DIGITAL TOOLS IN MALAYSIA AND CHINA TOWARDS CONSTRUCTION INDUSTRY REVOLUTION

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DEDICATION

This project report is dedicated to my parents, who always support me and love me unconditionally, who taught me that where there is a will, there is a way.

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ABSTRACT

The unprecedented, exponential pace of change in every industry has caused an undergoing change especially on collaborative platforms and transformation of digitalization. However, the construction industry seems to be quite slow for the digitization compared to other industries. Incongruent with the large-scale construction industry, the productivity of this industry has lagged behind. Therefore, the aim of this study is to assess the status and adoption of digital tools (DTs) in the architecture, engineering and construction (AEC) industry for Malaysia and China, whereby three (3) objectives has been carried out which covers the adoption level, challenges of DTs adoption and the impacts on adoption to develop relationship analysis model for DTs in this industry. Additionally, questionnaire surveys were distributed to developer, architects, engineers, contractors in Malaysia and China. Total 62 valid responses were received from respondents to be analyzed through Content Analysis, Principle component Analysis (PCA) and Structural Equation Modelling (SEM). The results obtained suggests that the status of DTs adoption in Malaysia and China is still at a low level compared to developed countries. The major challenges are managing change to new technology, lack of cyber security of digital tools outcomes, extra cost for training and convenience increasing profession's laziness. Moreover, the benefits of communication, management have a positive impact on future trend of management and profit; There is positive relationship between people related challenges and communication benefits; Productivity benefit has a significant relationship on assistance related future trend. People related challenges does give an impact on the relationship towards the success of the communication benefits. In order to drive the communication benefits, its import to cater the management as future trend to transform the success of DTs.

ABSTRAK

Perubahan yang mendadak dalam setiap industri telah menyebabkan berlakunya perubahan terutama pada platform kolaborasi dan transformasi digitalisasi. Walau bagaimanapun, pendedahan dan pelaksanaan pendigitan dalam industri pembinaan dilihat lebih perlahan berbanding dengan industri lain. Produktiviti industri pembinaan telah ketinggalan akibat ketidaksesuaian pendigitan dengan industri pembinaan yang berskala besar. Oleh itu, tujuan kajian ini adalah untuk menilai status dan adaptasi penggunaan alat digital (DT) dalam industri seni bina, kejuruteraan dan pembinaan (AEC) bagi negara Malaysia dan China. Di mana tiga (3) objektif telah dilaksanakan yang meliputi tahap adopsi, cabaran-cabaran adopsi DT dan kesan adopsi untuk mengembangkan model analisis hubungan DT dalam industri ini.. Selain itu, tinjauan soal selidik telah diedarkan kepada pemaju, arkitek, jurutera, kontraktor di Malaysia dan China. Sebanyak 62 respons telah diterima daripada responden untuk dianalisis melalui Analisis Kandungan, Analisis Komponen Prinsip (PCA) dan Pemodelan Persamaan Struktur (SEM). Hasil yang diperoleh menunjukkan bahawa status penggunaan DT di Malaysia dan China masih pada tahap yang rendah berbanding dengan negara maju. Cabaran utama adalah pengurusan perubahan teknologi baru, kekurangan keselamatan siber daripada hasil alat digital, kos tambahan untuk latihan dan kemudahan meningkatkan kemalasan profesion. Tambahan lagi, faedah komunikasi, pengurusan mempunyai kesan positif terhadap trend pengurusan dan keuntungan masa depan; Terdapat hubungan positif antara cabaran yang berkaitan dengan manusia dan faedah komunikasi; Manfaat produktiviti mempunyai hubungan yang signifikan terhadap trend masa depan yang berkaitan dengan bantuan. Cabaran yang berkaitan dengan manusia memberi kesan kepada hubungan ke arah kejayaan faedah komunikasi. Untuk mendorong faedah komunikasi, impornya untuk memenuhi pengurusan sebagai trend masa depan untuk mengubah kejayaan DT.

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LIST OF ABBREVIATIONS

3D	-	Three Dimensional
BIM	-	Building Information Modeling
AR	-	Augmented Reality
VR	-	Virtual Reality
MR	-	Mixed Reality
CC	-	Cloud Computing
UAV	-	Unmanned Aircraft Vehicle
GIS	-	Geographic Information System
AEC	-	Architecture Engineering and Construction
DTS	-	Digital Tools
ICTS	-	Information and Communication Technologies
MGI	-	Mckinsey Global Institute
ERP	-	Enterprise Resources Planning
PCA	-	Principle Component Analysis
KMO	-	Kaiser-Meyer-Olkin
CB	-	Communication Benefits
MB	-	Management Benefits
PB	-	Productivity Benefits
TC	-	Technical Challenges
LC	-	Legal Challenges
PC	-	People Related Challenges
CC	-	Cost Related Challenges
MFT	-	Management Related Future Trend
PFT	-	Profit Related Future Trend
AFT	-	Assistance Related Future Trend
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The Architecture, Engineering and Construction (AEC) industry plays an essential role in most countries (Sepasgozar & Davis, 2019; Statista, 2015). According to the data of the National Bureau of Statistics of China in 2018, the total output of the construction industry is 23.5 trillion yuan, 6.9% of the total GDP. Meanwhile, source shows that the value of construction done of RM36.1 billion in the third quarter of 2019, 4.7% of total GDP from Malaysia's Official Statistics. Construction industry has been suffering setbacks in time, cost and quality. Especially, high cost is an inevitable issue in this industry (Agarwal et. al., 2016; Statista, 2019). Obviously, the high productivity means high return and low cost (Kasih, et. al., 2019). However, according to statistics by McKinsey Global Institute, 2017, the productivity of construction industry has actually stagnated. Thus, it is extremely urgent to consider how to improve the productivity of construction industry. Hashim et al. (2013) indicated that using digital technologies and digital tools (DTs) is an effective way for construction industry to save the productivity.

Productivity generally refers to the ratio of work input to output, which is the key issue for every industry because it is able to bring more output under the smaller input to get more power of benefits and competition (Sahar, 2002). The survival of enterprises depends on productivity. The company has been in low productivity, it may be eliminated by the society (Carreira & Teixeira, 2011). Only when efficiency goes

up, the company can achieve the maximum output to maximize the benefits with the least investment (Nguyen, 2015). Productivity is important for AEC industry, however, as presented above that the productivity of this industry has not performed its potential (Barbosa et. al., 2017).

