Embracing The Digital Twin for Construction Monitoring and Controlling to Mitigate the Impact of COVID-19

Tan Jian Lin[1], and Nur Mardhiyah Aziz[1]*

[1]Department of Quantity Surveying, Faculty of Built Environment, University of Malaya, Malaysia.

Corresponding author: **nurmardhiyah@um.edu.my**

Published: 31st December 2022

COVID-19 has affected a lot of industries in Malaysia including the construction industry. In an effort to curb the spread of the pandemic, the government has introduced the Movement Control Order (MCO), which has halted all developments and construction activities. Thus, this study was conducted to understand the pandemic's effects on the construction industry and the usage of technology during the MCO. A quantitative research method was adopted, where 400 questionnaire surveys were sent to contractors' grade G5, G6, and G7 in Malaysia and 30.5% of responses were received. Data obtained were analysed using descriptive analysis and the Relative Important Index (RII). Findings show that the significant impacts are the increased project cost, labour shortage, project delay, late payment, COVID-19 cluster on-site, limitation to visit the site and reduced number of construction projects. In terms of technology usage, BIM, IoT, and Computing are commonly used by the majority of the contractors. These 3 technologies are vital in moving towards the implementation of Digital Twin. Based on the findings, the Digital Twin strategies were then proposed to mitigate the effects faced by the contractors in terms of automation, prediction, monitoring, modelling and resource management.

Keyword: Digital Twin, construction, pandemic, COVID-19, Malaysia

1. INTRODUCTION

The COVID-19 pandemic has impacted the global industry including the construction industry. Every country around the world has imposed a movement restriction to slow down the spread of the virus. During this time, only essential services like healthcare services, security, and food services are allowed to operate. Any activities from other industries like construction, education, and entertainment industries have been suspended.

According to Zamani et al. (2021), the movement restrictions imposed by the government have a big impact on the Malaysian economy. The Department of Statistics Malaysia reported that the construction industry in Malaysia has been hit particularly hard by the pandemic (Department of Statistics, 2020). During the first three lockdowns imposed by the Malaysian government, the construction industry lost RM18.5 billion (Fadilah, 2020). Between March 18 and April 14, losses reported were RM11.6 billion in the first and second stages of the shutdown, and RM6.9 billion between April 15 and April 28 in the third phase. The construction industry is predicted to have lost RM42 billion from March 18, 2020, to September 2021 as a result of the implementation of the movement control order (MCO) (Fadilah, 2021). Worse, some of the construction projects had been terminated, increasing the unemployment rate by 29% (Lee, 2020).

Realising the negative effects of suspending construction activities, the Malaysian government introduced a more relaxed movement restriction in January 2021, where the construction activity is allowed to be operated with 30% capacity with a specific SOP. Despite the effort to minimise the negative effects on the economy, it has added new COVID-19 cases. Damanlela Cluster is the first construction site cluster discovered in November 2020, involving 630 labours infected with COVID-19. On July 6, 2021, the Damenlela cluster contributed to the highest cases number of COVID-19 reported in Kuala Lumpur. Tan Sri Dr. Noor Hisham Abdullah, the Health Director-General, stated that the Damanlela site cluster has extended to six generations (The Malaysian Reserve, 2021). The cluster has 2,785 cases up to March 13, 2021, when it was declared ended.

As the country struggling to reduce the transmission of the virus, MCO has reduced the number of foreign labour available in Malaysia. Owing to the lockdown, many construction foreign employees have returned to their home countries and are unable to return to Malaysia (Wahab, 2020) due to numerous travel restrictions and visa requirements. The reduction in the number of labours has contributed to poor construction building progress (Zamani et al., 2021). Companies are experiencing a scarcity of competent personnel, primarily foreign labour. Due to the outbreak, many experienced construction employees were laid off (Rodzi, 2020).

During the COVID-19 pandemic, as a public health emergency, site visits had been reduced to lower the number of personnel on-site (Tobias, 2020). During a pandemic, everyone is expected to stay at home or limit their travels in order to prevent or spreading of a potentially fatal virus, (Kavanagh, 2021). As fears grow about the likelihood of a second wave of COVID-19, design professionals should think about how to transform construction activities using digital technologies (Baumgardner, 2020). All of these issues can be solved using Digital Twin. For example, the on-site construction condition and progress can be monitored in real-time using the drone. The monitoring or inspection process can be done remotely by the manager. Digital Twin can follow or replicate the construction process analysis cause in real time, minimise construction engineering disputes, and limit the incidence of engineering safety incidents in the event of an unusual condition (Chen et.al, 2021). Contractors should be prepared to execute virtual site inspections and payment certification obligations. The application of Digital Twin may be regularly updated with site information when utilised during construction. There is no need for several visits by the various parties involved because they can just inspect the digital model. Instead of scheduling several trips and meetings, a person who is always on-site might be entrusted with keeping the Digital Twin up to date (Tobias, 2020). The usage of Digital Twin also makes it easier to compile progress reports and other building papers. Instead of scheduling a site visit, key project information may be simply acquired. The flow of information is improved through an agile documentation process, which may also be utilised to better handle interim payments.

2. BACKGROUND

2.1 Research Gap

Despite the negative effect of COVID-19, this pandemic has encouraged the adoption of digitization in the construction industry. This further has strengthened the construction industry's digitization process. Chen et al. (2021) have reported that an emergency hospital has been built using the modular composite in a shorter time while maintaining COVID-19 norms. Other researchers also have reported the increased usage and adoption of smart buildings (Al-Humairi et al., 2021), the adoption of BIM (Wang et al., 2021), and the implementation of IR 4.0 tools to cope with the COVID-19 pandemic (Javaid et al., 2020). Furthermore, scholars have revealed the technology in changing the architectural design (Megahed & Ghoneim, 2021), and urban planning (Herman and Drozda, 2020) to avoid disease infection. Also, experts have highlighted the necessary remedial measures such as sanitization, social distancing, and remote working to limit the pandemic's influence on the building industry which require the aid of technologies (Biswas et al., 2021).

In facing a new global challenge, let alone a pandemic or other business challenges, the construction industry members need to formulate a new strategy by embracing the technology for future survival. According to Ibrahim et al. (2021) and Anassruddin et al. (2019), the adoption of technology in the Malaysian construction industry is improving but it is still far behind as compared to other Asian countries like China, Singapore, Japan, Hong Kong and South Korea. As for BIM, its adoption rate in Malaysia is 17%, as compared with the US (71%), UK (38%) and Singapore (65%) (Rafee, 2021). Thus, to accelerate technology adoption, the Malaysian government has highlighted technology and innovation as one of the policy enablers in the Twelfth Malaysian Plan. On top of that, the Construction Industry Development Board Malaysia has launched the Construction 4.0 Strategic Plan (2021-2025) that emphasizes changing the traditional way of the construction process to integrate the usage of technologies in enabling faster, flexible and efficient work processes.

