is combined with DOI and TOE in this research study. This research incorporates elements from the Technology Organization Environment framework, Diffusion of Innovation Theory, and European Union Interoperability framework, resulting in an integrated approach to BIM adoption issues in AEC organizations.

1.3 Problem Statement

BIM adoption will help Malaysian AEC firms cope with challenges and increase productivity (Enegbuma, et al., 2016). However, BIM adoption by AEC firms faces adoption issues in Malaysia. Existing BIM adoption studies discuss barriers in developed countries. Applying these studies' results in developing countries such as Malaysia is inappropriate as the AEC practices and proprieties are different. Also, there is limited attention to factors affecting BIM adoption. Existing studies on BIM adoption in Malaysia are limited, and the process of BIM adoption is not studied rigorously. Only a few studies have examined Malaysia's BIM adoption process (Matarneh and Hamed, 2013; Enegbuma, *et al.*, 2016) without applying information system theories. A few studies have mainly applied technology acceptance theories and frameworks to assess user perceptions and intentions to adopt BIM at the individual level (Takim, Harris and Nawawi, 2013; Enegbuma, Dodo and Ali, 2014). Limited studies discussing BIM adoption in AEC firms and BIM adoption are still unrepresented at the organizational level. A comprehensive model to address adoption issues is lacking in previous studies. Understanding the BIM adoption challenges in the Malaysian construction industry is a prerequisite to predicting the BIM adoption process. Identifying these challenges provides strategies to tackle the issues with BIM adoption. Hence, there is a need to identify the construction industry's BIM adoption challenges (CIDB, 2017). Thus, based on the above discussions, there is an urgent need to identify factors affecting BIM adoption in AEC firms in Malaysia. Therefore, this research study investigates the factors that influence BIM adoption in the AEC industry and provides strategies to policy-makers to tackle adoption challenges.

1.4 Research Questions

The main research question based on the problem stated above is "how BIM can be widely adopted in the Malaysian Architecture Engineering and Construction industry". Based on the main research question, the sub-questions are formulated:

1. What are the factors that influence BIM adoption in the AEC industry?
2. How to develop a BIM adoption model for the Malaysian AEC industry?
3. What are the implications of the important factors from the proposed model?

1.5 Research Objectives

1. To identify the factors that influence BIM adoption in the AEC.
2. To develop a BIM adoption model for the Malaysian AEC industry.
3. To investigate the implications of the important factors from the proposed model.

1.6 Scope and Limitations

This study aims to find factors that influence BIM adoption and propose a BIM adoption model. Therefore, the study's scope is only AEC firms that have adopted BIM at level 1 (3D architecture design), and data collection is done from AEC decision-makers (executives and senior managers) in Malaysia. The type of AEC firms for this research study include architectural firms, engineering firms, and construction firms. The architecture firms are composed of establishments engaged in the planning and design of residential and non-residential structures. The engineering firms perform activities such as engineering of reinforced concrete structures, steel, and wooden structures, hydraulic structures, deep excavations, and special foundations. The construction services sector includes services such as construction management, planning, and safety-related services.

1.7 The Significance of the Study

The significance of this study is twofold. In terms of theoretical contribution, this study combines elements from the Technology Organization Environment framework, Diffusion of Innovation Theory, and European Interoperability framework hence providing an integrated approach to address BIM adoption issues. Existing studies use traditional adoption theories such as TAM, Institutional theory, and UTAUT to address adoption issues. However, this study contributes to a new model for testing BIM adoption from multiple perspectives.

Concerning the study's practical contributions, the findings of the study provide guidelines to AEC stakeholders to address BIM adoption issues to enhance Malaysia's diffusion. Moreover, this analysis provides findings to practitioners to strengthen their BIM adoption process. The identified interoperability factors will help AEC professionals to improve interoperability activities, coordination, and mapping of the organizational process to make the collaborative project delivery more effective and well-informed. The findings will also help policymakers develop a roadmap to overcome interoperability obstacles. Focusing on the identified factors will help AEC professionals to improve interoperability activities, coordination, and mapping of the organizational processes to make the collaborative project delivery more effective and well-informed.

1.8 Thesis Organization

The rest of the thesis is divided into five chapters. This section provides an overview of the chapter's organization and its structures.

Chapter 2 explains a review of the literature done for this study. This chapter includes introducing the BIM domain, using BIM in the construction industry, the current status of BIM adoption in developed and developing countries, and barriers to BIM adoption. On the other hand, technology adoption in the construction industry, theories used for BIM adoption, and implementation are also discussed. Moreover, this research study performed a Systematic Literature Review (SLR) related to BIM adoption and diffusion, and the initial results are also presented in this chapter.

Chapter 3 highlights the research methodology's direction and proposed research framework. It includes selecting research frameworks such as positivism and research methods such as qualitative or quantitative data collection approaches. The research framework explains different steps to be followed for this study. These steps are problem formulation by reviewing existing literature, potential theories, and frameworks used in BIM research. The next step is to formulate research questions and objectives of the study, select the theory and framework for this study, identify factors for a research model, a pilot study for instrument validation, and data collection and analysis followed by interpretation and thesis writing.

Chapter 4 highlights the proposed research model. It includes selecting the theory and framework for this study and explaining the factors and variables chosen for the research model.

Chapter 5 discusses the data analysis results of the study. In the first section, the analysis results of the pilot study are presented. The statistical tests that are performed in data analysis are defined and explained. In the second section, the findings of the full data analysis after the revised instrument are presented. The analysis includes the measurement model and the structural model of the study. The demographic analysis of the study is also discussed. Finally, the discussion on findings after the statistical analysis is presented.

Chapter 6 discusses the achievements of the research study and conclusions. In the first section, the research objectives are discussed concerning research questions. There are three research questions for this study. The achievement of objectives is explained in detail. The next section presents the research contributions. It is followed by the research limitations and future work directions.

REFERENCES

Abanda, F. H. and Mzyece, D. (2018) 'A Study of the Potential of Cloud / Mobile BIM for the Management of Construction Projects', *Applied System Innovation*, 9(2), pp. 1–19.

Abd, A. M. and Khamees, A. S. (2017) 'As built case studies for BIM as conflicts detection and documentation tool', *Cogent Engineering*, 4(1).

Abdullah, M. R., Takim, R. and Mohammad, W. N. S. W. (2017) 'Overview of Building Information Modelling (BIM) Adoption Factors for construction organisations', IOP Conf. Series: earth and enviormental seience, (December).

Acquah, R., Eyiah, A. K. and Oteng, D. (2018) 'Acceptance of building information modelling: A survey of professionals in the construction industry in Ghana', *Journal of Information Technology in Construction*, 23(April), pp. 75–91.

Affairs, U. D. of V. (2017) *BIM Manual v 2.2*. Available at: https://www.cfm.va.gov/til/bim/BIM-Manual.pdf.

Ahmed, A. L. and Kassem, M. (2018) 'A unified BIM adoption taxonomy: Conceptual development, empirical validation and application', *Automation in Construction*, 96(September), pp. 103–127.

Ahmed, Kawalek and Kassem (2017) 'A comprehensive identification and categorisation of drivers, factors, and determinants for bim adoption: A systematic literature review', *Congress on Computing in Civil Engineering, Proceedings*, 0, pp. 220–227. doi: 10.1061/9780784480823.027.

Ahuja, R., *et al.* (2014) 'Understanding and improving project based production', in *22nd Annual Conference of the International Group for Lean Construction 2014 (IGLC 2014)*. Oslo, Norway, 25-27, p. 123.

Ahuja, R., *et al.* (2016) 'Adoption of BIM by architectural firms in India: technology–organization–environment perspective', *Architectural Engineering and Design Management*, 12(4), pp. 311–330. doi: 10.1080/17452007.2016.1186589.

Ahuja, R., *et al.* (2018a) 'Factors influencing BIM adoption in emerging markets – the case of India', International Journal of Construction Management, 3599, pp. 1–12. doi: 10.1080/15623599.2018.1462445.

Ahuja, R., *et al.* (2018b) 'Factors influencing BIM adoption in emerging markets – the case of India', *International Journal of Construction Management*, pp. 1–12. doi: 10.1080/15623599.2018.1462445.

Ahuja, R., Sawhney, A. and Arif, M. (2017) 'Driving lean and green project outcomes using BIM: A qualitative comparative analysis', *International Journal of Sustainable Built Environment*, 6(1), pp. 69–80. doi: 10.1016/j.ijsbe.2016.10.006.

Ajzen, I. (1991) 'Theory of planned behavior', *Organ. Behav. Hum. Decis. Process.*, 211, pp. 1–2. doi: 10.1037/t15668-000.

Akdogan, M. (2020) 'Trends of Building Information Modeling Adoption in the Turkish AEC Industry', in *Advances in Building Information Modeling: First Eurasian BIM Forum, EBF 2019, Istanbul, Turkey, May 31, 2019, Revised Selected Papers*, p. 3.

Akintola, A., Root, D. and Venkatachalam, S. (2017) 'Key constraints to optimal and widespread implementation of bim in the South African construction industry', in *Association of Researchers in Construction Management, ARCOM - 33rd Annual Conference 2017, Proceeding*, pp. 25–34. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85035315216&partnerID=40&md5=4a157ccba5727d8f9b752255ea8ec737.

Aksenova, G., *et al.* (2018) 'From Finnish AEC knowledge ecosystem to business ecosystem: lessons learned from the national deployment of BIM', *Construction Management and Economics*, (July). doi: 10.1080/01446193.2018.1481985.

Al-Hammadi, M. A. and Tian, W. (2020) 'Challenges and Barriers of Building Information Modeling Adoption in the Saudi Arabian Construction Industry', *The Open Construction & Building Technology Journal*, 14(1).