Digital technology has been defined by Hamelink (1997) as a process called Information and Communication Technologies (ICTs) that enable capturing, storage, processing, transportation, displaying and communication of information between human beings and electronic systems. With the extension and evolution of the digital technology, the AEC industry has also been changed in some extent. However, construction industry has constantly been considered as low-technology industry compared with other industries (Maskuriy, et. al.). Nowadays, the Industry 4.0 is arrived (The Working Group Industry 4.0 of the German government, 2013). As a part of Industry 4.0, this is an opportunity for the construction industry to keep up with the technological development of the times. The DTs are the essential power of the construction industry 4.0, which are capable to strongly push the digitalization (Maskuriy et. al., 2019; McKinsey Global Institute (MGI), 2017). Therefore, using DTs to close the construction technology gaps to promote productivity and prosper construction industry (Barbosa et. al., 2017).

1.2 Problem Statement

Generally, a construction project is expected to perform efficiently in accordance with the ideally planned design, scheduling and budget. Sufficient and competent labor, a satisfactory degree of digital application and a well-organized and sound management procedure are the foundation of this performance. However, most projects undergo problems, which generally suffer delay, overrun, changes and

reconstruction to impede the excellent construction performance as expected (Sepasgozar, et. al., 2019).

The construction project has a long cycle and complex technology, related to multidisciplinary and interdisciplinary professions including architecture, engineering, construction, Mechanical, Electrical and Plumbing, therefore, it requires a high integration and collaboration within these majors (Crotty, 2013). In contrast to the previous, the divisions pf these professions are more detailed, but the relationship among the various majors becomes worse (Liu, 2018). The lack of effective information sharing and poor coordination between these professions resulting in reconstruction, delaying duration, and even serious quality problems, which is a great waste of resources and investment (Gong et. al., 2019). All of these led to inefficient performance in construction industry. Therefore, DTs are essential to AEC industry for rescuing the productivity.

The productivity of construction industry is a long record about actually inefficiently shown in Figure 1.1. Particularly in comparison to other industries, over the past 20 years, the annual productivity growth has only raised averaged 1% (McKinsey Global Institute, 2017). Farmer (2016) identified that low productivity is one of the key factors in the poor performance of the UK construction industry. Chapman et. al. (2010) also pointed out that US construction productivity is also in a dilemma. Singapore has also been challenged for poor productivity (E. C. Lim & Alum, 1995). If the poor construction efficiency of the construction industry cannot be rescued, the bad phenomena such as delays, overruns, and low profits in the construction industry will become increasingly serious. As a result, it can bring great losses to the national economy, like a drop in GDP, a loss of foothold of construction industry, housing problems and even a series of social impacts caused by low construction productivity. Therefore, it is an urgent need to increasing adoption of DTs to promote productivity.

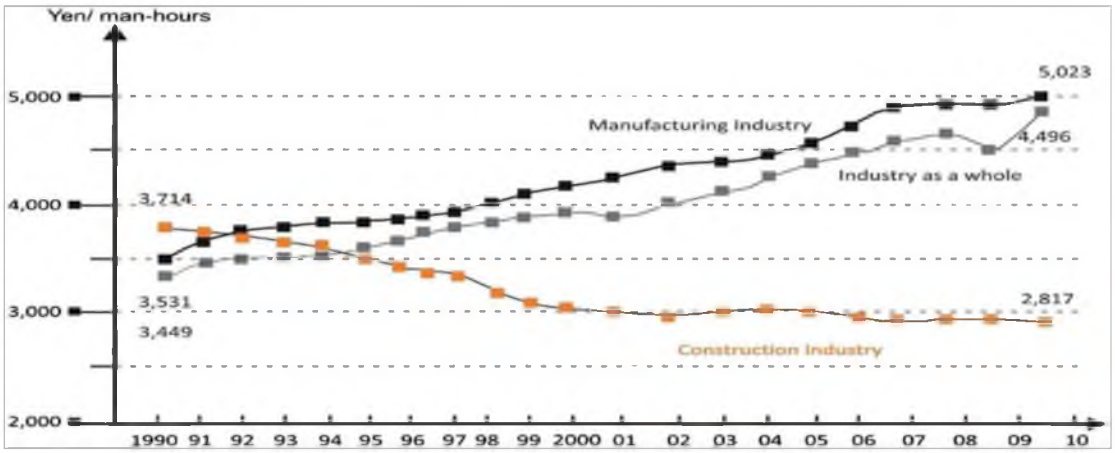


Figure 1.1 Labor Productivity in Industries (Bock, 2015)

In addition, the participants in the construction industry are intricate, involving owners, architecture design units, construction units, and supervision units (Alreshidi, Mourshed, & Rezgui, 2018). The phenomenon of subcontracting is widespread to bring more difficult in integration. Figure 1.2 shows the collaborative process among participants in AEC compared to DTs collaborative process. In actual construction projects, different parts are always eager for others to undertake more work and responsibilities due to their own interests (Zhao, 2019), which bring trouble to the management of the construction industry and the smooth implementation of the work. By adoption of DTs can integrate all participants and improve communication.

Traditional collaborative process **DTs collaborative process**

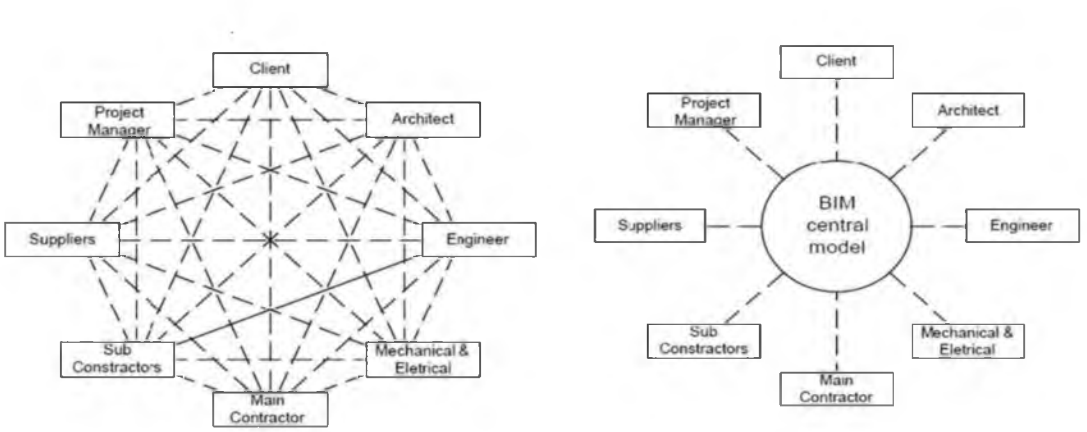


Figure 1.2 Collaborative Process vs DTs Collaborative in AEC (Carvalho et. al., 2019).