2.2 Literature Review

2.2.1 Impact on Construction Industry

Following WHO’s declaration of the COVID-19 outbreak as a pandemic, several countries have implemented a comprehensive national lockdown (Gamil & Alhagar, 2020). These rulings have restricted people's travels and resulted in the closure of several businesses including the construction industry. As a result, several pandemic effects on the construction industry have been identified in the literature. There are 3 impacts identified which are shortage of construction material, shortage of labour, and delay of the project.

COVID-19 has drastically disturbed the supply chain. Not only certain important building materials were difficult to get but also some of the components were required to fulfil hygiene and safety standards (Sierra, 2021). The material shortage and logistics will result in delays and price increases. The majority of construction players reported experiencing or anticipating material delivery delays (Alsharef et al., 2021). It slows down the construction work progress and causes a substantial effect on the project’s timeframe. The problem is worsening when the supply chain contained goods or raw materials from another nation. China accounts for around one-third of global production, and the Chinese lockdown in the first months of 2020 began to influence the supply of building materials in early March (Ren, 2020). Several other nations have had significant lockdowns since March, and not all supply chain participants have returned to work at the same rate (Osunsanmi et al., 2021). Alsharef et al. (2021) mentioned that numerous building materials were to be transported from Europe but the production units in Europe were closed owing to the COVID-19 epidemic. Supply chain disruptions include material and raw materials from China, Canada, Mexico and also Malaysia. On the other side, due to capacity constraints for the epidemic, manufacturing factories are experiencing decreased productivity (Alsharef et al., 2021).

The construction industry has continuously had a labour shortage, but the pandemic intensified when most of the construction labour has been infected with the coronavirus (Karimi et al., 2018). As COVID-19 spreads mostly through human contact, construction worker contacts have played a key role in the delays in restarting projects. Physical distance restrictions aimed at preventing viral transmission have influenced the number of individuals allowed to work in a particular place, how employees do their jobs, and how project managers plan for the working environment (Araya, 2021). Companies are experiencing a scarcity of competent personnel, primarily foreign labour. Due to the outbreak, many experienced construction employees were laid off (Rodzi, 2020). Social distancing has minimised the number of labour working in the same location at the same time due to the SOP in the construction sites. Labour may feel worried or anxious when faced with increasing workloads as a result of personnel shortages caused by virus-infected labour and self-isolation (Pamidimukkala & Kermanshachi, 2021). Workforce shortages have interrupted inspection and maintenance operations, causing more employees are working overtime to finish their duties, and there are more personal hazards and concerns (Nawi et al., 2017).

Projects are being delayed during COVID-19 owing to a labour shortage caused by the SOP of MCO. The most typical causes of project delays are that the daily working hours have been curtailed (Zamani et al., 2021). These new guidelines have caused a significant impact on how all industries are now conducting operations. Shortage of material and labour will consequently affect the work progress (Alsharef et al., 2021). If the job wants to be completed during COVID-19, organisations must undertake risk assessments and provide essential personal protective equipment while adhering to the working requirements. As a result of the present pandemic, most projects are facing delays (Jallow et al., 2020). Many site engineers and operations team members in the building infrastructure field have been compelled to work from home because they are either at high risk or because their employers have required it (Jallow et al., 2020). Because staff personnel are unable to physically go on site and undertake work, this might cause considerable delays on a project. While management strives to adjust to a new way of functioning, projects have been paused, delayed, or altered, and new initiatives have been postponed (Pamidimukkala & Kermanshachi, 2021).

2.2.2 Application of Digital Twin

Boje et al. (2020) suggest developing a construction Digital Twin over three generations. The first generation is described as an improved version of BIM currently used in construction. The second stage incorporates semantics, characterising the construction of Digital Twin as an upgraded monitoring platform with limited intelligence, with a common web language framework deployed to describe the Digital Twin and all its integrated IoT devices, providing a knowledge base. The third generation is the summit of Digital Twin implementation to date, representing a fully semantic Digital Twin that leverages learned knowledge through the deployment of AI-enabled agents. To build a self-sufficient, self-updatable, and self-learning Digital Twin, artificial intelligence such as machine learning and data analytics is a must. There are 3 functions that a Digital Twin can perform which are modelling, simulation and data fusion.

Building information modelling (BIM) is one of the most significant recent advances in the construction industry. BIM technology produces a precise virtual picture of a structure that is built digitally (Azhar, 2008). BIM has received a lot of attention and has spread throughout the last few decades (Li et al., 2017). A BIM model, as a 3D digital representation of a structure, comprises both geometric and semantic information on the building parts. BIM enables seamless communication between construction industry experts because of the sharable and consistent database and has therefore been widely employed in building life cycle management, spanning the design, construction, and operating stages (Deng et al., 2021). BIM is a virtual process that combines all elements, disciplines, and systems of a facility into a single virtual model, allowing all stakeholders (architects, engineers, contractors, subcontractors, and clients) to collaborate more effectively and accurately than traditional methods (Azhar, 2008). They are constantly improving and updating their parts in reaction to project factors and design changes, ensuring that the model is as accurate as possible before the project begins in earnest (Jung et al., 2016).

Internet of Things (IoT), which interconnected various sensors (Gubbi et al. cited in Deng et al., 2021), it became feasible to combine real-time detecting data with static information offered by BIM models (Tang et al., 2019). Smart devices enabled the viewing and analysis of real-time environmental data in BIM models, as well as the automated modification of BIM models based on real-time building status. The data generated by the sensors in the structures are monitored by supervisors or construction labour on several platforms (Kazado et. al., 2019). A large amount of data collected throughout the design and construction phases of the project that might be useful for the building's operation is passed to the management (Thabet & Lucas, 2017). As a consequence, a revolutionary technique combining BIM data with building sensors might provide a shared data environment for improving building energy and indoor environmental performance while reducing operational costs (Kazado et al., 2019). The Autodesk research group demonstrated a BIM-based building interface that visualises BIM with sensors. Not only facility management but it can also be adopted in the construction phase too (Begić & Galić, 2021).

Data fusion is another important supporting technology since Digital Twin must analyse a vast number of data acquired from many sources (Tao, 2018). Data fusion is the process of fully using numerous information sources by merging duplicated or complementing information by particular criteria to generate a constant interpretation or description of the assessed item, allowing the information system to outperform the system constructed of each subset it comprises (Kong et al., 2020). Building multisensor data fusion will bring fresh and useful insights that facility engineers may quickly incorporate into their control cycle or decision-making process (Kong et al., 2020). Artificial Intelligence or Machines Learning focuses on large data analytics to help object categorization evaluation. To begin, by sensing the data acquired by the device, the constituents of the physical entity are monitored and dynamically characterised. Second, historical data is evaluated, and the causes for changes in function and performance are investigated. Third, the relationship between various models and their ability to predict the future is revealed. Finally, conduct is led by understanding the past and forecasting the future (Wang et al., 2022).

