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DIGITAL TOOLS ADOPTION TOWARDS CONSTRUCTION INDUSTRY REVOLUTION

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Abstract

The pace of change brought about by digitalisation has resulted in an unprecedented and exponential trajectory, surpassing even the predictions of forward-thinking economists. However, the construction industry has exhibited a slower rate of adaptation to digitalisation compared to other sectors. In contrast to high-growth frontier industries like Information and Communication Technology, the construction industry has consistently lagged in terms of productivity, a phenomenon that is not entirely surprising. This study addressed this widening gap by assessing the adoption of digital tools (DTs) in the Architecture, Engineering, and Construction (AEC) industry, specifically in Malaysia and China. A questionnaire survey was conducted to collect data from construction practitioners in Malaysia and China. The analysis focused on sixty-one valid responses, utilising quantitative methodologies, notably Principal Component Analysis (PCA). The findings of this study indicated that the level of DTs adoption in Malaysia and China was relatively low compared to countries such as Singapore, Hong Kong, and the UK. The major challenges identified in adopting DTs included difficulties managing change towards new technology and the lack of cyber security in DTs. Furthermore, the study highlights that DTs' benefits significantly impact DTs' future trends. Therefore, it is highly recommended that managers in the construction industry, both in Malaysia and China, embrace the adoption of DTs to improve productivity and leverage the wide range of benefits they offer.

Keywords: Construction productivity, Digital tools, Principal Component Analysis (PCA).

1. Introduction

The Architecture, Engineering and Construction (AEC) industry plays a pivotal role in the rapid development processes of most countries [1, 2]. According to the National Bureau of Statistics of China, the construction industry in China recorded 23.5 trillion Yuan in production or 6.9% of its GDP in 2018. Similarly, the Department of Statistics Malaysia recorded RM36.1 billion as the value of output by the construction industry in the third quarter of 2019, equivalent to 4.7% of Malaysia's total GDP. Despite the meritorious contribution, data compiled by McKinsey Global Institute [3] paints a glimmer situation, in which, during 2017, it has been construed that the construction industry's productivity has stagnated statistically. Thus, it is exigent to deliberate on effective ways to improve the construction industry's productivity. Hashim et al. [4] suggested in their study that adopting digital technologies and digital tools (DTs) can effectively realise the deliberation.

The construction industry has a longstanding history of inefficiency, with its annual growth rate over the past 20 years averaging a dismal 1%, significantly lower than other industries [3]. Farmer [5] has identified low productivity as a key factor contributing to poor performance in the UK construction industry. If these persistently low productivity levels are not adequately addressed, contractual and business issues such as delays, cost overruns, and reduced profitability will become more pronounced in the construction industry. This, in turn, leads to significant economic losses, including a decline in GDP, housing challenges, as well as societal and environmental impacts. Therefore, there is an urgent need to adopt digital technologies (DTs) to prevent this trend from worsening and enhance construction industry productivity.

The construction industry involves various multidisciplinary professions, which leads to longer and more complex project cycles. Consequently, a high level of integration and collaboration is crucial to connect these different disciplines [6]. However, Liu [7] discovered that, for various reasons, there had been a growing divide rather than collaboration among these professions. Additionally, the complexity of relationships among owners, architectural design units, construction units, and supervision units, coupled with the lack of effective communication tools for sharing up-to-date information between these professions, often leads to rework, delays, and other quality issues, resulting in the wastage of valuable resources and investments [8, 9]. As a result, the performance of the construction industry is significantly affected. Thus, by integrating them as essential tools in project management, digital technologies (DTs) can potentially address the industry's productivity challenges.

The McKinsey Global Institute [3] survey estimated that the adoption of DTs in the whole project life cycle can increase the construction industry's productivity by more than 10%. However, Sepasgozar and Davis [10] highlighted that buying new technologies will not substantially improve construction productivity. Conversely, the digital gaps among construction players will increase, in which companies that choose to focus on strategic technology investments will gain lasting competitiveness. Therefore, it is necessary to identify and address these digital gaps within the AEC industry so that pioneering and growing organisations can acquire the relevant capabilities to remain competitive [11].