All of the time, the AEC industry has always lagged behind other industries in applying new technologies and tools (Maskuriy, et. al., 2019; Livotov, et. al., 2019). It always has some rejection and slowness of technological innovation. This industry still relys on 2D drawings, even different professions draw their own plans without communication, which will bring a series of trouble to the subsequent work such as changes and rework (Eastman et. al., 2011). The benefits of DTs have been commendably demonstrated, but a lot of companies are still unwilling to adopt it, which has hindered productivity as well (Sepasgozar et. al., 2019). In terms of BIM, the terminology of BIM was first proposed by GA van Nederveen and FP Tolman in 1992. However, it was not generally mentioned until 10 years later. In 2002, Autodesk published a paper called "Building Information Model", then BIM began to really enter people's eyes. Even today, the use of BIM is still not extensive as mentioned before., According to the survey of Zhiyan Consulting Group (2017), in China, the adopting of BIM in most construction project is still less than 10%. Researched by Al-Ashmori et. al. (2019) shows that the usage of BIM in Malaysia is not more than 5%.

The McKinsey Global Institute (2017) survey pointed out that implementing digital tools in the whole life cycle is potential to enhance the productivity of the construction more than 10%. However, Sepasgozar and Davis (2018) presented that simply buying new technologies does not have any substantial help for construction productivity, and it will grow digital gaps and lose competitiveness with companies that focus on strategic technology investments. It is necessary to close the digital gaps within pioneer companies to gain the capability of competitiveness in the AEC industry (Ayinla and Adamu, 2018).

For these problems which are presented above, this study discusses superficially the capability and application of DTs in the AEC industry and the relationship with construction productivity to know the advantages of DTs for the productivity of the AEC industry in Malaysia and China. For this issue, our research is guided by the following question:

(a) what is the level of adopting digital tools in China and Malaysia towards construction industry?

(b) What is the significance of adopting digital tools?

(c) What is the factor that affects the digital tools adoption in construction industry?

(d) How digital technology improve for productivity of construction?

1.3 Aim and Objectives

As times goes by, there is a major need regarding the benefits of DTs is increasing. Nevertheless, there is an insurmountable gap between the application and

energetical promotion, resulting in this industry missed a rare golden opportunity to boost productivity. Based on the research questions presented above, the aim of this study is to assess the level of digital tools adoption and application in construction industry for Malaysia and China, in increasing the construction productivity. Hence, the objectives are excogitated as follow:

(a) To identify the adoption level of digital tools in construction industry.

(b) To determine the challenges of digital tools adoption in Malaysia and China.

(c) To examine the causal relationship of digital tools adoption and challenges in construction industry.

1.4 Scope of Study

There are plenty research papers about the benefits of DTs. However, lack of studies that summary of DTs contributes to productivity in reality. Most of these researches are skated over it. Enterprises are not able to make a sufficient judgment when companies expect to know even invest in DTs due to the resource is not available for consulting (Ibem and Laryea, 2014). The construction life cycle is long and full of variables. As stated above, the productivity is really important to the construction industry and the digital tools have a positive impact on it. Therefore, it is a chance to pour fresh blood—DTs to stimulate productivity.

The advantages of DTs for construction productivity are gathered through reviewing related literature and reliable information to compare with the data collection of relevant issues in this industry later. In order to evaluate the actual progress of digitization in AEC between Malaysia and China, and explore the

possibility that DTs can be applied to increase construction productivity in the future. Table 1.1 is a number of researches related to DTs which have focused on in this paper and the missing gaps also be shown that the missing gap is lack of integration of these twelve digital tools in construction industry, so that this study is to close this gap. After that, a framework will be prepared to demonstrate the relationship that can be glittered between DTs and construction productivity.

Table 1.1 Researches Related to DTs

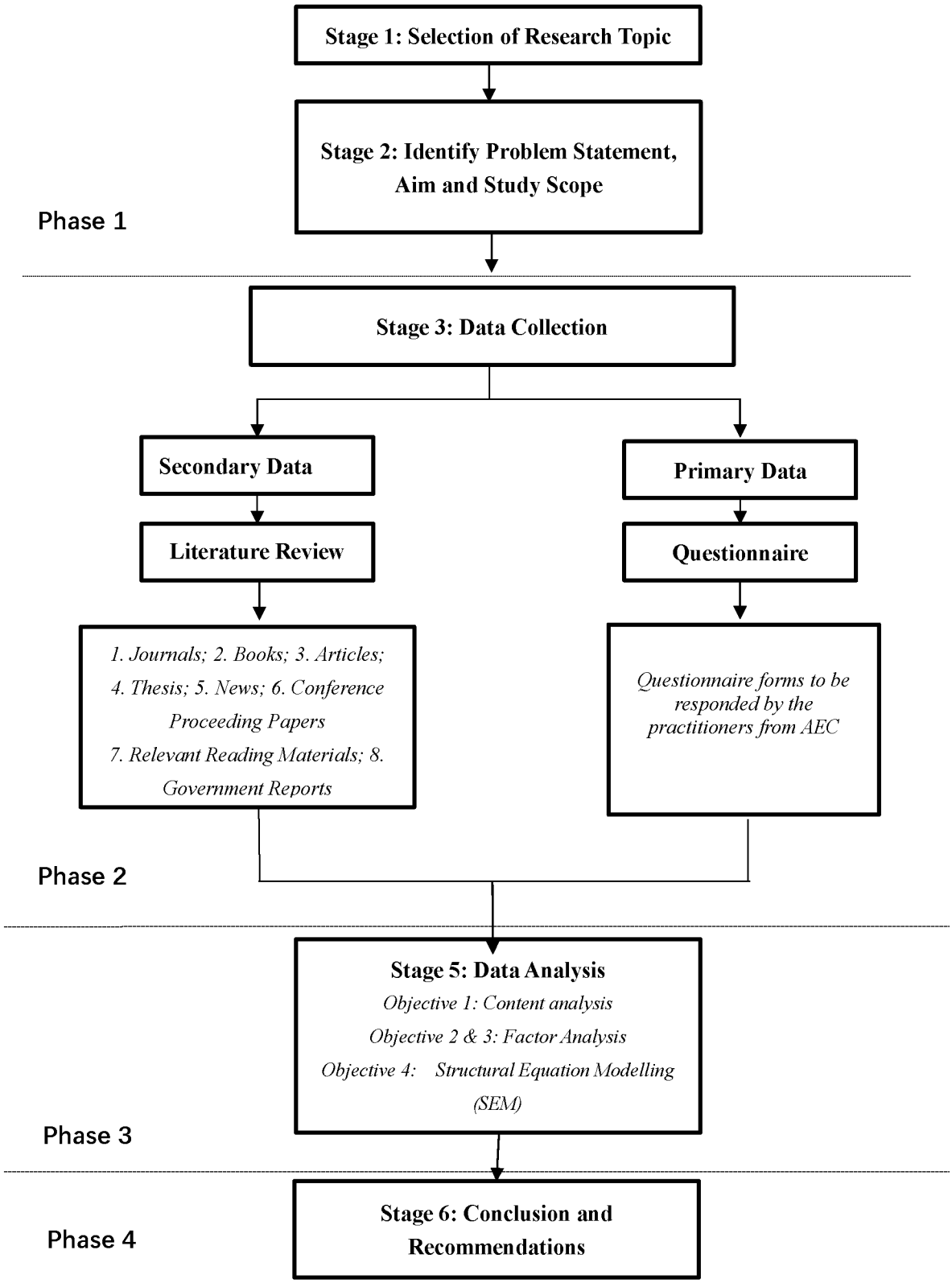
Title	Author	Related DTs	Missing Gaps
Using advanced manufacturing technology for smarter construction.	Griffin et al., 2019.	BIM, AR	-A systematic summary of DTs contributes to productivity in reality.
Augmented Reality Combined with Location-Based Management System to Improve the Construction Process, Quality Control and Information Flow.	Ratajczak et al., 2019	BIM, VR	
Efficiency Estimation Model of 3D Technology in the Construction Industry.	Bataev, 2019	3D Printing	
Autonomous Mobile Scanning Systems for the Digitization of Buildings: A Review.	Adán et al., 2019.	3D scanning	
An Application Oriented Scan-to-BIM Framework.	Wang et al., 2019	3D scanning, BIM	
Application of GIS Technology in Urban Planning Informatization.	Zhong, 2019	GIS	
Applications of multirotor drone technologies in construction management.	Li et al., 2019.	Drone Technology	