Aladag, H., Demirdögen, G. and Isik, Z. (2016) 'Building Information Modeling (BIM) Use in Turkish Construction Industry', in *Procedia Engineering*, pp. 174–179. doi: 10.1016/j.proeng.2016.08.520.

Alashwal, A. M. and Chew, M. Y. (2017) 'Simulation techniques for cost management and performance in construction projects in Malaysia', *Built Environment Project and Asset Management*, 7(5), pp. 534–545. doi: 10.1108/BEPAM-11-2016-0058.

Alhumayn, S., Chinyio, E. and Ndekugri, I. (2017) 'The barriers and strategies of implementing BIM in Saudi Arabia', *WIT Transactions on the Built*

Environment, 169, pp. 55–67. doi: 10.2495/BIM170061.

Ali, K. N., Mustaffa, N. E. and Enegbuma, W. I. (2016) 'Building Information Modelling (BIM) educational framework for quantity surveying students : The Malaysian perspective', *Journal of Information Technology in Construction*, 21(November), pp. 140–151.

Alreshidi, E., Mourshed, M. and Rezgui, Y. (2016) 'Requirements for cloud-based BIM governance solutions to facilitate team collaboration in construction projects', *Requirements Engineering*, 23(1), pp. 1–31. doi: 10.1007/s00766-016-0254-6.

Alreshidi, E., Mourshed, M. and Rezgui, Y. (2017) 'Factors for effective BIM governance', *Journal of Building Engineering*, 10(March), pp. 89–101. doi: 10.1016/j.jobe.2017.02.006.

Alshetewi, S., Alturise, F. and Karim, F. (2018) 'Factors Influencing Interoperability Level Required for the Implementation of T-Government in Saudi Arabia', *Computer and Information Science*, 11(2), p. 40. doi: 10.5539/cis.v11n2p40.

Amaral, D. S. and L. (2010) 'Information system interoperability in Public Administration:Identifying the Major Acting Forces through a Delphi Study', *Journal of Theoretical & Applied Electronic Commerce Research*.

Anderson, J. C. and Gerbing, D. W. (1988) 'Structural equation modeling in practice: A review and recommended two-step approach.', *Psychological bulletin*, 103(3), p. 411.

Anker Jensen, P. and Ingi Jóhannesson, E. (2013) 'Building information modelling in Denmark and Iceland', *Engineering, Construction and Architectural Management*, 20(1), pp. 99–110. doi: 10.1108/09699981311288709.

Aram, S., Eastman, C. and Sacks, R. (2013) 'Requirements for BIM platforms in the concrete reinforcement supply chain', *Automation in Construction*, 35, pp. 1–17. doi: https://doi.org/10.1016/j.autcon.2013.01.013.

Araszkiewicz, K. (2017) 'Digital technologies in Facility Management – the state of practice and research challenges', *Procedia Engineering*, 196(June), pp. 1034–1042. doi: 10.1016/j.proeng.2017.08.059.

Arayici, Y., *et al.* (2018) 'Interoperability specification development for integrated BIM use in performance based design', *Automation in Construction*, 85(November 2017), pp. 167–181. doi: 10.1016/j.autcon.2017.10.018.

Arceneaux, K. and Huber, G. A. (2007) 'What to do (and not do) with multicollinearity in state politics research', State Politics & Policy Quarterly, 7(1), pp. 81–101.

Army Corp. of Engineers (2009) *New York District US Army Corp. of Engineers official manual for building information modeling projects*. Available at: http://www.nan.usace.army.mil/Portals/37/docs/EngDiv/cenan_BIM_submission_manual.pdf.

Azadegan, A. and Teich, J. (2010) 'Effective benchmarking of innovation adoptions', *Benchmarking: An International Journal*, 17(4), pp. 472–490. doi: 10.1108/14635771011060558.

Azhar, S.; Hein, M.; Sketo, B. (2011) 'Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry', *Leadership and Management in Engineering*, 11(3), p. 241. doi: 1061/(ASCE)LM.1943-5630.0000127.

Babič, N. Č. and Rebolj, D. (2016) 'Culture change in construction industry: from 2d toward bim based construction', *Journal of Information Technology in Construction*, 21(June), pp. 86–99. doi: 10.18632/oncotarget.5527.

Baker, J. (2012) *Information Systems Theory, Springer New York Dordrecht Heidelberg London*. doi: 10.1007/978-1-4419-6108-2.

Bastan, M., Zarei, M. and Ahmadvand, A. M. (2020) 'Building Information Modeling Adoption Model in Iran', *Journal of Industrial Management Perspective*, 10(1, Spring 2020), pp. 9–39.

Boone, J. (2006) 'Competitive Pressure: The Effects on Investments in Product and Process Innovation', *The RAND Journal of Economics*, 31(3), p. 549. doi: 10.2307/2601000.

Borrego, M., Douglas, E. P. and Amelink, C. T. (2009) 'Quantitative, Qualitative, and Mixed Research Methods in Engineering Education', *Proceedings of the 34th Annual Utah Asphalt Conference*, (January). doi: 10.1002/j.2168-9830.2009.tb01005.x.

Bosch-Sijtsema, P., *et al.* (2017) 'Barriers and facilitators for BIM use among Swedish medium-sized contractors - "We wait until someone tells us to use it"', *Visualization in Engineering*, 5(1). doi: 10.1186/s40327-017-0040-7.

Boudreau, M.-C., Gefen, D. and Straub, D. W. (2001) 'Validation in Information Systems Research: A State-of-the-Art Assessment', *MIS Quarterly*, 25(1), p. 1. doi: 10.2307/3250956.

Bryde, D., Broquetas, M. and Volm, J. M. (2013) 'The project benefits of building information modelling (BIM)', *International Journal of Project Management*, 31(7), pp. 971–980. doi: 10.1016/j.ijproman.2012.12.001.

Build Laccd (2017) *LACCD Building Information Modeling Standards*. Available at: http://www.build-laccd.org/contractors-bidders/standards-guidelines.

Building and Construction Authority (2015) *BIM Particular Conditions*. Available at: https://www.corenet.gov.sg/media/1170529/bim-particular-conditions-version-2.pdf.

buildingSMART (2016) *Technical Vision - buildingSMART*. Available at: https://www.buildingsmart.org/standards/technical-vision/ (Accessed: 17 January 2019).

buildingSMART alliance (2015) 'NBIMS-US-3: 5.2 Minimum BIM', *National BIM Standard - United States - Version 3*, p. 13.

Büyükçolpan and Tol, B. panjang jalan (2019) *Risk factors for the successful implementation of the new european interoperability framework from the eu expert's perspective at the level of public administration*. Tallinn University of Technology School. Available at: https://www.bps.go.id/dynamictable/2018/05/18/1337/persentase-panjang-jalan-tol-yang-beroperasi-menurut-operatornya-2014.html.

Canadian, I. and Standards, B. I. M. (2014) *AEC (CAN) BIM Protocol*. Available at: https://raic.org/sites/raic.org/files/raic/documents/bim_explained.pdf.

Cao, D., *et al.* (2015) 'Practices and effectiveness of building information modelling in construction projects in China', *Automation in Construction*, 49(PA), pp. 113–122. doi: 10.1016/j.autcon.2014.10.014.

Cao, D., *et al.* (2016) 'Linking the Motivations and Practices of Design Organizations to Implement Building Information Modeling in Construction Projects: Empirical Study in China', *Journal of Management in Engineering*, 32(6), p. 04016013. doi: 10.1061/(ASCE)ME.1943-5479.0000453.

Cao, D., *et al.* (2017) 'Identifying and contextualising the motivations for BIM implementation in construction projectsAn empirical study in China', *International Journal of Project Management*, 35(4), pp. 658–669. doi: 10.1016/j.ijproman.2016.02.002.

Cao, D., Li, H. and Wang, G. (2014) 'Impacts of Isomorphic Pressures on BIM Adoption in Construction Projects', *Journal of Construction Engineering and Management*, 140(12), p. 04014056. doi: 10.1016/j.chemgeo.2003.12.009.

Cemesova, A., Hopfe, C. J. and Mcleod, R. S. (2015) 'PassivBIM: Enhancing interoperability between BIM and low energy design software', *Automation in Construction*, 57, pp. 17–32. doi: https://doi.org/10.1016/j.autcon.2015.04.014.

Chen, D. (2006) 'Enterprise interoperability framework', *CEUR Workshop Proceedings*, 200(January 2006). doi: 10.1.1.87.7959.

Chen, Y., *et al.* (2019) 'Adoption of building information modeling in Chinese construction industry: The technology-organization-environment framework', *Engineering, Construction and Architectural Management*. doi: 10.1108/ECAM-11-2017-0246.

Chien, K. F., Wu, Z. H. and Huang, S. C. (2014) 'Identifying and assessing critical risk factors for BIM projects: Empirical study', *Automation in Construction*, 45, pp. 1–15. doi: 10.1016/j.autcon.2014.04.012.

Chin, W. (1998) 'The Partial Least Squares Approach to Structural Equation Modeling', *Modern Methods for Business Research*, 295(2), pp. 295–336.

Chong, A. Y.-L., *et al.* (2009) 'Factors affecting the Adoption Level of C-Commerce: An Empirical Study', *Journal of Computer Information Systems*, 50(2), pp. 13–22. doi: 10.1080/08874417.2009.11645380.

CIDB (2018) *Handbook for the Implementation of Building Information Modelling in Construction Industry Transformation Programme 2016-2020*, *Construction Industry Development Board*.

CIDB Malaysia (2017) *Malaysia Building information modeling report 2016*, *Construction Industry Development Board Malaysia*. Available at: http://www.cidb.gov.my/images/content/penerbitan-IBS/BIM-REPORT.pdf (Accessed: 20 February 2019).