3. METHODOLOGY

Firstly, literature reviews are used to identify the information about the Digital Twin in the construction industry. These facts will help readers clarify the term Digital Twin comprehensively. Secondly, literature reviews are used to examine the types of Digital Twin. The database for conducting the literature reviews are Emerald, JSTOR, ScienceDirect, and Google Scholar. The articles and dissertations are searched within recent 5 years which is from 2016 to 2021. The keywords used during the searching of the papers are "Digital Twin", "AI", "BIM", "drones", "robotics", "construction", "pandemic", "COVID-19" and "Malaysia". The literature review begins by reviewing the issue faced by the Malaysian construction industry. This is followed by how COVID-19 impacted the construction industry during the pandemic. On top of that, this impact has induced the construction industry to adopt Digital Twin to mitigate the problems faced during the pandemic.

To describe a situation, the quantitative method was adopted by gathering data from a sample size of the Malaysian Contractor Grade 5 to Grade 7 through questionnaires and surveys. The purpose of the questionnaire is used to understand the impact of COVID-19 on the construction operation and to identify the implementation of Digital Twin or other IR 4.0 tools among the contractors. Only G5, G6 and G7 graded contractors are selected as they are involved in the construction works of over RM5 million. Thus, their capability to adopt IR 4.0 tools is higher compared to the lower-grade contractor. Besides, these classes represent the most organised group of companies. They have regular offices and contacts, and accessible administrative structures (Memon & Zin, 2010).

Based on the CIDB official website www.cidb.gov.my., the total number of contractors G5, G6 and G7 registered with CIDB in 2021 is 11208. Based on the Krejcie and Morgan table, the minimum optimal sample size for G5 to G7 contractors is S= 375 (N=15000). To reflect a cross-section of the population, a sample size of 375 people would be required. As a result, 400 questionnaires were sent to contractors to collect their responses.

The questionnaire was divided into 3 sections, Section A is on the demographic profile of the respondents, and section B is to determine the impacts of COVID-19 on the construction industry. Section C is to examine the initiative taken by contractors to mitigate the problems they faced during the pandemic. A set of multiple-choice answers were prepared in sections B and C. Google forms surveys were emailed to the companies that meet the criteria of the respondents. The list of targeted companies was retrieved from the CIDB official website with email addresses taken from their corporate websites. The surveys were distributed and collected over 4 weeks. Data were analysed using Microsoft Excel to calculate the relative significance index (RII).

4. RESULTS

4.1 Respondents' Background

At first, only 122 responses were received. Reminder emails were then sent to all the respondents to increase the response rate. Finally, the response rate achieved 30.5%. According to Ghaffar et al., (2020), a 30% of response rate is considered acceptable for research related to the construction industry.

A) *Work Position in Company*

Most of the respondents were project managers, which accounts for 45.9%. This is followed by 10.7% were the clerk of work, 5.7% were the company director and 3.3% were admin assistants. The other responses were responded by construction professionals such as engineers, general managers, managing directors, project directors, quantity surveyors and sales directors which contributed 4.9% of the responses.

B) *Years of Working Experience*

The majority of respondents have over 20 years of construction sector experience (50.8%). There were 19.7% of respondents who have more than 15 years but less than 20 years of construction industry experience. This shows that the majority of the respondents have vast experience in the construction industry. Only 19.7% have less than 5 years of experience, while 4.9% have been in this sector for 5 to 10 years, and 4.9% of respondents have working experience of 10 to less than 15 years.

C) *Grade of Contractor*

Grade 5 contractors had the greatest percentage of respondents with 40.2%, followed by Grade 6 contractors at 35.2%, and Grade 7 with (24.6%).

4.2 RII for Impacts of COVID-19

In this study, the Relative Importance Index (RII) analysis was used to rank the impacts based on their relative importance. RII is a statistical method to determine the ranking of variables (Hossen, 2015) and analyse the significance level of the variables (Chan, 2012). The relative index is calculated using the formula below

$$RII = \Sigma W / (A*N)$$

where w is the weights supplied by each of the respondents on a scale of 1 to 5, with 1 being the least and 5 denoting the most. A is the sample's greatest weight (5), and N is the total number of samples (122). The weighted average for the two groups will be established based on the ranking of relative indices (RII). RII values are translated into five important levels: high (H) ($0.8 \leq RII \leq 1$), high-medium (H–M) ($0.6 \leq RII \leq 0.8$), medium (M) ($0.4 \leq RII \leq 0.6$), medium-low (M-L) ($0.2 \leq RII \leq 0.4$) and low (L) ($0 \leq RII \leq 0.2$) (Rooshdi et al., 2018; Othman et al., 2021).

Table 1. Ranking of Impacts of COVID-19 on the Construction Industry

Level	Rank	RII	Impacts
High	1	0.8721	The increased cost of the project
	2	0.8656	Labour shortage
	3	0.8557	Delay of project
	4	0.8311	Late payment
	5	0.8148	COVID-19 cluster on site
	6	0.8049	Limitation to present on site
	7	0.8000	Reduced number of project
High - medium	8	0.7951	Difficulty in site monitoring
	9	0.7902	Logistics
	10	0.7852	Material shortage
	11	0.7656	Inoperative site
	12	0.7459	Suspension/ Termination of project
	13	0.6459	Low quality of works

Table 1 shows the RII of each impact that is caused by COVID-19. The impact with the highest index has the most significant consequences, whereas the lowest index factor affects the construction industry the least. Microsoft Excel was used to calculate the sum of weights using the RII formula shown above. The impacts with an RII value of higher than 0.8 are considered high levels of importance (Akadiri, 2011). The RII value between 0.6 and 0.8 is considered a high-medium level of importance. Hence, all of the impacts listed in Table 1 are considered significant.

4.3 Frequency Analysis for Solutions

In Section C of the questionnaire, the respondents are instructed to choose the measures they opt for to mitigate the operational impact of COVID-19 on the construction industry. The solutions will be related to the impacts mentioned in Section B. Therefore, there will be 4 parts for different types of solutions. The respondents are allowed to select more than 1 answer.

A) *Solutions for Operational Impact*

There are 8 solutions suggested for respondents to select for overcoming the operational problems as shown in Figure 1. The solution with the highest vote is reallocating resources (55.7%), followed by subcontracting (50.8%). Half of the respondents have implemented these 2 methods during the pandemic. The solutions implemented by around 40% of respondents are considering alternate materials (45.9%), getting a permit for movement across states/countries (45.9%), and hiring expensive labours (39.3%). The solutions that are implemented lesser are procuring expensive materials (29.5%), applying modular construction (24.6%), and using casual employment of labours (19.7%).