Title	Author	Related DTs	Missing Gaps
An investigation on virtual information modeling acceptance based on project management knowledge areas.	Didehvar et al., 2018	BIM, VR	- lack of integration of these twelve digital tools in constructio n industry
Three-Dimensional Printing Using Recycled High-Density Polyethylene: Technological Challenges and Future Directions for Construction.	Tahmasebin ia et al., 2018	3D Printing	
The Use of Modern Technologies in Conducting Research on the Performance of Construction Workers.	Malara, 2018	Drone Technology (UAV)	
Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective.	Song et al., 2017	BIM, GIS	
3D printing trends in building and construction industry: a review.	Tay et al., 2017.	3D printing	
Roles, Benefits, and Challenges of Using UAVs for Indoor Smart Construction Applications.	(McCabe, et al., 2017)	UAV, BIM	
Life cycle performance of modular buildings: A critical review.	(Kamali & Hewage, 2016)	Prefabricati on	
Big data architecture for construction waste analytics (CWA): A conceptual framework.	(Bilal et al., 2016)	Big data	

Title	Author	Related DTs	Missing Gaps
Enhanced Autocorrelation-Based Algorithms for Filtering Airborne Lidar Data over Urban Areas.	Shirowzhan et. al., 2015	3D Printing	- a relationship analysis model for digital tools adoption in constructio n industry
Construction automation with autonomous mobile robots: A review	(Ardiny, Witwicki, & Mondada, 2015)	Autonomou s construction	
Cloud computing to enhance collaboration, coordination and communication in the construction industry	(Amarnath et al., 2011)	Cloud, BIM	
Mixed Reality-based visualization interfaces for architecture, engineering, and construction industry	Dunston & Wang, 2005	MR	

1.5 Research Methodology

Table1.2 Flow Chart of Research Methodology



1.6 Significance of the Study

The bell of industry 4.0 is already rang and the pace of digitization cannot be stopped. More and more fields are beginning to develop the innovative way based on multidisciplinary data sharing, which can promote each other. Certainly, the AEC industry should not be left behind. Particularly, with the demand of high efficiency and quality for the consumers, it is inevitable for construction to upgrade the digital process that can produce the construction products within high productivity and quality.

The DTs, which have some advantageous characteristics such as information sharing, interoperability, combination reality with virtuality and so on to create the interconnection and cooperation of different construction jobs. It is able to bring more possibilities to the AEC industry. Perhaps we can boldly imagine that the future buildings are based on the data and information given, and a large mansion will be built up overnight by intelligently production and construction.

Sustainability is another global strategy. Rational use of digital tools can make the construction industry also closely follow the strategy of sustainable development. Conservation of resources and cost, safe and efficient output, which allow to bring more vitality to this industry. Malaysia and China should seize this opportunity to establish their status of digitization.

The study aims to understand the digitalization of the construction industry in Malaysia and China. Besides, the use of different digital tools in the actual construction projects to stimulate productivity, hereby contribute to efficient, high-quality, high-security construction products to enhance profitability ultimately.

REFERENCES

Abdi, H., & Williams, L. J. (2010). Principal component analysis. *Wiley Interdisciplinary Reviews: Computational Statistics*, *2*(4), 433–459.

Abeyasekera, S. (2013). Quantitative analysis approaches to qualitative data : why , when and how. In *UK : Statistical services centre, univesity of reading*.

Adán, A., Quintana, B., & Prieto, S. A. (2019). Autonomous mobile scanning systems for the digitization of buildings: A review. *Remote Sensing*, 11(3), 306.

Admin. (2019). *Discussion on the application of 3D scanning measurement and BIM technology in construction engineering*.

Agarwal, R., Chandrasekaran, S., & Sridhar, M. (2016). Imagining construction's digital future. *McKinsey Productivity Sciences Center*.

Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). The future of Big Data in facilities management: opportunities and challenges. *Facilities*, *35*(13–14), 725–745.

Alreshidi, E., Mourshed, M., & Rezgui, Y. (2018). Requirements for cloud-based BIM governance solutions to facilitate team collaboration in construction projects. *Requirements Engineering*, *23*(1), 1–31.

Al-Ashmori, Y. Y., Othman, I. B., Mohamad, H. B., Rahmawati, Y., & Napiah, M. (2019, August). Establishing the Level of BIM implementation–A Case Study in Melaka, Malaysia. In *IOP Conference Series: Materials Science and Engineering* (Vol. 601, No. 1, p. 012024). IOP Publishing.