While research on the benefits of digital technologies (DTs) is expanding, the construction industry continues to face low productivity, with promotional efforts not effectively accelerating. In light of this, the active promotion of DTs' application represents an opportunity to enhance construction productivity. However, there is a lack of a systematic summary regarding the impact of DTs on construction productivity in practice and a gap in analysing the relationship between DTs adoption and the challenges faced by the construction industry [12-18]. Moreover, relevant literature reviews and reliable sources were examined to gather information on the advantages and challenges of DTs for the construction industry, and the data collected from the industry was later compared against these findings. Therefore, this study aimed to assess the benefits, challenges, and future trends of DTs development in both China and Malaysia.

2. Literature Review

2.1. The role of digital technologies in the AEC industry

Hamelink [19] defined Digital Technology as a complex process involving Information and Communication Technologies (ICTs) that enables capturing, storage, processing, transportation, displaying and communicating information between human beings and electronic systems. With the extension and evolution of Digital Technology, the AEC industry has experienced significant changes.

Digital construction technology is a megatrend in the construction industry [20]. Digital construction refers to using and applying digital technologies (DTs) to enhance productivity and optimise the process of delivering and operating the built environment [21, 22]. Additionally, it offers significant benefits in terms of safety and quality within the construction industry [10].

2.2. An overview of digital evolution

Chakravorti et al. [23] presented the digital evolution index in four distinct (4) quadrants showing the progress of digital evolution among 60 different countries. These quadrants encompass: Watch Out, Stall Out, Break Out, and Stand Out, as illustrated in Fig. 1. Countries in the Watch Out quadrant have yet to start their digital revolution, which means they are the slowest in their adaptation. Countries such as Egypt, South Africa, Peru, and Pakistan represent this quadrant. In contrast, the countries in the Stall Out zone, such as Sweden and Norway, are considered well-digitalised and do not have much room for digital progress. In the meantime, Stand Out countries are at the first line of digitisation development, based on their superior digital foundation and advanced development. These countries are Singapore, New Zealand, and the UAE.

Alternatively, Malaysia and China are positioned in the crossover section between the Break Out and Stand Out quadrants, suggesting that these countries possess robust digital infrastructure foundations and are rapidly advancing in their digital evolution. However, this classification also signifies considerable room for further enhancement. As a result, this study critically examines the performance of digital technology adoption in Malaysia and China.

2.3. Benefits of digital tools adoption

BIM has brought revolutionary and even subversive changes to the construction industry. The industry chain realises the modern industrial factory production and refined management model [24]. It also contributed to the development of a highly skilled and proficient workforce. The adoption of 3D printing in the construction industry has larger significant benefits those advantages, including less waste, less manpower, and less cost and time. In the meantime, high construction productivity and high accuracy construction help high performance in some aspects of construction. Wang and Ning [25] highlighted that integrating 3D scanning with other advanced digital tools, such as BIM and drones, offers significant improvements in the execution of construction projects. This technology is effectively employed in surveying, operations, highway alignment, paving operations, and quality monitoring. The benefits of DTs are summarised in Table 1.

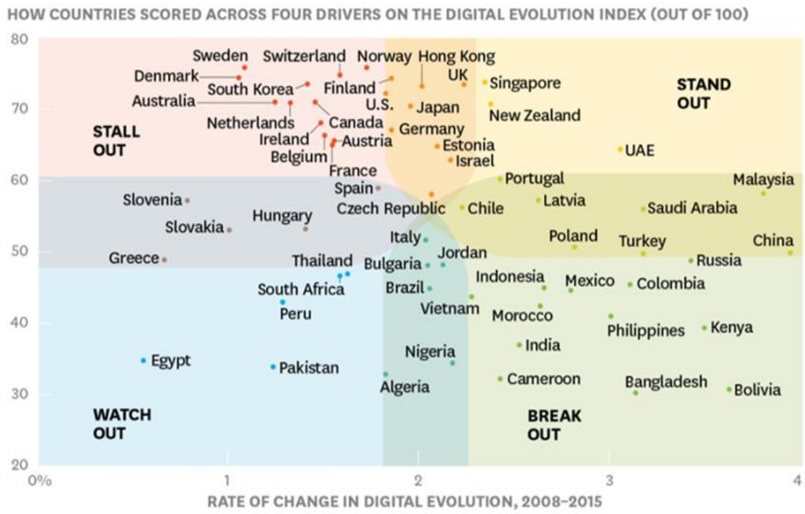

Fig. 1. Plotting the digital evolution index [23].