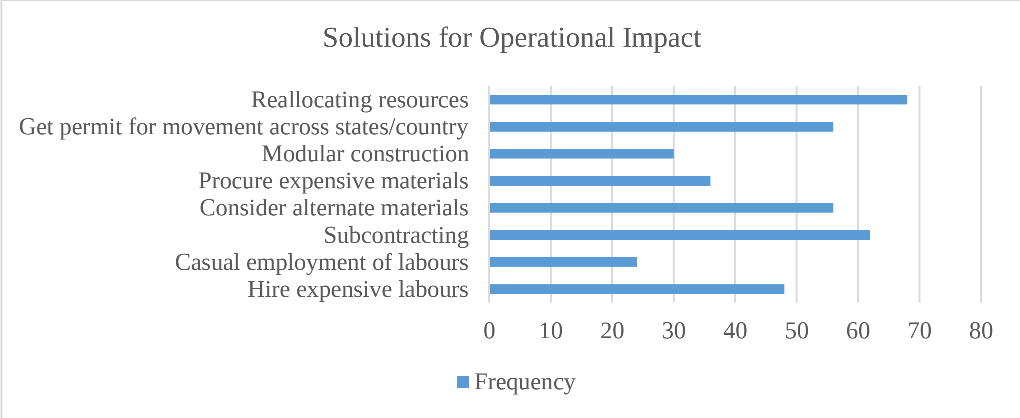

Figure 1. Percentage of Solutions Implemented for Operational Impact

B) *Solutions for Financial Impact*

Figure 2 shows solutions implemented to minimise the financial impact on the contractors. Applying government incentives for staff had been implemented by most of the respondents (65.6%). Other solutions implemented by more than half of the respondents were loan funding (55.7%) and extra financial resources (55.7%). Tendering for the available project (29.5%) and adjudication for non-payment/late payment (34.4%) were implemented too. The remaining solutions achieve very low frequency such as laying off staff (19.7%), insurance policies (9.8%) and lien and bond claims (4.9%).

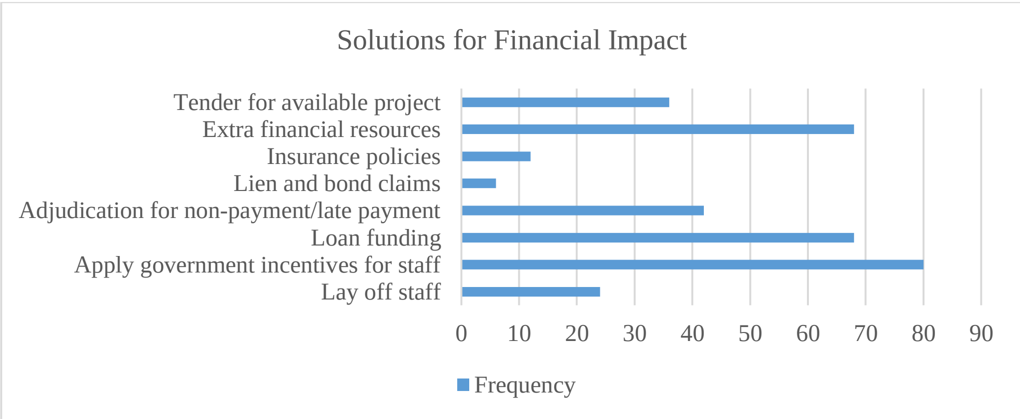

Figure 2. Percentage of Solutions Implemented for Financial Impact

C) *Solutions for On-site Impacts*

As shown in Figure 3, the screening test for COVID-19 on employees (85.2%), online meetings (80.3%) and standard operating procedures that follow local guidelines (75.4%) were implemented by the majority of the respondents to mitigate the on-site impacts. This is followed by site sanitizing (59.8%), training for employees on the spread of the disease (39.3%) and reducing the labour on site (39.3%). The lesser implemented solutions were installing a surveillance system/security (24.6%) and using a drone for a site inspection (14.8%).

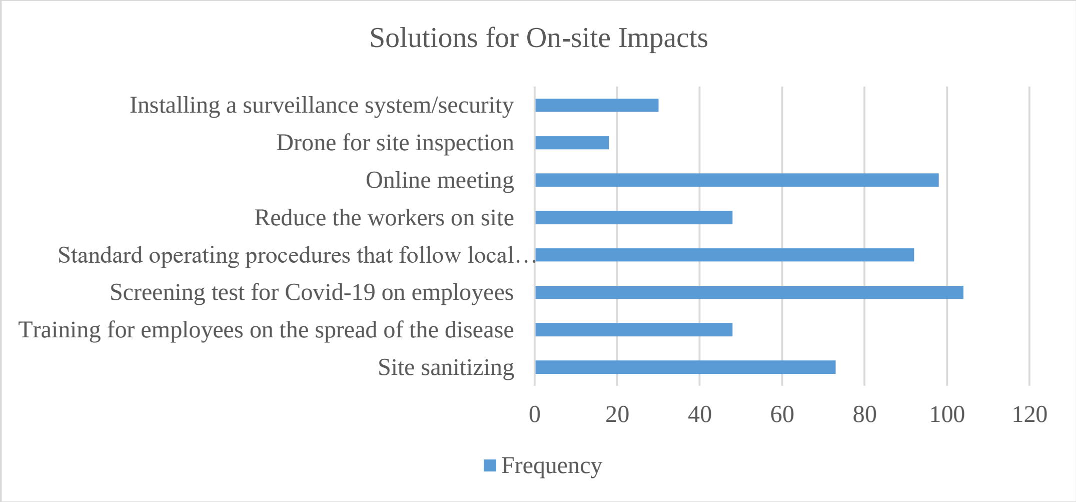

Figure 3. Percentage of Solutions Implemented for On-site Impact

D) *Solutions for Contractual Impacts*

For solutions for contractual impacts, only an extension of time was implemented by the majority of the respondents (80.3%) (refer to Figure 4). This is then followed by reprogramming of work (65.6%) and extra financial resources (54.9%). Some contractors also seek contractual provisions (44.3%) and reduce the number of projects (40.2%) to mitigate the contractual impacts. The solutions that were less implemented by the respondents are remobilization (29.5%) and design changes (24.6%). The least implemented solution would be insurance policies (9.8%).

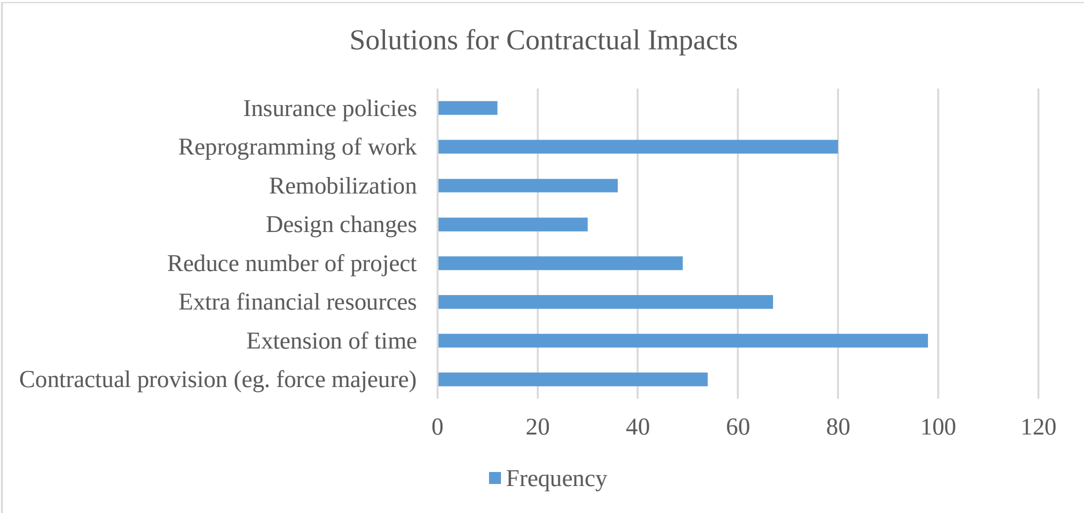

Figure 4. Percentage of Solutions Implemented for Contractual Impact

4.4 Frequency Analysis of Technologies Implemented

In this section, the respondents are also asked about the technology used by each contractor in their organisations. Figure 5. shows the technologies used in their business operations.