Amarnath, C. B., Sawhney, A., & Uma Maheswari, J. (2011). Cloud computing to enhance collaboration, coordination and communication in the construction industry. *Proceedings of the 2011 World Congress on Information and Communication Technologies, WICT 2011*, 1235–1240.

Anastasiadou, S. D. (2011). Reliability and Validity Testing of a New Scale for

Measuring Attitudes Toward Learning Statistics with Technology. *Acta Didactica Napocensia*, *4*(1), 1–10.

Aouad, G., Kagioglou, M., Cooper, R., Hinks, J., & Sexton, M. (1999). Technology management of IT in construction: a driver or an enabler? *Logistics Information Management*, *12*(1/2), 130–137.

Ardiny, H., Witwicki, S., & Mondada, F. (2015). Construction automation with autonomous mobile robots: A review. *International Conference on Robotics and Mechatronics, ICROM 2015*, 418–424.

Aryani, A. L., Brahim, J., & Fathi, M. S. (2014). The development of building information modeling (BIM) definition. *Applied Mechanics and Materials*, *567*, 625–630.

Ashour, R., Taha, T., Mohamed, F., Hableel, E., Kheil, Y. A., Elsalamouny, M., … Cai, G. (2016). Site inspection drone: A solution for inspecting and regulating construction sites. *Midwest Symposium on Circuits and Systems*, *0*(October), 1–4.

Ayinla, K. O., & Adamu, Z. (2018). Bridging the digital divide gap in BIM technology adoption. *Engineering, Construction and Architectural Management*, 25(10), 1398-1416.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252.

Bansal, V. K. (2007). Potential of GIS to Find Solutions to Space Related Problems in Construction Industry. *Proceedings of World Academy of Science Engineering Technology*, *136119*(8), 307–310. Retrieved from

Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M., ... & Brown, S. (2017). Reinventing construction: A route to higher productivity. McKinsey Global Institute.

Bataev, A. V. (2019, January). Efficiency Estimation Model of 3D Technology in the Construction Industry. In *2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering* (EIConRus) (pp. 1376-

1381). IEEE.

Bilal, M., Oyedele, L. O., Akinade, O. O., Ajayi, S. O., Alaka, H. A., Owolabi, H. A., … Bello, S. A. (2016). Big data architecture for construction waste analytics (CWA): A conceptual framework. *Journal of Building Engineering*, *6*, 144–156.

Bilal, M., Oyedele, L. O., Qadir, J., Munir, K., Ajayi, S. O., Akinade, O. O., … Pasha, M. (2016). Big Data in the construction industry: A review of present status, opportunities, and future trends. *Advanced Engineering Informatics*, *30*(3), 500–521.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113–121.

Bosché, F. (2010). Automated recognition of 3D CAD model objects in laser scans and calculation of as-built dimensions for dimensional compliance control in construction. *Advanced Engineering Informatics*, *24*(1), 107–118.

Boton, C., Gilles, H., Sylvain, K., & Forgues, D. (2015). Challenges of Big Data in the Age of Building Information Modeling: A High-Level Conceptual Pipeline. In *International Conference on Cooperative Design, Visualization and Engineering*.

Brender, N., & Markov, I. (2013). Risk perception and risk management in cloud computing: Results from a case study of Swiss companies. *International Journal of Information Management*, *33*(5), 726–733.

Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of building information modelling (BIM). *International journal of project management*, 31(7), 971-980.

Cao, X., Li, X., Zhu, Y., & Zhang, Z. (2015). A comparative study of environmental performance between prefabricated and traditional residential buildings in China. *Journal of Cleaner Production*, *109*, 131–143.

Carreira, C., & Teixeira, P. (2011). The shadow of death: analysing the pre-exit productivity of Portuguese manufacturing firms. *Small Business Economics*,

36(3), 337-351.

Carvalho, J. P., Bragança, L., & Mateus, R. (2019). Optimising building sustainability assessment using BIM. *Automation in Construction*, 102, 170-182.

Chakravorti, B., Bhalla, A., & Chaturvedi, R. S. (2017). 60 Countries' Digital Competitiveness, Indexed. *Harvard Business Review*, 1–10.

Chapman, R. E., Butry, D. T., & Huang, A. L. (2010, May). Measuring and improveing US construction productivity. In *Proceedings of TG65 and W065-Special Track*. 18th CIB World Building Congress.

Chen, B., Xu, C., & Wen, Z. (2015). Application of 3D Laser scanning technology in seismic damage survey. *Technology for Earthquake Disaster Prevention*, *8*, 87–94.

Chen, J., & Man, Q. (2018). A Critical Review on BIM Research Process and Future Trends at Home and Abroad. *ICCREM 2018: Innovative Technology and Intelligent Construction*, 104–112.

Chen, Q., García de Soto, B., & Adey, B. T. (2018). Construction automation: Research areas, industry concerns and suggestions for advancement. *Automation in Construction*, *94*(December 2017), 22–38.

Chen, X., & Lu, W. S. (2018). Scenarios for applying big data in boosting construction: A review. *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate, 2016*, (209889), 1299–1306.

Chen, Z., & Song, Y. (2018). Research on Drone Application in Construction Site. *China Management Informationization*, *3*, 167–169.

Cheok, G. S., Lipman, R. R., Witzgall, C., Bernal, J., & Stone, W. C. (n.d.). *field demonstration of laser scanning for excavation measurement*.

Costa, N. R., & Pereira, Z. L. (2010). Multiple response optimization: A global criterion-based method. *Journal of Chemometrics*, *24*(6), 333–342.

Council, N. R. (2010). Report of a workshop on the scope and nature of computational thinking. In *National Academies Press* (Vol. 22).

Crotty, R. (2013). The impact of building information modelling: transforming construction. *Routledge*.

Davila Delgado, J. M., Oyedele, L., Demian, P., & Beach, T. (2020). A research agenda for augmented and virtual reality in architecture, engineering and construction. *Advanced Engineering Informatics*, *45*(May), 101122.

Didehvar, N., Teymourifard, M., Mojtahedi, M., & Sepasgozar, S. (2018). An investigation on virtual information modeling acceptance based on project management knowledge areas. *Buildings*, 8(6), 80.

Dunston, P. S., & Wang, X. (2005). Mixed Reality-based visualization interfaces for architecture, engineering, and construction industry. *Journal of Construction Engineering and Management*, *131*(12), 1301–1309.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., & McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in construction*, 36, 145-151.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. *John Wiley & Sons*. -B20.