Table 1. The benefits of DTs.

Benefits	[26]	[27]	[28]	[29]	[30]
Allow better quality	✓	✓	✓	✓	
Ensure data consistency	✓		✓		✓
Reduce technical errors	✓			✓	
Improve productivity	✓	✓		✓	✓
Reduce reworks			✓	✓	
Improve communication	✓				
Minimise conflict	✓		✓		✓
Human error can be minimised	✓	✓		✓	
Reduce printing fees	✓				✓
Reduce the number of variation orders.			✓		
Reduce time	✓		✓		
Improving safety			✓	✓	
Decreasing project cost	✓	✓	✓	✓	✓
Less waste		✓		✓	✓
Ease of accessing data	✓				✓

2.4. The challenges of digital tools adoption

Even though many studies have suggested the myriad of advantages DTs have brought to the construction industry, the adoption rates are still on the lower side. Barriers or challenges remain to be addressed before the ideal situation can be attained. These challenges involve cost, technology, security, and people-related factors. In recent years, Malaysia and China have introduced BIM-related standards; however, they must be further refined [31, 32]. One of the major challenges in effective information sharing arises from using different digital platforms by various companies at different stages of construction. Due to these differences, construction companies generally suffer problems such as scattered applications and lack of a centralised database, which rendered the value of DTs much less evident than it should have been [33]. The summary of challenges affecting DTs is presented in Table 2.

Table 2. The challenges of DTs adoption.

Challenges	[26]	[34]	[35]	[36]	[37]
The technology is costly.		✓			✓
Extra cost for training			✓	✓	
Extra time needed for training			✓	✓	
The professionals stay in their comfort zone.		✓			
Conflicts due to different understandings and applications of technology				✓	
Lack of awareness toward digital tools			✓		✓
The current practice is better than switching to new technology.				✓	
The intellectual property is not secured.	✓		✓		
The client does not require the technology.				✓	
The technology is inappropriate for the project.			✓		
Technology is not common in the current trend.				✓	
Managing changes to new technology is challenging.			✓		
Hardware is incapable of running the new software.			✓	✓	✓
High cost of upgrading current IT systems			✓	✓	
Lack of cyber security	✓				
Lack of digital talents to operate digital tools			✓	✓	✓
Reluctant to initiate new workflows for the implementation of digital tools			✓		

3. Research Methodology

This study adopted a statistical approach, in which the questionnaire survey is the primary data collection tool. Using purposive sampling, the identified respondents for this study were practising professionals from the AEC industry in Malaysia and China. The questionnaire survey's response rate was minimally acceptable, where 200 online surveys received 61 valid responses indicating a 30.5% response rate [38]. Although the sample size for this study was relatively small in the context of empirical research, Erika et al. [39] emphasised that the importance of sample size should not merely be based on statistical power. The authors highlighted that bias considerations in parameter estimates and solution propriety are equally significant. The study discovered that increasing indicators per factor could compensate for the small sample size and maintain statistical power. The Principal Component Analysis (PCA) was performed to identify the critical indicators.

The preliminary analysis of the study showed that the reliability analysis test passed the threshold 0f 0.7 and recorded a highly reliable Cronbach's Alpha category at 0.941 (benefits), 0.932 (challenges), and 0.952 (future trend), respectively. Meanwhile, the sampling adequacy was tested using Kaiser-Meyer-Olkin (KMO), and Bartlett's Test recorded high adequacy as well, 0.851(benefits), 0.841 (challenges), and 0.855 (future trend).