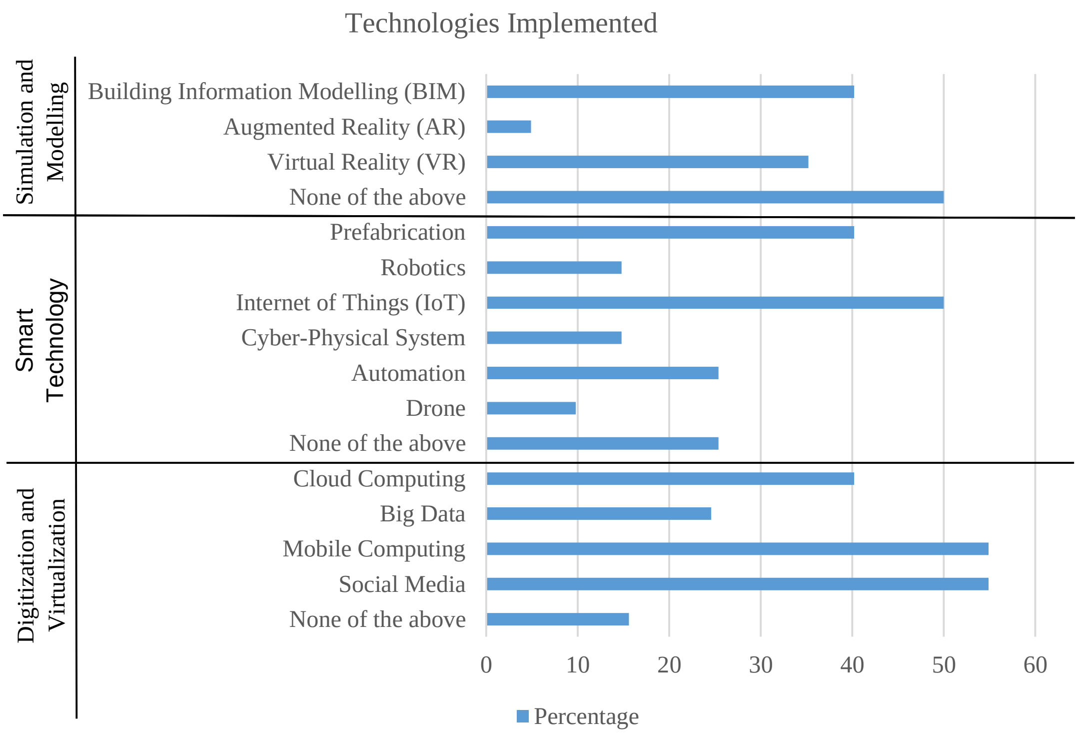

Figure 5. Technologies Implemented by Respondents

50.0 % of the respondents stated that their organisation does not use any simulation or modelling technology. Overall, 40.2 % of the contractors employ BIM technology, and 4.9 % of the contractors use VR in their business operations. AR is seen to be unpopular since only 6 contractors were implementing it. The vast majority of contractors use BIM to improve their operations.

Of all the respondents, 25.4 % declared that their company does not use smart technology. Half of the respondents (50.0 %) were integrating IoT systems for their corporate operations, while 40.2 % of the contractors employ prefabrication technology in their building projects. Only 14.8 % of respondents use robots, while 25.4 % use automation systems to boost efficiency in the building process. 14.8 % of all respondents, also employ cyber-physical systems to increase physical process integration and cooperation. While 9.8% of contractors utilised drones on building sites to obtain real-time data.

For digitization and virtualization, only 15.6 % of the respondents declared that their company did not use any relevant technologies in their work process. For their business operations, the majority of contractors (54.9 %) used both social media and mobile computing. About 40.2 % of contractors also used cloud computing to improve their organization's accessibility and transmission procedure. On the other hand, 24.6 % of contractors, used big data to boost efficiency and productivity.

4.5 Frequency Analysis and Measure of Central Tendency of Digital Twin

Surprisingly, 80.3% of the respondents are not aware of Digital Twin and only 19.7% of them aware of it as shown in Figure 6.

Figure 7 summarized the opinions among contractors. About 85.2% of respondents state that they have a neutral opinion regarding the usage of Digital Twin to mitigate the impacts of COVID-19 on the construction industry. 4.9% of the respondents strongly agree that Digital Twin can be used to mitigate the impacts of COVID-19 on the construction industry and 4.9% of the respondents agree with the same statement. However, 4.9% of the respondents strongly disagree that Digital Twin can mitigate the problems mentioned above. This may be due to the ignorance of the respondence on the existence of the Digital Twin, where 80.3% of them are not aware of Digital Twin.

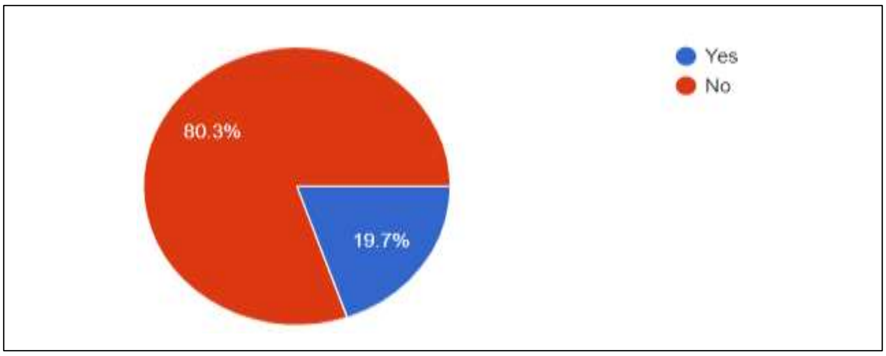

Figure 6. Percentage of Respondents who aware about Digital Twin

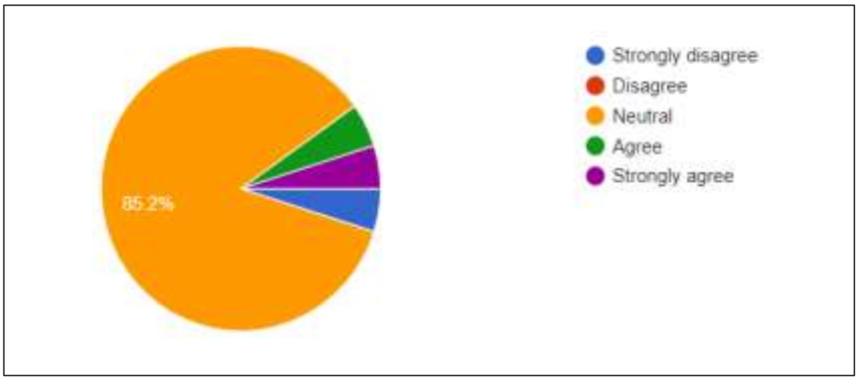

Figure 7. Agreement of Respondents on Implementing Digital Twin to Mitigate the Problems