Ciribini, A. L. C., *et al.* (2017) 'Tracking Users' Behaviors through Real-time Information in BIMs: Workflow for Interconnection in the Brescia Smart Campus Demonstrator', in *Procedia Engineering*, pp. 1484–1494. doi: 10.1016/j.proeng.2017.04.311.

Clark, T. and Jones, R. (1999) 'Organisational interoperability maturity model for C2', *Proceedings of the Command and Control Research and Technology Symposium (CCRTS)*. doi: 10.1080/07315724.2001.10719176.

Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. Edited by ed, 2nd. United States: Lawrence Erlbaum Associates, Publishers.

Coltman, T., *et al.* (2008) 'Formative versus reflective measurement models: Two applications of formative measurement', *Journal of Business Research*, 61(12), pp. 1250–1262. doi: 10.1016/j.jbusres.2008.01.013.

Commerce Technology Administration, U. s. D. (2014) *Cost Analysis of Inadequate Interoperability in the U.s. Capital Facilities Industries*. Createspace Independent Pub. Available at: https://books.google.com.my/books?id=x6PyoAEACAAJ.

Cortina, J. M. (1993) 'What is coefficient alpha? An examination of theory and applications.', *Journal of applied psychology*, 78(1), p. 98.

Costa, G. and Madrazo, L. (2015) 'Connecting building component catalogues with BIM models using semantic technologies: an application for precast concrete components', *Automation in Construction*, 57, pp. 239–248. doi: https://doi.org/10.1016/j.autcon.2015.05.007.

Creswell, J. W. (2002) *Educational research: Planning, conducting, and evaluating quantitative*. Prentice Hall Upper Saddle River, NJ.

Creswell, J. W. (2013) 'Steps in Conducting a Scholarly Mixed Methods Study: What I am looking for core characteristics: Do you have a quantitative database? (closed- ended)', *University of Nebraska - Lincoln*, p. 54.

Creswell, J. W. (2014) *A concise introduction to mixed methods research*. Sage Publications.

Cronbach, L. J. (1951) 'Coefficient alpha and the internal structure of tests', *psychometrika*, 16(3), pp. 297–334.

Dao, T.-N. and Chen, P.-H. (2021) 'Critical Success Factors and a Contractual Framework for Construction Projects Adopting Building Information Modeling in Vietnam', *International Journal of Civil Engineering*, 19(1), pp. 85–102.

Das, T. K. (2012) 'Addressing the Influencing Factors for Interoperability in a Global Domain', *IOSR Journal of Computer Engineering*, 7(2), pp. 41–48. doi: 10.9790/0661-0724148.

Date, H., Gangwar, H. and Raoot, A. D. (2014) 'Review on IT adoption: insights from recent technologies', *Journal of Enterprise Information Management*, 27(4), pp. 488–502. doi: 10.1108/JEIM-08-2012-0047.

Davies, R. and Harty, C. (2013) 'Measurement and exploration of individual beliefs about the consequences of building information modelling use', *Construction*

Management and Economics, 31(11), pp. 1110–1127. doi: 10.1080/01446193.2013.848994.

Davis, F. D. (1989) 'Perceived Usefulness , Perceived Ease of Use , and User Acceptance of Information Technology', *Management Information Systems Research Center*, 13(3), pp. 319–340. doi: 10.1155/2013/591796.

Dedrick, J. and West, J. (2004) 'An exploratory study into open source platform adoption', in *Proceedings of the 37th Hawaii International Conference on System Sciences - 2004*, p. 10 pp. doi: 10.1109/hicss.2004.1265633.

DeLone, W. H. and McLean, E. . (1992) 'Information systems Success:The quest for the Dependent Variables', *Information Systems Research*, 64(42), pp. 823–824. doi: 10.1287/isre.3.1.60.

DOSM; Malaysia (2018) Department of Statistics Malaysia Official Portal. Available at: https://www.dosm.gov.my/v1/index.php?r=column/pdfPrev&id =RmpwV3lVVVtemdIdHYyKzdZT2dvQT09 (Accessed: 20 February 2019).

DeSanctis, G. and Poole, M. S. (1994) 'Capturing the Complexity in Advanced Technology Use: Adaptive Structuration Theory', *Organization Science*, 5(2), pp. 121–147. doi: 10.1287/orsc.5.2.121.

Desbien, A. L. (2017) 'Using BIM capabilities to improve existing building energy modelling practices', *Engineerinng construction and architectural managment*, 21(1), pp. 16–33. doi: 10.3130/jaabe.15.279.

Díaz, H., *et al.* (2017) 'Multidisciplinary Design Optimization through process integration in the AEC industry: Strategies and challenges', *Automation in Construction*, 73, pp. 102–119. doi: https://doi.org/10.1016/j.autcon.2016.09.007.

Ding, L. and Xu, X. (2014) 'Application of cloud storage on BIM life-cycle management', *International Journal of Advanced Robotic Systems*, 11(1). doi: 10.5772/58443.

Ding, Z. (2015) 'Key factors for the BIM adoption by architects : a China study', *Engineerinng construction and architectural managment*, (71202101). doi: 10.1108/ECAM-04-2015-0053.

Dong-Gun, L., Ji-Young, P. and Song, S.-H. (2018) 'BIM-Based Construction Information Management Framework for Site Information Management', *Advances in Civil Engineering*, 2018, p. 14. doi: http://dx.doi.org/10.1155/2018/5249548.

Dong, B., O'Neill, Z. and Li, Z. (2014) 'A BIM-enabled information infrastructure for building energy Fault Detection and Diagnostics', *Automation in Construction*, 44(null), pp. 197–211. doi: 10.1016/j.autcon.2014.04.007.

Dong, R. R. and Martin, A. (2017) 'Research on barriers and government driving force in technological innovation of architecture based on BIM', *Eurasia Journal of Mathematics, Science and Technology Education*, 13(8), pp. 5757–5763. doi: 10.12973/eurasia.2017.01025a.

Dossick, C. S. and Neff, G. (2010) 'Organizational Divisions in BIM-Enabled Commercial Construction', *Journal of Construction Engineering and Management*, 136(4), pp. 459–467. doi: 10.1061/(ASCE)CO.1943-7862.0000109.

Drazin, R. (1991) *The processes of technological innovation*, *The Journal of Technology Transfer*. doi: 10.1007/BF02371446.

Eadie, R., *et al.* (2013) 'BIM implementation throughout the UK construction project lifecycle: An analysis', Automation in Construction, 36, pp. 145–151. doi: 10.1016/j.autcon.2013.09.001.

Eadie, R., *et al.* (2015) 'A survey of current status of and perceived changes required for BIM adoption in the UK', *Built Environment Project and Asset Management*, 5(1), pp. 4–21. doi: 10.1108/BEPAM-07-2013-0023.

Elshafey, A., *et al.* (2020) 'Technology acceptance model for Augmented Reality and Building Information Modeling integration in the construction industry.', *ITcon*, 25, pp. 161–172.

Enegbuma, W. I., *et al.* (2016) 'Confirmatory strategic information technology implementation for building information modelling adoption model', *Journal of Construction in Developing Countries*, 21(2), pp. 113–129. doi: 10.21315/jcdc2016.21.2.6.

Enegbuma, W. I., Dodo, Y. A. and Ali, K. N. (2014) 'Building Information Modelling Penetration Factors in Malaysia', *International Journal of Advances in Applied Sciences (IJAAS)*, 3(1), pp. 47–56. Available at: http://iaesjournal.com/online/index.php/IJAAS.

Englund, E. and Grönlund, M. (2018) *Current Legal Problems and Risks with BIM in the Swedish AEC Industry*. STOCKHOLM, SWEDEN.

Euisoon, A. and Kim, M. (2016) 'BIM Awareness and Acceptance by Architecture Students in Asia', *Journal of Asian Architecture and Building Engineering*.

EIF, European Commission (2004) *An interoperability framework for Pan-European E-Government Services (PEGS)*. doi: 10.1109/HICSS.2007.68.

EIF, European and Commission (2017) *New European Interoperability Framework*. doi: 10.2799/78681.

Fan, S. L., *et al.* (2018) 'A critical review of legal issues and solutions associated with building information modelling', *Technological and Economic Development of Economy*, 24(5), pp. 2098–2130. doi: 10.3846/tede.2018.5695.

Fareed, N., *et al.* (2015) 'The influence of institutional pressures on hospital electronic health record presence', *Social Science & Medicine*, 133, pp. 28–35.

Farghaly, K., *et al.* (2017) 'BIM for asset management: A taxonomy of non-geometric BIM data for asset management', in *Digital Proceedings of the 24th EG-ICE International Workshop on Intelligent Computing in Engineering 2017*, pp. 96–105. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85026801747&partnerID=40&md5=c221361152828a8892fac974fb9c119d.

Farghaly, K., *et al.* (2018) 'Taxonomy for BIM and Asset Management Semantic Interoperability', *Journal of Management in Engineering*, 34(4). doi: 10.1061/(ASCE)ME.1943-5479.0000610.

Fishbein, M. and Ajzen, I. (1975) *Belief, attitude, intention, and behavior: an introduction to theory and research*. Edited by null. (null). Available at: https://people.umass.edu/aizen/f&a1975.html.

Fornell and Larcker (1981a) 'J. Cha (1994),"Partial Least Squares,"' *Advances Methods of Marketing Research*. Cambridge, MA: Blackwell Publishers, pp. 52–78.

Fornell and Larcker (1981b) 'Structural equation models with unobservable variables and measurement error: Algebra and statistics'. Sage Publications Sage CA: Los Angeles, CA.

Fuchs, S. (2005) 'Organizational Adoption Models for Early ASP Technology Stages. Adoption and Diffusion of Application Service Providing (ASP) in the Electric Utility Sector', (November).