In terms of the respondent demographic, the highest number of respondents were quantity surveyors, 35% (10). The second one is civil and structural engineers (C & S engineer) 24% (7), followed by mechanical and electrical engineers (M &

E engineer) 17%. As for China, the highest number of respondents is quantity surveyors, 45.5%, followed by M & E engineers, 24.2%; architects, 12.1%; contractors, 9.1%; academics, 6.1%; and safety officers, 3.0%. Most respondents who answered this questionnaire have less than five years of work experience, accounting for 62.1% in Malaysia. Same as Malaysia, the major respondents in China are concentrated in those with less than 5 years of work experience, 57.6%.

The working experience between 5 and 10 years is the second, with 20.7% for Malaysia and 27.3% for China. For the working experience “10-<15” and “>=20”. The highest percentage of respondents are from the Junior level (Site Manager, Project Executive, Junior Quantity Surveyor, and others), with 48.3% for Malaysia and 66.7% for China. The highest percentage of age is in the 21-25 groups, with 37.9% in Malaysia and 45.5% in China.

4. Results and Discussion

4.1. Digital tools awareness in Malaysia and China

In Malaysia, over 50% of respondents have knowledge of BIM, Autodesk Revit, and CAD. However, most respondents lacked knowledge of other digital technologies, including Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), 3D printing, 3D scanning, big data, autonomous construction, cloud, and prefabrication.

In contrast, China presents a slightly more favourable situation, with over 70% of respondents indicating familiarity with BIM. Additionally, 60% of respondents possess knowledge of CAD, while approximately 50% have knowledge of Autodesk Revit and Glodon. Conversely, understanding other digital technologies was mostly below the 20% threshold, with MR, Autonomous Construction, and Cloud computing even exhibiting a concerning knowledge level below 10%. Table 3 summarises the knowledge level of DTs of respondents in both countries.

Table 3. Awareness of digital tools in Malaysia and China

DTs	Malaysia		China	
	Knowledge (%)	Preferred (%)	Knowledge (%)	Preferred (%)
BIM	64.3	65.5	78.8	78.8
Autodesk Revit	53.6	48.3	54.5	39.4
Cubicost	17.9	27.6	48.5	48.5
CAD	75.0	55.2	66.7	48.5
3D printing	17.9	17.2	18.2	12.1
3D scanning	14.3	20.7	12.1	6.1
AR	25.0	13.8	15.2	3.0
VR	32.1	13.8	21.2	6.1
MR	10.7	10.3	6.1	0
GIS	17.9	17.2	12.1	6.1
UAV	14.3	10.3	18.2	9.1
Autonomous Construction	7.1	10.3	6.1	3.0
Big data	7.1	31.0	15.2	15.2
Cloud	17.9	27.6	9.1	3.0
Prefabrication	17.9	6.9	12.1	3.0
Other	3.6	3.4	0	0
No, I have never heard of these technologies before.	0	0	3.0%	3.0%

The result also revealed that there are commendable preferences by Malaysian construction industry professionals toward BIM (66%) and Autodesk Revit (48%), but relatively low preference toward Cubicost (28%), Big Data (31%), Cloud computing (28%), and 3D Scanning (20.7%). Disappointingly, there is significantly less interest in adopting other digital technologies, as only 20% or fewer respondents expressed willingness to adopt these alternative DTs. Similarly, respondents in China indicated a high preference for BIM (78.8%) and a moderate preference for Autodesk Revit (39.4%) and Cubicost (48.5%).

Unfortunately, the remaining digital technologies recorded considerably lower interest. For example, Big Data and 3D printing garnered only 15% and 12% interest, respectively, while the other digital technologies fared even worse, with less than 10% interest. However, it is worth noting that approximately 50% of respondents from both countries demonstrated a high level of enthusiasm for CAD, indicating a relatively strong reliance on 2D drawings [40]. Overall, the analysis results from Table 3 indicate that Malaysia and China are still in the early stages of adopting digital technologies.