El-Omari, S., & Moselhi, O. (2009). Data acquisition from construction sites for tracking purposes. *Engineering, Construction and Architectural Management*, *16*(5), 490–503.

Esposito Vinzi, V. ., Chin, W. W. ., Henseler, J. ;, & Wang, H. (2010). Handbook of Partial Least Squares: Concepts, Methods and Applications. In *Heidelberg, Dordrecht, London, New York : Springer*.

Farmer, M. (2016). The farmer review of the UK construction labour model. *Construction Leadership Council*.

Fincham, J. E. (2008). Response rates and responsiveness for surveys, standards, and the Journal. *American Journal of Pharmaceutical Education*, *72*(2), 43.

Fornell, C., & Larcker, D. F. (1981). Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. *Journal of Marketing Research*, *18*(1), 39–50.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, *75*(November 2016), 1046–1053.

GIS (Geographic Information System) | National Geographic Society. (n.d.).

Goedert, J. D., & Meadati, P. (2008). Integrating Construction Process Documentation into Building Information Modeling. *Journal of Construction Engineering and Management*, *8*(July), 509–516.

Gong Zongyi, Liu Guoguang, & Shi Jun. (2019). Application of BIM in project quality control. *Value engineering*, 123-126.

Goodrum, P. M., Zhai, D., & Yasin, M. F. (2009). Relationship between changes in material technology and construction productivity. *Journal of construction engineering and management*, 135(4), 278-287.

Griffin, A., Hughes, R., Freeman, C., Illingworth, J., Hodgson, T., Lewis, M., & Perez, E. (2019, April). Using advanced manufacturing technology for smarter construction. In *Proceedings of the Institution of Civil Engineers-Civil Engineering* (pp. 1-31). Thomas Telford Ltd.

Hair, J.F., Anderson, R. E., Babin, B. J., & Black, W. C. (2010). Multivariate Data Analysis (Vol.7). In *Upper Saddle River,, NJ: Pearson*.

Hair, Joseph F., Ringle, C. M., & Sarstedt, M. (2013). Partial Least Squares Structural Equation Modeling: Rigorous Applications, Better Results and Higher Acceptance. *Long Range Planning*, *46*(1–2), 1–12.

Hamelink, C. J. (1997). New information and communication technologies, social development and cultural change (Vol. 86). *Geneva*: *United Nations Research Institute for Social Development.*

Han, C. (2017). The Future Development Trend of Intelligent Construction Industry in Internet Era. *Journal of Intelligent Building*, 64–65.

Hashim, N., Said, I., & Idris, N. H. (2013). Exploring e-procurement value for construction companies in Malaysia. *Procedia Technology*, 9, 836-845.

Holton, A., Lawson, S., & Love, C. (2015). Unmanned Aerial Vehicles: Opportunities, barriers, and the future of "drone journalism." *Journalism Practice*, *9*(5), 634–650.

Ibem, E. O., & Laryea, S. (2014). Survey of digital technologies in procurement of construction projects. *Automation in Construction*, 46, 11-21.

Jia, M., & Li, S. (2019). Discussion on the Fusion Apllication of BIM and GIS in Smart City Based on Standard Fusion. *Journal of Intelligentization and Informatization*, 203–205.

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. *Renewable and Sustainable Energy Reviews*, *62*, 1171–1183.

Kamardeen, I. (2010). 8D BIM modelling tool for accident prevention through design. *Association of Researchers in Construction Management, ARCOM 2010 - Proceedings of the 26th Annual Conference*, (September), 281–289.

Kasih, R. P. A., & Adi, T. J. W. (2019). Construction project productivity assesment model and its implementation in Indonesia construction industry. In *MATEC Web of Conferences* (Vol. 258, p. 02026). EDP Sciences.

Khoi, B. H., & Van Tuan, N. (2018). Using SmartPLS 3.0 to analyse internet service quality in Vietnam. *Studies in Computational Intelligence*, *760*, 430–439.

Khoshnevis, B., Hwang, D., Yao, K. T., & Yeh, Z. (2006). Mega-scale fabrication by Contour Crafting. *International Journal of Industrial and Systems Engineering*, *1*(3), 301–320.

Khosrowshahi, F., & Arayici, Y. (2012). Roadmap for implementation of BIM in the UK construction industry. *Engineering, Construction and Architectural Management*, *19*(6), 610–635.

Kumar, B., Cheng, J., & McGibbney, L. (2010). Cloud computing and its implications for construction IT. *In Computing in Civil and Building Engineering, Proceedings of the International Conference*, *30*, 315.

Le, T. T., Austin, S. A., Lim, S., Buswell, R. A., Gibb, A. G. F., & Thorpe, T. (2012). Mix design and fresh properties for high-performance printing concrete. *Materials and Structures/Materiaux et Constructions*, *45*(8), 1221–

1232.

Leach, N. (2010). Digital Cities. *Politics, Democracy and E-Government*, 275–291.

Li, H., Chen, Z., Yong, L., & Kong, S. C. W. (2005). Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency. *Automation in Construction*, *14*(3), 323–331.

Li, H. X., Al-Hussein, M., Lei, Z., & Ajweh, Z. (2013). Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation. *Canadian Journal of Civil Engineering*, *40*(12), 1184–1195.

Livotov, P., Sekaran, A. P. C., Law, R., Reay, D., Sarsenova, A., & Sayyareh, S. (2019). Eco-innovation in process engineering: Contradictions, inventive principles and methods. *Thermal Science and Engineering Progress*, 9, 52-65.

Li, X., Yi, W., Chi, H. L., Wang, X., & Chan, A. P. C. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, *86*(November 2017), 150–162.

Li, Y., & Liu, C. (2019). Applications of multirotor drone technologies in construction management. *International Journal of Construction Management*, *19*(5), 401–412.

Liang, J. (2019). On the trend of construction industry and the path of transformation and upgrading of construction enterprises. *Journal of China Construction Information*, 26–31.

Lim, E. C., & Alum, J. (1995). Construction productivity: Issues encountered by contractors in Singapore. *International Journal of Project Management*, *13*(1), 51–58.

Lim, S., Buswell, R. A., Le, T. T., Austin, S. A., Gibb, A. G. F., & Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes. *Automation in Construction*, *21*(1), 262–268.

Liu Jiajian. (2018). Research on improving factors and paths of BIM-based collaborative design efficiency.