G.David Garson (2016) *Partial Least Squares: regression & Structural Equation Models*. Statistical Assosiates Blue Book Series. doi: 10.3726/978-3-0353-0280-6/8.

Gallaher, M. P., *et al.* (2004) 'Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry'. doi: 10.6028/NIST.GCR.04-867.

Gao, H., Yu, M. and Liu, H. (2013) 'De-normalize IFC model for data extraction', in *AEI 2013: Building Solutions for Architectural Engineering - Proceedings of the 2013 Architectural Engineering National Conference*, pp. 467–475. doi: 10.1061/9780784412909.045.

Gao, J., Li, M. and Tan, C. Y. (2013) 'A Concept model for Innovation Diffusion in Construction Industry', *International Conference on Innovations in Engineering and Technology*, pp. 262–266. Available at: https://iieng.org/siteadmin/upload/1215E1213582.pdf.

Gao, Q. and Feng, C. (2016) 'Branding with social media: User gratifications, usage patterns, and brand message content strategies', *Computers in Human Behavior*, 63, pp. 868–890.

Gao, S., Krogstie, J. and Siau, K. (2011) 'Developing an instrument to measure the adoption of mobile services', *Mobile Information Systems*, 7(1), pp. 45–67. doi: 10.3233/MIS-2011-0110.

Gefen, D. and Straub, D. (2005) 'A practical guide to factorial validity using PLS-Graph: Tutorial and annotated example', *Communications of the Association for Information systems*, 16(1), p. 5.

Georgia Institute of Technology (2016) *Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors*.

Georgiadou, M. C. (2019) 'An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects', *Construction Innovation*, 19(3), pp. 298–320. doi: 10.1108/CI-04-2017-0030.

Giel, B. K. and Issa, R. R. A. (2013) 'Return on Investment Analysis of Using Building Information Modeling in Construction', *Journal of Computing in Civil Engineering*, 27(5), pp. 511–521. doi: 10.1061/(ASCE)CP.1943-5487.0000164.

Glanville, N. (2013) 'Building information modeling (bim): a potential for effective building industry practice in malaysia', *Jurnal Teknologi*, 15(January), pp. 81–92.

Golzarpoor, H. (2010) *Applicatio of BIM in sustainability analisis*. Universiti Teknologi Malaysia, Faculty of Civil Engineering. Available at: http://civil.utm.my/ethesis/files/MASTERS/DSM/S10/Application-Of-Bim-In-Sustainability-Analysis-—-Hamed-Golzarpoor.pdf.

Gong, P., *et al.* (2019) 'An Empirical Study on the Acceptance of 4D BIM in EPC

Projects in China', *Sustainability (Switzerland)*, 11(5), pp. 1–19. doi: 10.3390/su11051316.

Gourlis, G. and Kovacic, I. (2017) 'Building Information Modelling for analysis of energy efficient industrial buildings – A case study', *Renewable and Sustainable Energy Reviews*, 68, pp. 953–963. doi: 10.1016/j.rser.2016.02.009.

Grant, M. P. and Mohd-Nor, M. F. . (2014) 'Building Information Modelling (BIM) in the Malaysian Architecture Industry', *WSEAS Transactions on Environment and Development*, 10(May), pp. 264–273.

Grilo, A. and Jardim-Goncalves, R. (2010) 'Value proposition on interoperability of BIM and collaborative working environments', *Automation in Construction*, 19(5), pp. 522–530. doi: 10.1016/j.autcon.2009.11.003.

Guo, Y. and Manatunga, A. K. (2009) 'Measuring agreement of multivariate discrete survival times using a modified weighted kappa coefficient', *Biometrics*, 65(1), pp. 125–134.

Gupta, A., *et al.* (2014) 'A conceptual framework to support solar PV simulation using an open-BIM data exchange standard', *Automation in Construction*, 37(2), pp. 166–181. doi: 10.1016/j.autcon.2013.10.005.

Hair, J. F. (2009) *Multivariate data analysis*. Upper Saddle River, NJ: Pearson Prentice Hall.

Hair, J. F., *et al.* (2013) *A Primer on Partial Least Squares Structural Equation Modeling, SAGE Publications Ltd.* SAGE Publications Ltd. doi: 10.1016/j.lrp.2013.01.002.

Hamid, A. B., *et al.* (2018) 'The Barriers and Causes of Building Information Modelling Usage for Interior Design Industry', in *IOP Conference Series: Materials Science and Engineering*. doi: 10.1088/1757-899X/291/1/012002.

Hanafi, M. H., *et al.* (2016) 'Organisational readiness of building information modelling implementation: Architectural practices', *Jurnal Teknologi*, 78(5), pp. 121–126. doi: 10.11113/jt.v78.8265.

Harty, J. and Laing, R. (2013) 'Facilitating meaningful collaboration in architectural design through the adoption of BIM (Building Information Modelling)', in *Proceedings of the 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2013*, pp. 502–508. doi: 10.1109/CSCWD.2013.6581013.

Heap-Yih Chong (2015) 'The Outlook of Building Information Modeling for

Sustainable Development Heap-Yih Chong1 and Xiangyu Wang2,3 1School', *1School of Built Environment, WA 6845, Australia*, pp. 6–8. doi: 10.3233/978-1-61499-456-5-50.

Herbert Kubicek, Ralf Cimander Hans, J. S. (2012) *Organizational Interopebality in E-government*, *Foreign Affairs*. doi: 10.1017/CBO9781107415324.004.

Herr, C. M. and Fischer, T. (2018) 'BIM adoption across the Chinese AEC industries: An extended BIM adoption model', *Journal of Computational Design and Engineering*, pp. 1–6. doi: 10.1016/j.jcde.2018.06.001.

Hinkin, T. R., Tracey, J. B. and Enz, C. A. (1997) 'Scale Construction : Developing Reliable and Valid Measurement Instruments Scale Construction : Developing Reliable and Valid Measurement Instruments'. doi: 10.1177/109634809702100108.

Hong, S. H. and Yu, J. H. (2018) 'Identification of external variables for the Technology Acceptance Model(TAM) in the assessment of BIM application for mobile devices', *IOP Conference Series: Materials Science and Engineering*, 401(1). doi: 10.1088/1757-899X/401/1/012027.

Hosseini, M. R., *et al.* (2016) 'BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model', *Construction Economics and Building*, 16(3), p. 71. doi: 10.5130/AJCEB.v16i3.5159.

Howard, R., Restrepo, L. and Chang, C. Y. (2017) 'Addressing individual perceptions: An application of the unified theory of acceptance and use of technology to building information modelling', *International Journal of Project Management*, 35(2), pp. 107–120. doi: 10.1016/j.ijproman.2016.10.012.

Howell, S., *et al.* (2016) 'Semantic interoperability for holonic energy optimization of connected smart homes and distributed energy resources', in *eWork and eBusiness in Architecture, Engineering and Construction - Proceedings of the 11th European Conference on Product and Process Modelling, ECPPM 2016*, pp. 259–268. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85016613199&partnerID=40&md5=8b7a39786b1f84aff44dc44eb00b9244.

Hu, Z. Z., *et al.* (2016) 'Improving interoperability between architectural and structural design models: An industry foundation classes-based approach with web-based tools', *Automation in Construction*, 66, pp. 29–42. doi: 10.1016/j.autcon.2016.02.001.

Ifinedo, P. (2011) 'Internet/e-business technologies acceptance in Canada's SMEs: An exploratory investigation', *Internet Research*, 21(3), pp. 255–281. doi: 10.1108/10662241111139309.

Indiana University Architect's Office (2012) *Indiana University Building Information Modeling (BIM) Guidelines and Standards for Architects, Engineers, and Contractors*. Available at: http://www.indiana.edu/~uao/iubim.html.

Isikdag, U., *et al.* (2007) 'Investigating the role of building information models as a part of an integrated data layer: A fire response management case', *Architectural Engineering and Design Management*, 3(2), pp. 124–142. doi: 10.1080/17452007.2007.9684636.

ISO (2016) *ISO 29481-1:2016 - Building information models -- Information delivery manual -- Part 1: Methodology and format*. Available at: https://www.iso.org/standard/60553.html (Accessed: 17 January 2019).

Jeyaraj, A., Rottman, J. W. and Lacity, M. C. (2006) 'A review of the predictors, linkages, and biases in IT innovation adoption research', *Journal of Information Technology*, 21(1), pp. 1–23. doi: 10.1057/palgrave.jit.2000056.

Jiang, S., *et al.* (2017) 'A literature review of the factors limiting the application of BIM in the construction industry AU - Sun, Chengshuang', *Technological and Economic Development of Economy*, 23(5), pp. 764–779. doi: 10.3846/20294913.2015.1087071.

Jin, R., *et al.* (2017) 'BIM Investment, Returns, and Risks in China's AEC Industries', *Journal of Construction Engineering and Management*, 143(12), p. 04017089. doi: 10.1061/(ASCE)CO.1943-7862.0001408.

Juan, Y.-K., Lai, W.-Y. and Shih, S.-G. (2017) 'Building information modeling acceptance and readiness assessment in Taiwanese architectural firms', *Journal of Civil Engineering and Management*, 23(3), pp. 356–367. doi: 10.3846/13923730.2015.1128480.

Kamel, E. and Memari, A. M. (2019) 'Review of BIM ' s application in energy simulation : Tools , issues , and solutions', *Automation in Construction*, 97(October 2018), pp. 164–180. doi: 10.1016/j.autcon.2018.11.008.

Karam, K., *et al.* (2018) 'Integration of ifc objects and facility management work information using Semantic Web', *Automation in Construction*, 87(November 2016), pp. 173–187. doi: 10.1016/j.autcon.2017.12.019.

Karlshøj, J. and Coordinator, I. D. M. (2013) 'Contractual arrangement Status Part 2

Interaction framework'.