4.2. Comparison between China and Malaysia

There were significant differences between Malaysia and China in terms of the benefits, challenges, and future trends of digital technologies (DTs). In Malaysia, as indicated in Table 4, the highest recorded factor loading in the benefits was "Reduce printing fee", with a value of 0.797. This was confirmed by previous studies [41], highlighting the immediate cost savings associated with the adoption of digital tools in the Malaysian construction industry. Conversely, in China, "Improving safety" was identified as the most significant benefit of DTs, recorded with a factor loading of 0.930. This may have been due to China's relatively high construction accident death index, which stood at 1.99 per day [42]. Both countries shared CB3 (Minimise conflict) and MB1 (Reduce printing fee) as top-five benefits. This was mainly attributed to the increasing emphasis on sustainable development, where the integration of digital tools played a significant role [43].

In terms of the challenges, "The technology is not common in the current trend" emerged as the major obstacle that impeded the implementation of DTs in Malaysia, with a factor loading of 0.793. This finding highlighted the low adoption of technology in the construction industry [44]. Conversely, in China, the "High cost of upgrading the current IT system" ranked as the top challenge for adopting DTs, with a factor loading of 0.911. Both countries faced obstacles such as "Reluctance to initiate new workflows for the implementation of DTs" and "Difficulty in managing the change to new technology," as shown in Table 4. These challenges hampered the adoption of DTs in both countries. In the Malaysian construction industry, the top future trend of DTs was identified as "Improving safety," with a factor loading of 0.800. However, according to Table 4, the greatest expected benefit for the future trend in the Chinese construction industry was "Better decision making," recorded at 0.944. These conflicting results revealed that both countries were focusing on different aspects, suggesting diverse future expectations of DTs. As a developing country, Malaysia is highly dependent on foreign workers, with a current count of 1.45 million foreign workers, 46.63% of whom are in the construction sector. Men-driven construction work has recorded the highest rate of occupational fatalities, which is 3.3 times higher than the overall national occupational fatalities in Malaysia [45].

Owners often held absolute authority in construction projects, leading to their disagreement with the expected benefits of DTs for such projects. Consequently, they did not allocate budgetary funds for parties involved in DTs implementation [46]. As a result, DTs were initially placed in a lower-priority sequence at the beginning of construction projects.

Table 4. Digital tools adoption factors in the Chinese and Malaysian construction industry.

Benefits of DTs in the Malaysian construction industry	Factor loading
Reduce printing fee (MB1)	.797
Allow better quality (PB1)	.788
Minimise conflict (CB3)	.783
Improve communication (CB2)	.743
Ensure data consistency (PB2)	.702
Benefits of DTs in the Chinese construction industry	
Improving safety (MB2)	.930
Decreasing project cost (MB3)	.906
Reduce the number of Variation Orders (CB4)	.903
Minimise conflict (CB3)	.900
Reduce printing fee (MB1)	.890
Challenges of DTs in the Malaysian construction industry	
Technology is not common in the current trend	.793
Managing change to new technology is hard	.725
Reluctant to initiate new workflows for implementation of DTs	.667
Lack of digital talents	.640
More time for training	.613
Challenges of DTs in the Chinese construction industry	
High cost of upgrading the current IT system	.911
Reluctant to initiate new workflows for implementation of DTs	.894
Existing hardware incapable of running basic software	.880
Not appropriate to the project	.876
Managing change to new technology is hard	.870
Future trends of DTs in the Malaysian construction industry	
Improve the safety	.800
Easier to present to the client	.798
Better communication	.749
Increase global opportunity	.746
Assistance in data management	.686
Future trends of DTs in the Chinese construction industry	
Better decision making	.944
High value for future market	.931
Improve the safety	.914
Avoid Conflict	.911
Increase global opportunity	.906
Improve the quality	.906

Experienced engineers in the construction industry have traditionally been trained and accustomed to implementing conventional construction models. Their lack of confidence in new digital tools has hindered the adoption of digital technologies in the industry. However, once the challenges related to people's mindset and confidence are addressed, there is potential for the vigorous development of DTs in the construction industry.