Liu, X., Wang, X., Wright, G., Cheng, J. C. P., Li, X., & Liu, R. (2017). A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS International Journal of Geo-Information*, *6*(2), 1–21.

MA, Cong. (2017). The Management and Application of GIS in the Construction Field. *Geomatics & Spatial Information Technology*, *2*, 119–120.

Malara, J. (2018, July). The use of modern technologies in conducting research on the performance of construction workers. In *AIP Conference Proceedings* (Vol. 1978, No. 1, p. 240007). AIP Publishing.

Ma, Z. (2019). Move Towards High Intelligence Building. *Construction Technology*, *3*, 1–3.

Mao, Z. (2019). Intelligent Construction Determines the Future of the Construction Industry. *Construction and Architecture*, *3*, 22–24.

Maskuriy, R., Selamat, A., Ali, K. N., Maresova, P., & Krejcar, O. (2019). Industry 4.0 for the Construction Industry—How Ready Is the Industry?. *Applied Sciences*, 9(14), 2819.

Mattern, H., Bruckmann, T., Spengler, A., & König, M. (2016). Simulation of automated construction using wire robots. *In 2016 Winter Simulation Conference (WSC)*, *0*, 3302–3313.

McCabe, B. Y., Hamledari, H., Shahi, A., Zangeneh, P., & Azar, E. R. (2017). Roles, Benefits, and Challenges of Using UAVs for Indoor Smart Construction Applications. *In Computing in Civil Engineering*, 667–674.

Mell, P., & Grance, T. (2011). The NIST-National Institute of Standars and Technology- Definition of Cloud Computing. *NIST Special Publication 800-145*, 7.

NASA. (n.d.). *NASA - Contour Crafting Simulation Plan for Lunar Settlement Infrastructure Build-Up*.

NBS National BIM Report. Accessed 10th May 2015

Nguyen, TN. (2015). Determinants of Firm Survival: The Case of the Manufacturing

Industry in Vietnam. *Proceedings of the 2nd international conference on finance and economics*. 346-358.

Oke, A., Aigbavboa, C., & Mabena, S. (2017). *Effects of Automation on Construction Industry Performance*. *102*(Icmmse), 370–374.

Osmani, M., Glass, J., & Price, A. (2006). Architect and contractor attitudes to waste minimisation. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, *159*(2), 65–72.

Pan, J., & Zhao, Y. (2012). Research on Barriers of BIM Application in China'S Building Industry. *Journal of Engineering Management*, *6*, 6–11.

Panda, B. N., Bahubalendruni, R. M. V. A., Biswal, B. B., & Leite, M. (2016). A CAD-based approach for measuring volumetric error in layered manufacturing. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *231*(13), 2398–2406.

Pena, G. (2011). *Evaluation of training needs for Building Information Modeling (BIM)*. *11*(2), 10–14.

Perkins, I., & Skitmore, M. (2015). Three-dimensional printing in the construction industry: A review. *International Journal of Construction Management*, *15*(1), 1–9.

Porwal, A., & Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*, *31*, 204–214.

Provost, F., & Fawcett, T. (2013). Data Science and its Relationship to Big Data and Data-Driven Decision Making. *Big Data*, *1*(1), 51–59.

Ratajczak, J., Schweigkofler, A., Riedl, M., & Matt, D. T. (2019). Augmented Reality Combined with Location-Based Management System to Improve the Construction Process, Quality Control and Information Flow. In *Advances in Informatics and Computing in Civil and Construction Engineering* (pp. 289-296). Springer, Cham.

Reyes, P., Suresh, S., & Renukappa, S. (2018). The adoption of big data concepts for sustainable practices implementation in the construction industry. *2018*

International Conference on Utility and Cloud Computing Compan (UCC Companion 2018), 341–348.

Rogers, J., Chong, H. Y., & Preece, C. (2015). Adoption of Building Information Modelling technology (BIM): Perspectives from Malaysian engineering consulting services firms. *Engineering, Construction and Architectural Management*, *22*(4), 424–445.

Sahar Sauian, M. (2002). Labour productivity: an important business strategy in manufacturing. *Integrated Manufacturing Systems*, 13(6), 435-438.

Salama, T., Salah, A., Moselhi, O., & Al-Hussein, M. (2017). Near optimum selection of module configuration for efficient modular construction. *Automation in Construction*, *83*, 316–329.

Salman, A., Abid, N., Johnny, Y. N. M., & Brian, H. Y. L. (2008). Building Information Modeling (BIM) A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects. *In Proc., First International Conference on Construction in Developing Countries (Vol. 1, Pp. 435-46)*, *1*.

Sawhney, A., & Maheswari, J. (2013). Design Coordination Using Cloud-based Smart Building Element Models. *International Journal of Computer Information Systems and Industrial Management Applications*, *5*(2013), 445–453.

Sepasgozar, S. M., & Davis, S. (2019). Digital Construction Technology and Job-site Equipment Demonstration: Modelling Relationship Strategies for Technology Adoption. *Buildings*, 9(7), 158.

Sepasgozar, S., & Davis, S. (2018). Construction technology adoption cube: An investigation on process, factors, barriers, drivers and decision makers using NVivo and AHP analysis. *Buildings*, 8(6), 74.

Sepasgozaar, S. M. E., Shirowzhan, S., & Wang, C. (2017). A Scanner Technology Acceptance Model for Construction Projects. *Procedia Engineering*, *180*, 1237–1246.

Sepasgozar, S. M. E., & Bernold, L. E. (2013). Factors Influencing Construction Technology Adoption. *In 19th CIB World Building Congress, Brisbane.*

Shirowzhan, S., Lim, S., & Trinder, J. (2015). Enhanced autocorrelation-based algorithms for filtering airborne lidar data over urban areas. *Journal of Surveying Engineering*, 142(2), 04015008.

Shlens, J. (2014). *A Tutorial on Principal Component Analysis*.

Silverio, M., Renukappa, S., Suresh, S., & Donastorg. (2017). Mobile Computing in the Construction Industry: Main Challenges and Solutions. In *Leadership, innovation and entrepreneurship as driving forces of the global economy* (pp. 85–99).

Smith, P. (2014). BIM & the 5D Project Cost Manager. *Procedia - Social and Behavioral Sciences*, *119*, 475–484.

Song, Y., Wang, X., Tan, Y., Wu, P., Sutrisna, M., Cheng, J. C. P., & Hampson, K. (2017). Trends and opportunities of BIM-GIS integration in the architecture, engineering and construction industry: A review from a spatio-temporal statistical perspective. *ISPRS International Journal of Geo-Information*, *6*(12), 1–32.