Kassem, M. and Succar, B. (2017) 'Macro BIM adoption: Comparative market analysis', *Automation in Construction*, 81(May), pp. 286–299. doi: 10.1016/j.autcon.2017.04.005.

Ke Chen, *et al.* (2015) 'Bridging BIM and Building: From litrature review to an integrated conceptual framework', *International Journal of Project Management*, 33(6), pp. 1405–1416.

Kenley, R., Harfield, T. and Behnam, A. (2016) 'BIM Interoperability Limitations: Australian and Malaysian Rail Projects', in *MATEC Web of Conferences*. doi: 10.1051/matecconf/20166600102.

Kim, *et al.* (2018) 'Computers in Human Behavior Exploring Determinants of Semantic Web Technology Adoption from IT Professionals ' Perspective : Industry Competition , Organization Innovativeness , and Data Management Capability', *Computers in Human Behavior*, 86, pp. 18–33. doi: 10.1016/j.chb.2018.04.014.

Kim, H. and Anderson, K. (2013) 'Energy Modeling System Using Building Information Modeling Open Standards', *Journal of Computing in Civil Engineering*, 27(3), pp. 203–211. doi: 10.1061/(ASCE)CP.1943-5487.0000215.

Kim, J. I., *et al.* (2016) 'Integration of BIM and GIS for formal representation of walkability for safe routes to school programs', *KSCE Journal of Civil Engineering*, 20(5), pp. 1669–1675. doi: 10.1007/s12205-015-0791-4.

Kim, S. B. (2014) 'Assessment of CII Best Practices usage in the construction industry', *KSCE Journal of Civil Engineering*, 18(5), pp. 1228–1238. doi: 10.1007/s12205-014-0221-z.

Kim, S., Park, C. H. and Chin, S. (2016) 'Assessment of BIM acceptance degree of Korean AEC participants', *KSCE Journal of Civil Engineering*, 20(4), pp. 1163–1177. doi: 10.1007/s12205-015-0647-y.

Klein, H. K. and Myers, M. D. (1999) 'A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems', *MIS Quarterly*, 23, pp. 67–94.

Koo, B., Shin, B. and Lee, G. (2017) 'A cost-plus estimating framework for BIM related design and engineering services', *KSCE Journal of Civil Engineering*, 21(7), pp. 2558–2566. doi: 10.1007/s12205-017-1808-y.

Kothari, C. . (2004) *Research Methodology Methods and Techniques*. second. India: New aga international limited. Available at: https://documents.pub/document/research-methodology-by-crkothari.html.

Latiffi, A. A., *et al.* (2013) 'Building Information Modeling (BIM) Application in Malaysian Construction Industry', *International Journal of Construction Engineering and Management*, 2(June 2014), pp. 1–6. doi: 10.5923/s.ijcem.201309.01.

Latiffi, A. A., Brahim, J. and Fathi, M. S. (2016) 'Transformation of Malaysian Construction Industry with Building Information Modelling (BIM)', *MATEC Web of Conferences*, 66, p. 00022. doi: 10.1051/matecconf/20166600022.

Latiffi, A. A., Brahim, J. and Fathi, M. S. (2017) 'Building information modelling (BIM) after ten years: Malaysian construction players' perception of BIM', *IOP Conference Series: Earth and Environmental Science*, 81(1). doi: 10.1088/1755-1315/81/1/012147.

Latiffi, A. A. and Tai, N. H. (2017) 'Exploring developers' understanding on Building Information Modelling (BIM) and its impact on Return on Investment (ROI)', in *International Conference on Research and Innovation in Information Systems, ICRIIS*, pp. 1–5. doi: 10.1109/ICRIIS.2017.8002494.

Lee, C. K., Yiu, T. W. and Cheung, S. O. (2018) 'Understanding Intention to Use Alternative Dispute Resolution in Construction Projects : Framework Based on Technology Acceptance Model', *J. Leg. Aff Dispute Resolut. Eng. Constr*, 10(1), pp. 1–12. doi: 10.1061/(ASCE)LA.1943-4170.0000245.

Lee, G., Sacks, R. and Eastman, C. M. (2006) 'Specifying parametric building object behavior (BOB) for a building information modeling system', *Automation in Construction*, 15(6), pp. 758–776. doi: https://doi.org/10.1016/j.autcon.2005.09.009.

Lee, S. and Yu, J. (2017) 'Discriminant model of BIM acceptance readiness in a construction organization', *KSCE Journal of Civil Engineering*, 21(3), pp. 555–564. doi: 10.1007/s12205-016-0555-9.

Lee, S., Yu, J. and Jeong, D. (2015) 'BIM Acceptance Model in Construction Organizations', *Journal of Management in Engineering*, 31(3), p. 04014048. doi: 10.1061/(ASCE)ME.1943-5479.0000252.

Lee, Y.-C., Eastman, C. M. and Lee, J.-K. (2015) 'Validations for ensuring the interoperability of data exchange of a building information model', *Automation* *in Construction*, 58, pp. 176–195. doi: https://doi.org/10.1016/j.autcon.2015.07.010.

Lee, Y.-C., Eastman, C. M. and Solihin, W. (2016) 'An ontology-based approach for developing data exchange requirements and model views of building information modeling', *Advanced Engineering Informatics*, 30(3), pp. 354–367. doi: https://doi.org/10.1016/j.aei.2016.04.008.

Lee, Y.-C., Eastman, C. M. and Solihin, W. (2018) 'Logic for ensuring the data exchange integrity of building information models', *Automation in Construction*, 85, pp. 249–262. doi: https://doi.org/10.1016/j.autcon.2017.08.010.

Lee, Y., Eastman, C. M. and Solihin, W. (2020) 'Rules and validation processes for interoperable BIM data exchange', *Journal of Computational Design and Engineering*, 0(June), pp. 1–18. doi: 10.1093/jcde/qwaa064.

Leinbach, T. R. (2008) 'Global E-Commerce: Impacts of National Environment and Policy', *The Information Society*, 24(2), pp. 123–125. doi: 10.1080/01972240701883989.

Liu, D., Lu, W. and Niu, Y. (2018) 'Extended Technology-Acceptance Model to Make Smart Construction Systems Successful', *Journal of Construction Engineering and Management*, 144(6), pp. 1–9. doi: 10.1061/(ASCE)CO.1943-7862.0001487.

Liu, Z.-Q., Zhang, F. and Zhang, J. (2016) 'The building information modeling and its use for data transformation in the structural design stage', *Journal of Applied Science and Engineering*, 19(3), pp. 273–284. doi: 10.6180/jase.2016.19.3.05.

Liu, Z., *et al.* (2020) 'Leveraging micro-level building information modeling for managing sustainable design: United Kingdom experience', *Advances in Civil Engineering*, 2020.

Love, P. E. D., *et al.* (2011) 'Design error reduction: toward the effective utilization of building inform', *Research in Engineering Design*, 22(3), p. 173.

Love, P. E. D., *et al.* (2014) 'A benefits realization management building information modeling framework for asset owners', *Automation in Construction*, 37, pp. 1–10. doi: 10.1016/j.autcon.2013.09.007.

Low, C., Chen, Y. and Wu, M. (2011) 'Understanding the determinants of cloud computing adoption', *Industrial Management and Data Systems*, 111(7), pp. 1006–1023. doi: 10.1108/02635571111161262.

Ma, G., *et al.* (2019) 'Interpretive structural model based factor analysis of BIM adoption in Chinese construction organizations', *Sustainability (Switzerland)*, 11(7). doi: 10.3390/su11071982.

Mahalingam, A., Yadav, A. K. and Varaprasad, J. (2015) 'Investigating the Role of Lean Practices in Enabling BIM Adoption: Evidence from Two Indian Cases', *Journal of Construction Engineering and Management*, 141(7), p. 5015006.

Mahamadu, A. M., Mahdjoubi, L. and Booth, C. (2013) 'Challenges to bim-cloud integration: Implication of security issues on secure collaboration', in *Proceedings of the International Conference on Cloud Computing Technology and Science, CloudCom*, pp. 209–214. doi: 10.1109/CloudCom.2013.127.

Mahamadu, A., Mahdjoubi, L. and Booth, C. (2014) 'Determinants of Building Information Modelling (BIM) acceptance for supplier integration: A conceptual model', in *Proceedings 30th Annual ARCOM Conference. Portsmouth: Association of Researchers in Construction Management, 2014.*, pp. 723–732.

Mamter, S., Abdul-Aziz, A. R. and Mamat, M. E. (2017) 'Stimulating a Sustainable Construction through Holistic BIM Adoption: The Root Causes of Recurring Low BIM Adoption in Malaysia', *IOP Conference Series: Materials Science and Engineering*, 216(1). doi: 10.1088/1757-899X/216/1/012056.

Manderson, A., Jefferies, M. and Brewer, G. (2015a) 'Building Information Modelling and Standardised Construction Contracts: a Content Analysis of the GC21 Contract', *Construction Economics and Building*, 15(3), pp. 72–84. doi: 10.5130/ajceb.v15i3.4608.

Manderson, A., Jefferies, M. and Brewer, G. (2015b) 'Building Information Modelling and Standardised Construction Contracts: a Content Analysis of the GC21 Contract', *Construction Economics and Building*, 15(3), p. 72. doi: 10.5130/AJCEB.v15i3.4608.

Matarneh, R. and Hamed, S. (2017) 'Barriers to the Adoption of Building Information Modeling in the Jordanian Building Industry', *Open Journal of Civil Engineering*, pp. 325–335. doi: 10.4236/ojce.2017.73022.

Matarneh, R. T. and Hamed, S. A. (2013) 'Exploring the Adoption of Building Information Modeling (BIM) in the Malaysian Construction Industry:A qualitative approach', *Journal of Architectural Engineering Technology*, 06(01). doi: 10.4172/2168-9717.1000189.