Communication is regarded as a process of exchanging information that fosters understanding between individuals. It is crucial to enhance project planning, influence and support behavioural changes, and determine the necessary measures to sustain and solidify improvements. Effective communication is vital in all aspects of high-quality management [47]. Therefore, incorporating communication strategies to cater to management needs represents a future trend that can drive the successful transformation of DTs in the industry.

5. Conclusion

In summary, this study aimed to understand the digitalisation status of the Architecture, Engineering, and Construction (AEC) industry in Malaysia and China by assessing digital technologies' knowledge and adoption levels (DTs). Additionally, the study determined the benefits of implementing various DTs in real construction projects. These benefits encompassed the capability to enhance productivity, thereby contributing to producing high-efficiency, high-quality, high-security construction products, resulting in enhanced profitability. Furthermore, the study compared the actual progress of digitalisation in the AEC industry between Malaysia and China to explore the potential application of DTs in improving productivity in both countries.

This study also explored the challenges of adopting DTs in Malaysia and China and examined the relationship between the challenges, benefits, and future trends of DTs. The key three benefits of adopting DTs were reduced variation orders, cost savings in project execution, and improved productivity. The four primary challenges encountered in the adoption of DTs included difficulties in managing changes towards new technology, the lack of cyber security in DTs outcomes, a potential increase in professional complacency due to convenience, and the additional costs incurred for training and reskilling.

In terms of future trends, the three highest expectations were focused on better problem-solving, improving customer experience, and handling more complex tasks. Furthermore, it was noted that communication benefits positively influence future management trends and profitability. Thus, a positive relationship existed between people-related challenges and the benefits of effective communication. Additionally, the study revealed that the benefits of DTs significantly influence the developments in DT adoption.

It can be concluded that the benefits of DTs were evident to the AEC industry in Malaysia and China, but regrettably, the adoption level of DTs in both countries was found to be still relatively low due to several challenges, as identified by previous researchers. Compared to developed countries such as Singapore, there is still a significant gap in this adoption level. Nevertheless, the two governments have successfully introduced policies addressing these challenges in recent years. ‘Made in China 2025’ emphasises the integration of different industries and promoting new information technology to accelerate the construction industry's transformation in promoting green, intelligent, and sustainable construction. Meanwhile, Malaysia's Construction Industry Transformation Programme (CITP) focuses on improving productivity, increasing safety standards, and enforcing sustainable development by effectively implementing new technologies and modern practices and employing highly skilled professionals.

This study contributed to addressing the industry-specific need, focusing on addressing the industry-specific needs and challenges related to the adoption of digital tools in construction. This includes exploring specialised tools for construction processes, such as Building Information Modelling (BIM), Augmented Reality (AR), Virtual Reality (VR), robotics, and the Internet of Things (IoT). Understanding these technologies' unique requirements and potential applications has supported the Malaysian Construction 4.0 Strategic Plan 2021-2025 development.

6. Limitations and Future Works

This study recognises the response biases that might have occurred as respondents were allowed to convey their responses through a self-reported questionnaire without the researcher's face-to-face explanation. Justification through Cronbarch's Alpha, KMO, and Barlett's Test were conducted to justify the reliability and validity of the questionnaire to minimise the impact.

Future studies may consider extending the research into a larger geographical area to obtain more comprehensive insights into the adoption levels of DTs in different parts of the world. With the relentless development of technologies, the challenges of adopting DTs warrant constant research to keep pace with the real-time dynamics of the construction industry. Newer and more sophisticated methods need to be explored to promote the adoption of DTs to accommodate the fluidity of the ever-changing situation accordingly.

Furthermore, the relationship between the implementation of DTs and challenges should be further studied in other locations. Finally, the relationship between each DT could be further investigated based on each own challenges and benefits to attain a more detailed insight. All this information will provide valuable guidance to the respective policymakers in different states and even countries by assisting them in developing effective and sustainable strategic plans to enhance further and support the digitalisation process of the construction industry.

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