5. DISCUSSION

5.1 Discussion on Impacts of COVID-19 faced by the Respondents

Findings from this study show that the most significant impact of COVID-19 on the construction industry is the increased cost of the project. This is due to the increased material price which is reflected in the fluctuations in foreign currency rates and increasing demand for suppliers. The shortage of labour and material will consequently increase the cost of both items. Furthermore, the SOP specifically for the construction industry has incurred additional costs as a result of COVID-19 prevention measures (Simpeh, 2021). The second-ranked impact is the labour shortage. This is due to the laid off of many experienced construction employees (Rodzi, 2020). This issue is worsen when many foreign employees went back to their home countries and were unable to return to Malaysia (Wahab, 2020) due to numerous travel restrictions and visa requirements. Not only that, delay in projects is faced by most contractors and ranked third place in this study. The number of contractual difficulties in terms of conflicts, litigation, and claims on building projects would dramatically grow (Alsharef et al., 2021). The main reasons for these contractual problems might include delays as a result of the epidemic. Contractors may not be able to complete the project, leading to an increase in variation orders and claims.

According to Zamani et al. (2021), the problems faced by most contractors is a reduced number of projects, followed by increased project cost and then late payment. However, in this study, the reduced number of projects is ranked seventh. The differences may result from the different periods of data collection, where research by Zamani et al. (2021) was conducted during the early phase of the pandemic when most of the projects are suspended or cancelled. After more relaxed movement restrictions were introduced by the government, ongoing projects are granted an extension of time and can proceed. For the fourth impact, payments for projects are frequently made based on the work progress. Payment will be provided once the government projects. Due to the disruption of construction activities during the MCO, payment and claims was delayed as they are no work progress. The COVID-19 cluster on site was ranked as the fifth impact. The majority of construction labour had caused the outbreak of COVID-19. Indirectly, to prevent the spread of the virus, people are restricted to gather in certain places. This led to the limitation to be present on the construction site which was ranked sixth. During the MCO, people's movement is restricted, as they may not be able to cross the district or state to be present on the construction site (Bunyan, 2020).

Lastly, the pandemic also reduced the number of construction projects. The pandemic had caused the governments to reallocate funding and prioritise the country's expenditure to manage the pandemic. All of this has caused a decrease in the country's short- and medium-term infrastructure investment budgets (Deloitte, 2020). Furthermore, the pandemic has caused significant economic uncertainty. Governments are thus compelled to put off or cancel public projects and reserve spending, which affects construction activities (King & Rahman, 2021).

5.2 Discussion on Solutions to Mitigate the Problem

A) *Solutions Implemented for Operational Impact*

For labour shortage problems, almost half of the contractors choose to subcontract their projects. Vithana (2020) also states that the construction industry discourages permanent employment but encourages subcontracting. Since the foreign labour returning to their country and the entry restrictions for new labour (Zamani et al., 2021), the demand has increased the labour cost. However, there is still around one-third of the contractors who choose to hire expensive labours whereas casual employment of labours is implemented by a few respondents only. Several contractors have considered alternate materials to provide faster delivery (Alsharef et al., 2021). Procuring expensive materials or using modular construction are done by about a quarter of the respondents. Logistics problems are mostly resolved by getting a permit for movement across states and the country. Overall, reallocating resources is done by more than half of the respondents, especially skilled labour whenever it is possible to carry out the work (Wang, 2021). Since material and labour shortages have led to an increase in cost, the contractors can only reallocate their resources to cope with the price fluctuation.

B) *Solutions Implemented for Financial Impact*

Solutions implemented for financial impact are mostly related to financial resources since the increased cost of the project is ranked as the top problem faced by the respondents. The most implemented solution is applying government incentives for staff. During the pandemic, the government introduced National Economic Recovery Plan (PENJANA) to promote employee retention and reduce layoffs by extending the wage subsidy programme (Yeoh & Pua, 2020). Employers are given a wage subsidy to retain their employees with a salary below RM 4,000. However, there is still one-fifth of the respondents choose to lay off staff due to the cash flow problem. It is then followed by loan funding and extra financial resources which are opted for by half of the respondents. Bank Negara Malaysia has bridged financing for the construction and development of properties (BNM, 2020). One-third of the respondents have sought adjudication for late payments or non-payments, while a quarter of the respondents have tendered for available projects when there is a reduced number of projects. Lien and bond claims and insurance policies are not chosen by many respondents due to inapplicable issues.

C) *Solutions Implemented for On-site Impact*

The most significant on-site impact is the emergence of the COVID-19 cluster site. Screening test for COVID-19 on employees is done by most of the respondents to prevent the spread of the virus. 3 quarters of the respondents follow the SOP that is required by the local authority. Site sanitizing is done relatively lesser probably due to the large and open area of the site. Research conducted by Simpeh (2021) also shows that labour is not used to sanitise the workplace and the equipment due to the nature of the work. Only one-third of the respondents trained their employees on the preventive measures against the spreading of the virus and reduce labour on site. The majority of the respondents have conducted an online meeting to mitigate the problem of the limitation to present on site. Similar to the research by Pamidimukkala and Kermanshachi (2021) and Jamaludin (2020), the virtual meeting was used as the new normal in a pandemic. Site monitoring can be overcome by the drone and surveillance system, but only a few contractors use a drone for site inspection.

D) *Solutions Implemented for Contractual Impact*

The majority of the respondents are granted an extension of time for their projects to avoid the delay of the project. The government has introduced an automatic Extension of Time (EOT) of 60 days for all government projects (Fadilah, 2021). Part of the respondents also seeks EOT using contractual provisions such as force majeure. For both suspension or termination of project and low quality with the lowest agreement level of impacts, most of the respondents have reprogrammed the work, one-third of the respondents have reduced the number of projects and half of the respondents have sought extra financial resources to prevent the works to be suspended or completed in low quality. According to Alsharef et al. (2021), approximately 90% of the pre-project planning phase project had to be halted. Other projects that were in the bidding stage were either cancelled or delayed. Part of the respondents remobilized the project after the suspension of work and also changed their design to avoid the low quality of work. Insurance policies are not widely implemented due to the coverage of the insurance (Koster, 2020).

5.3 Discussion on Digital Twin

There are certain impacts discussed in the previous section which actually can be resolved using Digital Twin. However, there are a majority of the respondents do not aware of the Digital Twin. Most of them also have a neutral agreement on using Digital Twin to mitigate the problems during the pandemic.

A) *Awareness of Contractors*

For simulation and modelling technologies, half of the respondents do not apply any of the
B) *Strategy Proposed*

technologies listed. Part of the respondents was implementing BIM and VR. When BIM and Digital Twin are combined, it allows for real-time building life-cycle management from design through operation and construction (Lim, 2021). Besides, a Digital Twin system based on VR serves as a digital duplicate of the physical human-robot interactive operating environment. A bidirectional information flow connects a human user with a model in the Digital Twin system. For the smart technologies categories, only a few of the respondents do not implement any of the technology listed. The most implemented technology is the IoT which can improve the performance of a Digital Twin model by combining the real-time detecting data with static information offered by BIM models (Tang et al., 2019). Not only that but prefabrication is also implemented by some respondents. The prefabricated building construction system based on Digital Twin technology may effectively monitor and precisely anticipate the damages to building components that may develop in the overall system (Zhou et al., 2021).