Matějka, P., *et al.* (2016) 'The Integration of BIM in Later Project Life Cycle Phases in Unprepared Environment from FM Perspective', *Procedia Engineering*, 164, pp. 550–557. doi: 10.1016/J.PROENG.2016.11.657.

McArthur, J. J. (2015) 'A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability', *Procedia Engineering*, 118, pp. 1104–1111. doi: https://doi.org/10.1016/j.proeng.2015.08.450.

Merschbrock, C. and Munkvold, B. E. (2015) 'Effective digital collaboration in the construction industry - A case study of BIM deployment in a hospital construction project', *Computers in Industry*, 73, pp. 1–7. doi: 10.1016/j.compind.2015.07.003.

Merschbrock, C. and Nordahl-Rolfsen, C. (2016) 'BIM technology acceptance among reinforcement workers - The case of oslo airport's terminal 2', *Journal of Information Technology in Construction*, 21(March), pp. 1–12.

Miettinen, R. and Paavola, S. (2014) 'Beyond the BIM utopia: Approaches to the development and implementation of building information modeling - 1-s2.0-S0926580514000612-main.pdf', *Automation in Construction*, 43(null), p. 84. Available at: http://ac.els-cdn.com/S0926580514000612/1-s2.0-S0926580514000612-main.pdf?_tid=a26173d0-8f64-11e5-86a4-00000aab0f01&acdnat=1448009988_fbec5690544e561abcab75d6521c9678.

Migilinskas, D., *et al.* (2013) 'The Benefits, Obstacles and Problems of Practical Bim Implementation - 1-s2.0-S1877705813008308-main.pdf', *Procedia Engineering*, 57(null), p. 767. doi: 10.1016/j.proeng.2013.04.097.

MITI Malaysia (2018) *Ministry of International Trade and Industry*. Available at: https://www.miti.gov.my/index.php/pages/view/industry4.0?mid=559 (Accessed: 20 February 2019).

Mohammad, W. N. S. W., *et al.* (2019) 'Technology-Organisation-Environment Framework for Building Information Modelling (BIM) Adoption Challenges for Contractor's Organisations in Malaysia', *Journal of Computational and Theoretical Nanoscience*, 16(5–6), pp. 2282–2288.

Mohsenijam, A. and Lu, M. (2016) 'Achieving Sustainable Structural Steel Design by Estimating Fabrication Labor Cost Based on BIM Data', in *Procedia Engineering*, pp. 654–661. doi: 10.1016/j.proeng.2016.04.056.

Morgan, M. G. (1983) 'Inside the black box: Technology and economics, by Nathan

Rosenberg. New York: Cambridge University Press, 1982, 344 pp. Price: $29.95 cloth, $12.95 paper', *Journal of Policy Analysis and Management*, 3(1), pp. 156–157. doi: 10.2307/3324062.

MPCM; Malaysia (2016) Malaysia Productivity Corporation (MPC). Available at: http://www.mpc.gov.my/ (Accessed: 20 February 2019).

Muguira, J. A. (2003) 'The Levels of Conceptual Interoperability Model', in *2003 Fall Simulation Interoperability Workshop*.

Muller, M. F., *et al.* (2017) 'Data interoperability assessment though IFC for BIM in structural design–a five-year gap analysis', *Journal of Civil Engineering and Management*, 23(7), pp. 943–954. doi: 10.3846/13923730.2017.1341850.

Muller, M. F., Loures, E. R. and Junior, O. C. (2015) 'Interoperability Assessment for Building Information Modelling', *Proceedings of the 3rd International Conference on Mechatronics, Robotics and Automation*, (Icmra). doi: 10.2991/icmra-15.2015.45.

Mustaffa, N. E., Salleh, R. M. and Ariffin, H. L. B. T. (2017) 'Experiences of Building Information Modelling (BIM) adoption in various countries', in *2017 International Conference on Research and Innovation in Information Systems (ICRIIS)*. IEEE, pp. 1–7. doi: 10.1109/ICRIIS.2017.8002508.

National BIM Standard - United States (2012) 'National BIM Standard - United States Version 2', *Nbims-Us*, p. 182. doi: 10.1016/S0040-4039(01)82124-9.

NATSPEC Construction Information (2016) *NATSPEC National BIM Guide v1.0*. Australia. Available at: www.natspec.com.au.

Netemeyer, R. G., Bearden, W. O. and Sharma, S. (2003) *Scaling procedures: Issues and applications*. Sage Publications.

Niknam, M. and Karshenas, S. (2015) 'Sustainable Design of Buildings using Semantic BIM and Semantic Web Services', in *Procedia Engineering*, pp. 909–917. doi: 10.1016/j.proeng.2015.08.530.

Niknam, M. and Karshenas, S. (2017) 'A shared ontology approach to semantic representation of BIM data', *Automation in Construction*, 80, pp. 22–36. doi: 10.1016/j.autcon.2017.03.013.

Nunnally, J. C. (1994) *Psychometric theory 3E*. Tata McGraw-hill education.

Oduyemi, O., Okoroh, M. I. and Fajana, O. S. (2017) 'The application and barriers of BIM in sustainable building design', *Journal of Facilities Management*, 15(1), pp. 15–34. doi: 10.1108/JFM-03-2016-0008.

Okakpu, A., *et al.* (2018) 'A proposed framework to investigate effective BIM adoption for refurbishment of building projects', *Architectural Science Review*, 61(6), pp. 467–479. doi: 10.1080/00038628.2018.1522585.

Okakpu, A., *et al.* (2019) 'Exploring the environmental influence on BIM adoption for refurbishment project using structural equation modelling', *Architectural Engineering and Design Management*, pp. 1–17. doi: 10.1080/17452007.2019.1617671.

Olawumi, T. O., *et al.* (2018) 'Barriers to the Integration of BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts', *Journal of Building Engineering*, 20(January), pp. 60–71. doi: doi.org/10.1016/j.jobe.2018.06.017.

Oliveira, T., Thomas, M. and Espadanal, M. (2014) 'Assessing the determinants of cloud computing adoption: An analysis of the manufacturing and services sectors', *Information and Management*, 51(5), pp. 497–510. doi: 10.1016/j.im.2014.03.006.

Orlikowski, W. J. and Baroudi, J. J. (1991) 'Studying information technology in organizations: Research approaches and assumptions', *Information Systems Research*, 2(1), pp. 1–28. doi: 10.1287/isre.2.1.1.

Parasuraman, A. and Colby, C. L. (2015) 'An Updated and Streamlined Technology Readiness Index: TRI 2.0', *Journal of Service Research*, 18(1), pp. 59–74. doi: 10.1177/1094670514539730.

Park, E., Kwon, S. J. and Han, J. (2019) 'Antecedents of the adoption of building information modeling technology in Korea', *Engineering, Construction and Architectural Management*, 26(8), pp. 1735–1749. doi: 10.1108/ECAM-04-2018-0174.

Park, Y., Son, H. and Kim, C. (2012) 'Investigating the determinants of construction professionals' acceptance of web-based training: An extension of the technology acceptance model', *Automation in Construction*, 22, pp. 377–386. doi: 10.1016/j.autcon.2011.09.016.

Pauwels, P., Strobbe, T. and De Meyer, R. (2015) 'Analysing how constraints impact architectural decision-making', *International Journal of Design Sciences and Technology*, 21(1), pp. 83–111.

Pauwels, P., Zhang, S. and Lee, Y. (2017) 'Semantic web technologies in AEC industry: A literature overview', *Automation in Construction*, 73, pp. 145–165.

doi: 10.1016/j.autcon.2016.10.003.

Pishdad-Bozorgi, P., *et al.* (2018) 'Planning and developing facility management-enabled building information model (FM-enabled BIM)', *Automation in Construction*, 87(February 2017), pp. 22–38. doi: 10.1016/j.autcon.2017.12.004.

Plume, J., *et al.* (2017) 'Proposal for an Open Data Model Schema for Precinct-scale Information Management', in *Procedia Engineering*, pp. 822–831. doi: 10.1016/j.proeng.2017.04.243.

Poirier, E., Forgues, D. and Staub-French, S. (2014) 'Dimensions of Interoperability in the AEC Industry', in *Construction Research Congress 2014*, pp. 1987–1996. doi: 10.1061/9780784413517.203.

Polit, D. F. and Beck, C. T. (2006) 'The content validity index: are you sure you know what's being reported? Critique and recommendations', *Research in nursing & health*, 29(5), pp. 489–497.

Porwal, A. and Hewage, K. N. (2013) 'Building Information Modeling (BIM) partnering framework for public construction projects', *Automation in Construction*, 31, pp. 204–214. doi: 10.1016/j.autcon.2012.12.004.

Prashant, G., Somesh, K. and Sree, R. (2016) *Which Industries Are the Most Digital and Why*, *Harward Buisniess review*. Available at: https://hbr.org/2016/04/a-chart-that-shows-which-industries-are-the-most-digital-and-why (Accessed: 18 January 2019).

Premkumar, G. and Roberts, M. (1999) 'Adoption of new information technologies in rural small businesses', *Omega*, 27(4), pp. 467–484. doi: 10.1016/S0305-0483(98)00071-1.

Protasius Ipinge (2017) 'Proposing an E-Governance Interoperability Framework for Nambia', *Talinn University of Technology*. Available at: https://digi.lib.ttu.ee/i/file.php?DLID=8710&t=1.

Qi, C. A., Liu, L. and Jupp, J. (2019) 'China's AEC industry and BIM adoption challenges: Understanding the influence of positive and negative mindsets', in *Proceedings of 22nd International Conference on Advancement of Construction Management and Real Estate, CRIOCM 2017*, pp. 1050–1057.