Stanciu, A., Condrea, E., & Zamfir, C. (2016). The Importance of Communication in Quality Management. *Ovidius University Annals, Economic Sciences Series*, XVI(2), 393–396.

Stemler, S. (2000). An overview of content analysis. *Practical Assessment, Research and Evaluation*, *7*(17).

Tabachnick, B. G., & Fidell, L. S. (2007). Using Multivariate Statistics. In *Boston, MA: Pearson*.

Tabachnick, B. G., & Fidell, L. S. (2013). Using Multivariate Statistics(6th ed.). In *New Jersey: Pearson Education Inc.*

Tahmasebinia, F., Niemelä, M., Ebrahimzadeh Sepasgozar, S., Lai, T., Su, W., Reddy, K., ... & Marroquin, F. (2018). Three-Dimensional Printing Using Recycled High-Density Polyethylene: Technological Challenges and Future Directions for Construction. *Buildings*, 8(11), 165.

Tam, V. W. Y., Tam, C. M., Zeng, S. X., & Ng, W. C. Y. (2007). Towards adoption of prefabrication in construction. *Building and Environment*, *42*(10), 3642–3654.

Tang, W. (2016). Key technology analysis and application research of accounting informationization under cloud environment. *Proceedings - 2015 International Conference on Intelligent Transportation, Big Data and Smart City, ICITBS 2015*, 507–510.

Tang, X., Zhang, Y., & Deng, S. (2019). *Application of BIM+GIS in City Construction*. *3*(5), 59–61.

Tay, Y. W. D., Panda, B., Paul, S. C., Noor Mohamed, N. A., Tan, M. J., & Leong, K. F. (2017). 3D printing trends in building and construction industry: a review. *Virtual and Physical Prototyping*, *12*(3), 261–276.

TEO, X. Q. (2012). *A study of Building Information Modeling (BIM) in malaysia construction industry* (Vol. 66). Universiti Tunku Abdul Rahman.

Thompson, B. (2004). Exploratory and Confirmatory Factor Analysis: Understanding Concepts and Applications. In *American Psychological Association*.

Types of Drones: Multi-Rotor vs Fixed-Wing vs Single Rotor vs Hybrid VTOL - AUAV. (n.d.). Retrieved December 6, 2019, from

Vanlande, R., Nicolle, C., & Cruz, C. (2008). IFC and building lifecycle management. *Automation in construction*, 18(1), 70-78.

Vass, S., & Gustavsson, T. K. (2017). Challenges when implementing BIM for industry change. *Construction Management and Economics*, *35*(10), 597–610.

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings - Literature review and future needs. *Automation in Construction*, *38*, 109–127.

Wan, X. (2018). Taking Advantage of the Cloud and Inspiring New Momentum for Construction Enterprises. *China Construction Informatization*, *3*, 23–25.

Wang, H., & Ning, P. (2019). Application of 3D Scanning Measurement and BIM Technology in Construction Engineering. *City & House*, 88–90.

Wang, L. (2018). The study of adoption VR in construction industry. *Tax Paying*, *2*, 232–233.

Wang, M. (2016). Preliminary Study on the Application of Virtual Reality Technology and Augmented Reality Technology in Construction Industry. *The Fortune Time*, *1*(1), 334.

Wang, Q., Guo, J., & Kim, M. K. (2019). An application oriented scan-to-bim framework. *Remote Sensing*, *11*(3).

Wei, W., Deng, L., Gao, Z., Zhao, C., Zhao, Y., & Zhang, C. (2019). Study on Drone Application in Building Construction Site. *Construction Materials and Decoration*, 39–40.

Wong, J., Wang, X., Li, H., Chan, G., & Li, H. (2014). A review of cloud-based bim technology in the construction sector. *Journal of Information Technology in Construction*, *19*(August), 281–291.

Wu, P., Wang, J., & Wang, X. (2016). A critical review of the use of 3-D printing in the construction industry. *Automation in Construction*, *68*, 21–31.

Yin, H., Qu, M., Zhang, H., & Lim, Y. C. (2018). 3D Printing and Buildings: A Technology Review and Future Outlook. *Technology Architecture and Design*, *2*(1), 94–111.

Zainuddin, N., Yusuff, R. C. M., & Samy, G. N. (2020). Current State of Cloud Computing Risk Assessment in Malaysian Private Sector. *Proceedings of the 2020 6th International Conference on Computer and Technology Applications*, 26–30.

Zhang, L., Li, Y., & Gao, Y. (2013). Barrier and Countermeasures of the BIM Application in China. *Journal of Civil Engineering and Management*, *6*, 65-69,85.

Zhang, Q., Cheng, L., & Boutaba, R. (2010). Cloud computing: State-of-the-art and research challenges. *Journal of Internet Services and Applications*, *1*(1), 7–18.

Zhang, S., Teizer, J., Lee, J. K., Eastman, C. M., & Venugopal, M. (2013). Building Information Modeling (BIM) and Safety: Automatic Safety Checking of

Construction Models and Schedules. *Automation in Construction*, *29*, 183–195.

Zhang, W., Lee, M. W., Jaillon, L., & Poon, C. S. (2018). The hindrance to using prefabrication in Hong Kong's building industry. *Journal of Cleaner Production*, *204*(2018), 70–81.

Zhang, X., Skitmore, M., & Peng, Y. (2014). Exploring the challenges to industrialized residential building in China. *Habitat International*, *41*, 176–184.

Zhao Yuntong. (2019). Application of BIM technology in construction. *Engineering construction*. 2(2), 54-55.

Zhiyan Consulting Group. (2017). 2017-2022 China Building Information Model (BIM) Market In-depth Research and Investment Strategy Research Report.

Zhong Zhaodong. (2019). Application of GIS Technology in Urban Planning Informatization. *4th International Workshop on Materials Engineering and Computer Sciences (IWMECS)*.

Zhou, L. (2017). Obstacles and countermeasures of BIM development in China's construction industry. *Journal of Building Materials Development Orientation*, 397–398.

Zhou, W., Whyte, J., & Sacks, R. (2012). Construction safety and digital design: A review. *Automation in Construction*, 22, 102-111.

Zhang, Y. (2018). Analysis of the impediments to BIM promotion from the perspective of project management. *Shanxi Architecture*, 255–256.

Zhou, Z., Goh, Y. M., & Li, Q. (2015). Overview and analysis of safety management studies in the construction industry. *Safety Science*, *72*, 337–350.