For digitization technologies, the respondents show a positive rate of implementation in mobile computing and cloud computing. Cloud computing enables massive amounts of data to be collected while allowing real-time communication for the realisation of the Digital Twin paradigm throughout the complete product's life cycle (Fuller et. al, 2020). According to other research, AI is a critical component to allow the Digital Twin to forecast, optimise, and make choices. By examining the information that people upload and like on social media, Digital Twin models may be used to capture human preference when designing a project. Generally, most contractors have implemented IR 4.0 technology to boost their productivity in building projects and make their jobs easier by using technology intelligence. As most contractors may not be able to afford the hefty implementation costs, simulation and modelling technology are the least popular among contractors. On the other hand, because of its simplicity and ease of use, digitization is the most often used technology among contractors in our business.

Figure 6 has shown how Digital Twin can assist the contractors in mitigating the issues they faced during COVID-19. There are 5 categories that Digital Twin can help with which are automation, prediction, monitoring, modelling and resource management. Each alternative solution by Digital Twin is categorized and grouped accordingly. Figure 6 has shown each problem that can be minimised with the application of the Digital Twin technology.

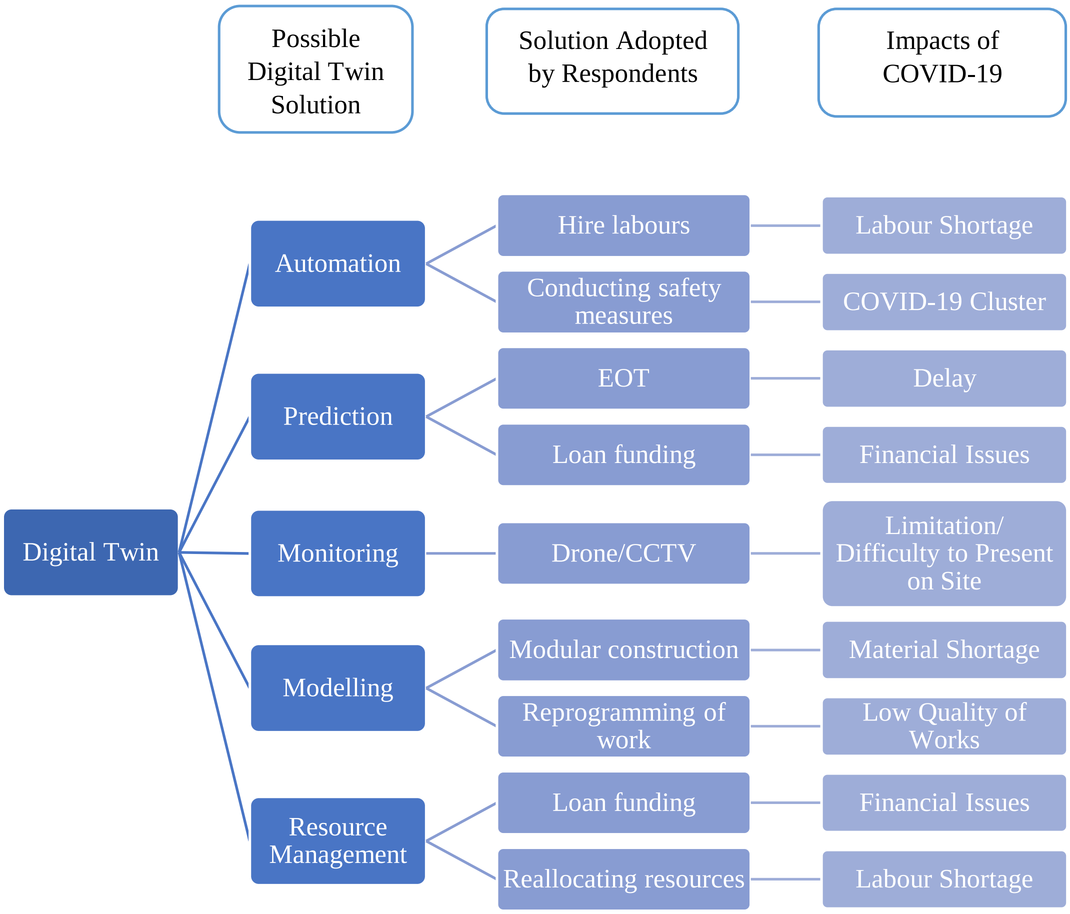

Figure 8. Digital Twin Solutions

The Digital Twin extends the usage of virtual simulation models produced during a manufacturing system's design phase to operations for real-time control, and dynamic skill-based work allocation between humans and robots. The integration of process automation and intelligent collaborative robots makes them ideal alternatives for expert labour in some repetitive jobs (Perez et al., 2020). The human workforce can be replaced by robots for repetitive work which can be realized through AI. With less labour, the COVID-19 cluster also can be prevented. For the project delay and financial issues, although Digital Twin is unable to solve them directly, the prediction function of Digital Twin can aid certainly. From fault detection, the contractors can save a huge cost and time. The Digital Twin led to more accurate forecasting and early conflict detection. The BIM model in the Digital Twin helps to save costs by preventing errors throughout the design and construction phases (Khajavi et al., 2019). With a virtual model, the construction project can be monitored easily with the aid of sensors and IoT. Although there is a limitation or difficulty in presenting on-site, Digital Twin can easily mitigate this problem. One of the greatest advantages of digital is to monitor the construction progress of a building. The data and information about the building will be retrieved from sensors and drones and transferred to the Digital Twin (To et al., 2021; Kong et al., 2020). The virtual component of the Digital Twin can be represented by the recovered real-time and historical data (Kazado et. al., 2019).

Furthermore, the material shortage and low quality of work can be solved by the Digital Twin. The respondents used to reprogram the work, consider alternative materials and use modular construction. These solutions can be aided by the BIM model of Digital Twin. According to Chen, et. al. (2021), a BIM model can use applicable technologies to control all parameters at the same time. If the input data changes, the data associated with it will change as well. Meanwhile, it can amend the inappropriate layout by viewing the site model's dynamic change information in real time according to the project timetable. Last but not least, Digital Twin can realise resource management to solve the problems faced by the contractors. Digital Twin performs numerous physical testing mechanisms. They refine the design to improve performance while lowering construction costs (Leng & Jiang, 2019). This allows for simultaneous real-time monitoring and updates from numerous sources. Virtual models could understand the condition of physical entities, as well as estimate and analyse dynamic changes such as financial issues and labour shortages.