Ramanayaka, C. D. D. and Venkatachalam, S. (2015) 'Reflection on BIM Development Practices at the Pre-maturity', in *Procedia Engineering*, pp. 462–470. doi: 10.1016/j.proeng.2015.10.092.

Redmond, A., *et al.* (2012) 'Exploring how information exchanges can be enhanced through Cloud BIM', *Automation in Construction*, 24, pp. 175–183. doi: 10.1016/j.autcon.2012.02.003.

Reuters (2018) *Building Information Modeling (BIM) Market 2018: Global Demand, Sales, Production, Supply, Manufacturers, Competitive Development - Reuters*. Available at: https://www.reuters.com/brandfeatures/venture-capital/article?id=34655 (Accessed: 3 March 2019).

Rezgui, Y., Beach, T. and Rana, O. (2013) 'A Governance Approach for Bim Management Across Lifecycle and Supply Chains Using Mixed-Modes of Information Delivery', *Journal of Civil Engineering and Management*, 19(2), pp. 239–258. doi: 10.3846/13923730.2012.760480.

Ringle, C. M. (2004) 'Gütemaße für den Partial-least-squares-Ansatz zur Bestimmung von Kausalmodellen'. Univ. Hamburg, Inst. für Industriebetriebslehre und Organisation~.... Available at: https://www.econbiz.de/archiv/hh/uhh/iindustrie/guetemasse_pls-ansatz_kausalmodelle.pdf.

Rogers, E. M. (1983) *Diffusion of innovations*. 3rd edn. Edited by Press, F.

Rogers, E. M. (2003) *Diffusion of innovations*. Fifth. New York, 551.: Free press.

Rogers, E. M. and York, N. (1995) *Diffusion of Innovations*. 4th edn, *New York: The Free Press*. 4th edn. The Free Press. doi: citeulike-article-id:126680.

Rogers, J., Chong, H. Y. and Preece, C. (2015) 'Adoption of Building Information Modelling technology (BIM): Perspectives from Malaysian engineering consulting services firms', *Engineering, Construction and Architectural Management*, 22(4), pp. 424–445. doi: 10.1108/ECAM-05-2014-0067.

Russell, S. M., *et al.* (2016) 'Measuring and Evaluating Interoperability for Complex C2 Information Management System-of-Systems', *21st International Command and Control Reserch and Technology Symposium*, pp. 1–16. Available at: https://static1.squarespace.com/static/53bad224e4b013a11d687e40/t/57d6995f893fc0cb7a12e334/1473681759965/paper_64.pdf.

Sabri, S. M., *et al.* (2015) 'A comparative study on it outsourcing models for Malaysian SMEs e-business transformation', *ARPN Journal of Engineering and Applied Sciences*, 10(23), pp. 17863–17870.

Sacks, R., Gurevich, U. and Shrestha, P. (2016) 'A Review of Building Information

Modeling Protocols, Guides and Standards for Large Construction Clients', *Journal of Information Technology in Construction*, 21, pp. 479–503.

Saka, A. B. and Chan, D. W. M. (2020) 'Profound barriers to building information modelling (BIM) adoption in construction small and medium-sized enterprises (SMEs)', *Construction Innovation*.

Salahshour, M., Nilashi, M. and Dahlan, H. (2017) 'Information technology adoption: a review of the literature and classification', *Universal Access in the Information Society*, 17(2), pp. 361–390. doi: 10.1007/s10209-017-0534-z.

Scott, R. W. (2004) 'Institutional Theory: Contributing to a Theoretical Research Program". Chapter prepared for Great Minds in Management: The Process of Theory Development, Smith, K. G. & Hitt, M. A.', (January 2005).

Seed, L. S. (2015) 'The Dynamics of BIM Adoption : A Mixed Methods Study of BIM as an Innovation within the United Kingdom Construction Industry', *Thesis*, 1(May).

Sekaran, U. and Bougie, R. (2013) 'Edisi 6', *Research Methods for Business*.

Senate Properties (2012) *Common BIM Requirements*. Finland. Available at: http://www.en.buildingsmart.kotisivukone.com/3.

Shibeika, A. and Harty, C. (2015) 'Diffusion of digital innovation in construction: a case study of a UK engineering firm', *Construction Management and Economics*, 33(5–6), pp. 453–466. doi: 10.1080/01446193.2015.1077982.

Simonen, J. and McCann, P. (2008) 'Innovation, R&D cooperation and labor recruitment: Evidence from Finland', *Small Business Economics*, 31(2), pp. 181–194. doi: 10.1007/s11187-007-9089-3.

SBCA, Singapore Building and Construction Authority (2012) *Singapure BIM Guide Version 1.0*. Available at: https://www.corenet.gov.sg/media/586135/Singapore_BIM_Guide_Version_1.pdf.

Sinoh, S. S., Othman, F. and Ibrahim, Z. (2018) 'Factors affecting success and difficulty to adopt Building Information Modelling (BIM) among construction firms in Sabah and Sarawak', *IOP Conference Series: Materials Science and Engineering*, 431(8). doi: 10.1088/1757-899X/431/8/082012.

Smith and Edgar (2008) *Building Information Modeling (BIM) | WBDG - Whole Building Design Guide*. Available at: http://www.wbdg.org/building-information-modeling-bim (Accessed: 22 January 2019).

Sodangi, M., Salman, A. F. and Saleem, M. (2018) 'Building Information Modeling: Awareness Across the Subcontracting Sector of Saudi Arabian Construction Industry', *Arabian Journal for Science and Engineering*, 43(4), pp. 1807–1816. doi: 10.1007/s13369-017-2756-z.

Son, H., *et al.* (2014) 'The Adoption of Building Information Modeling in the Design Organization: An Empirical Study of Architects in Korean Design Firms', *31st International Symposium on Automation and Robotics in Construction and Mining, (ISARC 2014)*, (Isarc), pp. 194–201. Available at: http://www.iaarc.org/publications/2014_proceedings_of_the_31st_isarc_sydney_australia/the_adoption_of_building_information_modeling_in_the_design_organization-an_empirical_study_of_architects_inkorean_design_firms.html.

Son, H., Lee, S. and Kim, C. (2015) 'What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions', *Automation in Construction*, 49(PA), pp. 92–99. doi: 10.1016/j.autcon.2014.10.012.

Song, J., *et al.* (2017) 'Exploring the Influence of System Quality, Information Quality, and External Service on BIM User Satisfaction', *Journal of Management in Engineering*, 33(6), p. 04017036. doi: 10.1061/(ASCE)ME.1943-5479.0000549.

Staden, S. Van and Mbale, J. (2012) 'The Information Systems Interoperability Maturity Model (ISIMM): Towards Standardizing Technical Interoperability and Assessment within Government', *Information Engineering and Electronic Business*, 5(5), pp. 36–41. doi: 10.5815/ijieeb.2012.05.05.

Statsbygg, B. (2019) *Statsbygg bim-manual 2.0 (SBM2)*. Available at: https://www.statsbygg.no/.

Stone, M. (1974) 'Cross-validation and multinomial prediction', *Biometrika*, 61(3), pp. 509–515.

Succar, B. (2014) 'Building Information Modelling Maturity Matrix', in *Building Information Modeling and Construction Informatics: Concepts and Technologies*. Building Information Modelling Maturity Matrix (chapter) by Bilal Succar, Nov 09 P 8 of 50 Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies, pp. 65–103. doi: 10.4018/978-1-60566-928-1.ch004.

Succar, B. and Kassem, M. (2015) 'Macro-BIM adoption: Conceptual structures', Automation *in Construction*, 57, pp. 64–79. doi: 10.1016/j.autcon.2015.04.018.

Succar, B. and Kassem, M. (2016) 'Building Information Modelling : Point of Adoption', in *CIB World Conference*, p. 162. doi: http://dx.doi.org/10.1016/j.autcon.2015.04.018.

Sulehat, N. A. and Taib, D. C. A. (2016) 'E-Government Information Systems Interoperability in Developing Countries', *Journal of Business and Social Review in Emerging Economies*, 2(1), pp. 49–60. doi: 10.26710/jbsee.v2i1.18.

Takim, R., Harris, M. and Nawawi, A. H. (2013) 'Building Information Modeling (BIM): A New Paradigm for Quality of Life Within Architectural, Engineering and Construction (AEC) Industry', *Procedia - Social and Behavioral Sciences*, 101, pp. 23–32. doi: 10.1016/j.sbspro.2013.07.175.

The British Standards, I. (2019) *Little Book of BIM*. France. Available at: https://www.bsigroup.com/globalassets/localfiles/fr-fr/construction/bim/bsi-little-book-of-bim.pdf.

The National 3D-4D-BIM Program, O. of the and Chief Architect, P. B. S. (2007) *GSA Building Information Modeling Guide Series 01 – Overview*. Available at: https://www.gsa.gov/cdnstatic/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf.

The Ohio state university (2019) *Building Information Modeling (BIM) Project Delivery Standards*. Available at: https://www.aiacolumbus.org/ohio-states-bim-project-delivery-standard/.

Thong, J. Y. L. (1999) 'An Integrated Model of Information Systems Adoption in Small Businesses', *Journal of Management Information Systems*, 15(4), pp. 187–214. doi: 10.1080/07421222.1999.11518227.

Toinpre, O., Mackee, J. and Gajendran, T. (2018) 'A Framework for Understanding the Influence of Isomorphic Pressures on Governance of Disaster Risks', *Procedia Engineering*, 212, pp. 173–180. doi: https://doi.org/10.1016/j.proeng.2018.01.023.

Tommasi, C. and Achille, C. (2017) 'Interoperability matter: Levels of data sharing, starting from a 3D information modelling', in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, pp. 623–630. doi: 10.5194/isprs-archives-XLII-2-W3-623-2017.

Törmä, S. (2013) 'Semantic linking of building information models', in *Proceedings - 2013 IEEE 7th International Conference on Semantic Computing, ICSC 2013*, pp. 412–419. doi: 10.1109/ICSC.2013.80.

Tornatzky and Fleischer (1990) *The Processes of Technological Innovation.* Lexington Books, Lexington.

Tripathi, R., Gupta, M. and Bhattacharya, J. (2012) 'Selected aspects of interoperability in one-stop government portal of India', *Indian Institute of Technology* ..., pp. 1–11. Available at: https://www.csi-sigegov.org/2/1_414_2.pdf.

Tripathi, R., Gupta, M. P. and Bhattacharya, J. (2013) 'Effect of organizational factors on interoperability adoption for Indian portals', *Transforming Government: People, Process and Policy*, 7(3), pp. 285–308. doi: 10.1108/TG-10-2012-0009.

Tsai, M.-C., Lai, K.-H. and Hsu, W.-C. (2013) 'A study of the institutional forces influencing the adoption intention of RFID by suppliers', *Information & Management*, 50(1), pp. 59–65.

Turk, Ž. (2020) 'Interoperability in Construction – Mission Impossible?', *Developments in the Built Environment*, p. 100018. doi: 10.1016/j.dibe.2020.100018.

UKBIMA (2016) *BIM in the UK: past, present & future*. Available at: http://www.ukbimalliance.org/media/1050/ukbima_bimreview_past_present_future_20161019-1.pdf.

University, B. city (2014) *BIM stakeholders.* Available at: http://blogs.bcu.ac.uk/bsbe/what-does-the-i-in-bim-mean/ (Accessed: 3 March 2019).

Urbach, N. and Ahlemann, F. (2010) 'Structural equation modeling in information systems research using partial least squares', *Journal of Information Technology Theory and Application*, 11(2), pp. 5–40.

USC, C. C. D. and F. M. S. (2012) *University of Southern California Building Information Modeling (BIM) Guidelines version 1.6 For Design Bid Build Contracts.* Available at: http://facilities.usc.edu/uploads/documents/cas/BIMGuidelines_VS1_6_2012.pdf.

Venkatesh., *et* al. (2003) 'User Acceptance of Information Technology: Toward a

Unified View', *MIS Quarterly*, 27(3), p. 425. doi: 10.2307/30036540.

Venugopal, M., Eastman, C. M. and Teizer, J. (2015) 'An ontology-based analysis of the industry foundation class schema for building information model exchanges', *Advanced Engineering Informatics*, 29(4), pp. 940–957. doi: 10.1016/j.aei.2015.09.006.

Vishal and Holmström (2015) 'Needs and technology adoption : observation from BIM experience', *Engineering, Construction and Architectural Management*, 22(2). doi: 10.1108/ECAM-09-2014-0124.

Volk, R., Stengel, J. and Schultmann, F. (2014) 'Corrigendum to "Building Information Modeling (BIM) for existing buildings — Literature review and future needs"', *Automation in Construction*, 43, p. 204. doi: 10.1016/j.autcon.2014.02.010.

Wang, S.-J., Liu, S.-F. and Wang, W.-L. (2008) 'The simulated impact of RFID-enabled supply chain on pull-based inventory replenishment in TFT-LCD industry', International *Journal of Production Economics*, 112(2), pp. 570–586.

Weber, R. H. (2014) 'Legal Interoperability as a Tool for Combatting Fragmentation', *Global Commission on Internet Governance Paper Series*, 4(December), pp. 1–20.

Werts, C. E., Linn, R. L. and Jöreskog, K. G. (1974) 'Intraclass reliability estimates: Testing structural assumptions', *Educational and Psychological measurement*, 34(1), pp. 25–33.

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, pp. 312–326. doi: 10.1016/j.autcon.2018.04.006.

Wu, C., *et al.* (2017) 'Overview of Bim Maturity Measurement Tools', *Journal of Information Technology in Construction*, 22, pp. 34–62.

Wu, L. and Chen, J.-L. (2014) 'A stage-based diffusion of IT innovation and the BSC performance impact: A moderator of technology--organization--environment', *Technological Forecasting and Social Change*, 88, pp. 76–90.

Wu, Y. W., *et al.* (2016) 'An integrated BIM and cost estimating blended learning model - acceptance differences between experts and novice', *Eurasia Journal of Mathematics,* Science *and Technology Education*, 12(5), pp. 1347–1363. doi: 10.12973/eurasia.2016.1517a.

Xu, H., Feng, J. and Li, S. (2014) 'Users-orientated evaluation of building information model in the Chinese construction industry', *Automation in Construction*, 39, pp. 32–46. doi: 10.1016/j.autcon.2013.12.004.

Yang, A., *et al.* (2021) 'Adopting Building Information Modeling (BIM) for the Development of Smart Buildings: A Review of Enabling Applications and Challenges', *Advances in Civil Engineering*, 2021.

Yang, Q. Z. and Zhang, Y. (2006) 'Semantic interoperability in building design: Methods and tools', *Computer-Aided Design*, 38(10), pp. 1099–1112. doi: https://doi.org/10.1016/j.cad.2006.06.003.

Yin, R. K. (2017) *Case study research and applications: Design and methods*. 6th edn. Edited by Corporation, C. Sage publications. Available at: https://uk.sagepub.com/en-gb/eur/case-study-research-and-applications/book250150.

Yoon, T. E. and George, J. F. (2013) 'Why aren't organizations adopting virtual worlds?', *Computers in Human Behavior*, 29(3), pp. 772–790. doi: 10.1016/j.chb.2012.12.003.

Young, R. and Jordan, E. (2008) 'Top management support: Mantra or necessity?', *International Journal of Project Management*, 26(7), pp. 713–725. doi: 10.1016/j.ijproman.2008.06.001.

Yusuf, B. Y., Ali, K. N. and Embi, M. R. (2016) 'Building Information Modeling as a Process of Systemic Changes for Collaborative Education in Higher Institution', *Procedia - Social and Behavioral Sciences*, 219, pp. 820–827. doi: 10.1016/j.sbspro.2016.05.072.

Yusuf, B. Y., Embi, M. R. and Ali, K. N. (2017) 'Academic readiness for building information modelling (BIM) integration to Higher Education Institutions (HEIs) in Malaysia', in *International Conference on Research and Innovation in Information Systems, ICRIIS*, pp. 1–6. doi: 10.1109/ICRIIS.2017.8002491.

Zhang, J., *et al.* (2017) 'A multi-server information-sharing environment for cross-party collaboration on a private cloud', *Automation in Construction*, 81, pp. 180–195. doi: 10.1016/j.autcon.2017.06.021.

Zhang, L., Wang, G. and Liu, H. (2014) 'The development trend and government policies of open BIM in China', in *Proceedings of the 17th International Symposium on* Advancement *of Construction Management and Real Estate*, pp. 981–993. doi: 10.1007/978-3-642-35548-6_101.

Zhenhua, L., Qingfei, M. and Shaobo, J. (2008) 'A comprehensive review of research in IT adoption', *2008 International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2008*, pp. 1–5. doi: 10.1109/WiCom.2008.2808.

Zhu, J., *et al.* (2018) 'A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level', *Isprs international journal of geo-information*, 7(2). doi: 10.3390/ijgi7020066.

Zikmund, W., *et al.* (2013) *Business Research Methods*. 9th edn. United States: Cengage Learning. doi: 10.1093/embo-reports/kvf016.

LIST OF PUBLICATIONS

Hafiz Muhammad Faisal Shehzad , Roliana Binti Ibrahim , Ahmad Fadhil Yusof, Khairul Anwar Mohamed khaidzir, Muhammad Iqbal, Saad Razzaq. The Role of Interoperability Dimensions in Building Information Modelling. Computers in Industry **(2021).** Computers in Industry **(ISI)**

Shehzad, H.M.F., Ibrahim, R.b., Yusof, A.F., Mohamed khaidzir, K.A., Shawkat, S. and Ahmad, S., (**2020**). Recent developments of BIM adoption based on categorization, identification and factors: a systematic literature review. International. *Journal of Construction Management,* pp.1-13. **(Scopus)**

Hafiz Muhammad Faisal Shehzad, Roliana Ibrahim, AHMAD FADHIL YUSOF, Khairul Anwar Mohamed khaidzir, Israr Ghani, Abba Kyari Buba. Factors Influencing the Interoperability of Building Information Modeling in Architecture, Engineering and Construction Industry. The 12th International Conference on Internet (**ICONI 2020**)

Hafiz Muhammad Faisal Shehzad, Roliana Binti Ibrahim, Ahmad Fadhil Yusof, Khairul Anwar Mohamed Khaidzir, Omayma Husain Abbas Hassan, Samah Abdelsalm Abdalla, The Evolution of Technology Adoption Theories in Building Information Modelling Research, 5th International Conference of Reliable Information and Communication Technology 2020 **(IRICT 2020)**

Hafiz Muhammad Faisal Shehzad, Roliana Binti Ibrahim, Ahmad Fadhil Yusof, Khairul Anwar Mohamed Khaidzir, Muhammad Mahboob Khurshid and Farah Zeehan Othman, Building Information Modelling Adoption Model for Malaysian Architecture, Engineering and Construction Industry, 5th International Conference of Reliable Information and Communication Technology 2020 **(IRICT 2020)**

Shehzad, H.M.F., Ibrahim, R.B., Yusof, A.F. and Khaidzir, K.A.M., **2019**, December. Building Information Modeling: Factors Affecting the Adoption in the AEC Industry. In 2019 6th International Conference on Research and Innovation in Information Systems (ICRIIS) (pp. 1-6). IEEE.

Understanding the determinants of Building Information Modelling **(Under review)**