6. CONCLUSION

This quantitative research reveals the problems faced by contractors during the pandemic. The respondents have rated their level of agreement on several impacts. The survey reveals that the top 7 impacts faced by the contractors are increased project cost, labour shortage, project delay, late payment, COVID-19 cluster on site, limitation to present on site and reduced number of projects. The solutions to minimise or resolve each problem are also sought from the respondents. The majority of the respondents are not aware of Digital Twin, so they are holding back on using Digital Twin to mitigate the COVID-19 impacts. Furthermore, the most implemented technologies from each category are Building Information Modelling (BIM), Internet of Things (IoT), and Mobile Computing which are the basis of the implementation of the Digital Twin. A few existing Digital Twin usage were listed to mitigate the impacts of COVID-19 on the construction industry. Based on those impacts, the functions of Digital Twin stated in the literature review are implemented to mitigate each of the significant problems.

7. REFERENCES

1. Akadiri, O. P. (2011). Development of a multi-criteria approach for the selection of sustainable materials for building projects, PhD Thesis, University of Wolverhampton, Wolverhampton, UK
2. Al-Humairi, S. N. S., & Kamal, A. A. A. (2021). Opportunities and challenges for the building monitoring systems in the age-pandemic of COVID-19: Review and prospects. Innovative Infrastructure Solutions, 6(2), 1-10. https://doi.org/10.1007/s41062-020-00454-0
3. Alsharef, A., Banerjee, S., Uddin, S. M., Albert, A., & Jaselskis, E. (2021). Early impacts of the COVID-19 pandemic on the United States construction industry. International journal of environmental research and public health, 18(4), 1559. https://doi.org/10.3390/ijerph18041559
4. Ansaruddin Agus, M. A. P., Hamzah, N., & Khoiry, M. A. (2019). BIM Implementation in Asia Towards Functionalities: A Systematic Review. International Journal of Engineering & Technology, 8(1.2), 60–65. https://dx.doi.org/10.14419/ijet.v8i1.2.24873
5. Araya, F. (2021). Modeling the spread of COVID-19 on construction workers: An agent-based approach. Safety Science, 133, 105022. https://doi.org/10.1016/j.ssci.2020.105022
6. Azhar, S., Nadeem, A., Mok, J. Y., & Leung, B. H. (2008, August). 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).

7. Baumgardner, B. (2020). Navigating Construction Site Visits During COVID-19. Oswald. https://www.oswaldcompanies.com/media-center/navigating-construction-site-visits-during-covid-19/
8. Begić, H., & Galić, M. (2021). A Systematic Review of Construction 4.0 in the Context of the BIM 4.0 Premise. Buildings, 11(8), 337. https://doi.org/10.3390/buildings11080337
9. Biswas, A., Ghosh, A., Kar, A., Mondal, T., Ghosh, B., & Bardhan, P. K. (2021, February). The impact of COVID-19 in the construction sector and its remedial measures. In Journal of Physics: Conference Series (Vol. 1797, No. 1, p. 012054). IOP Publishing. https://doi.org/10.1088/1742-6596/1797/1/012054
10. BNM. (2020). Coping with COVID-19: Risk Developments in the First Half of 2020. Bank Negara Malaysia https://www.bnm.gov.my/documents/20124/1395181/ch1.pdf
11. Boje, C., Guerriero, A., Kubicki, S., & Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research. Automation in Construction, 114, 103179. https://doi.org/10.1016/j.autcon.2020.103179
12. Bunyan, J. (2020). pm: Malaysia under movement control order from Wed until March 31, all shops closed except for essential services. MalayMail. https://www.malaymail.com/news/malaysia/2020/03/16/pm-malaysia-inlockdown-from-wed-until-march-31-all-shops-closed-except-for/1847204
13. Chan, C. T. (2012). The principal factors affecting construction project overhead expenses: an exploratory factor analysis approach. Construction Management and Economics, 30(10), 903-914. https://doi.org/10.1080/01446193.2012.717706
14. Chen, L. K., Yuan, R. P., Ji, X. J., Lu, X. Y., Xiao, J., Tao, J. B., ... & Jiang, L. Z. (2021). Modular composite building in urgent emergency engineering projects: A case study of accelerated design and construction of Wuhan Thunder God Mountain/Leishenshan hospital to COVID-19 pandemic. Automation in Construction, 124, 103555. https://doi.org/10.1016/j.autcon.2021.103555
15. Deloitte (2020), COVID-19's Impact on the Engineering and Construction Sector, Deloitte. https://www2.deloitte.com/global/en/pages/about-deloitte/articles/covid-19/understanding-the-sector-impact-of-covid-19--engineering---const.html
16. Deng, M., Menassa, C. C., & Kamat, V. R. (2021). From BIM to Digital Twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry. Journal of Information Technology in Construction (ITcon), 26(5), 58-83. https://doi.org/10.36680/j.itcon.2021.005
17. Department of Statistics. (2020). Quarterly construction statistics. First Quarter 2020. ISSN 2232-173X. Published on May 2020. Department of Statistics Malaysia. https://www.dosm.gov.my
18. Fadilah. (2021). Construction industry suffers RM42 billion losses due to MCO. Bernama. https://www.bernama.com/v2/en/general/news_COVID19.php?id=2008706
19. Fadillah, F. (2020) Malaysia's construction industry records $6b losses in first three lockdown phases. The Straits Times. https://www.straitstimes.com/asia/se-asia/malaysiasconstruction-industry-records-s6-bil-losses-in-first-three-lockdown-phases
20. Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. IEEE access, 8, 108952-

108971. https://doi.org/10.1109/ACCESS.2020.2998358
21. Gamil, Y., & Alhagar, A. (2020). The impact of pandemic crisis on the survival of construction industry: a case of COVID-19. Mediterranean Journal of Social Sciences, 11(4), 122-122. https://doi.org/10.36941/mjss-2020-0047
22. Ghaffar, S. H., Burman, M., & Braimah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery, Journal of Cleaner Production, 244, 118710, https://doi.org/10.1016/j.jclepro.2019.118710.
23. Herman, K., & Drozda, Ł. (2021). Green Infrastructure in the Time of Social Distancing: Urban Policy and the Tactical Pandemic Urbanism. Sustainability, 13(4), 1632. https://doi.org/10.3390/su13041632
24. Hossen, M.M., Kang, S. & Kim, J. 2015. Construction schedule delay risk assessment by using combined AHPRII methodology for an international NPP project. Nuclear Engineering and Technology, 47(3): 362–379. http://dx.doi.org/10.1016/j.net.2014.12.019.
25. Ibrahim, F. S., Esa, M., & A. Rahman, R. (2021). The Adoption of IOT in the Malaysian Construction Industry: Towards Construction 4.0. International Journal of Sustainable Construction Engineering and Technology, 12(1), 56–67. https://doi.org/10.30880/ijscet.2021.12.01.00
26. Jallow, H., Renukappa, S. and Suresh, S. (2020), The Impact of COVID-19 Outbreak on United Kingdom Infrastructure Sector. Smart and Sustainable Built Environment, Vol. 10 No. 4, pp. 581-593. https://doi.org/10.1108/SASBE-05-2020-0068
27. Jamaludin, S., Azmir, N. A., Ayob, A. F. M., & Zainal, N. (2020). COVID-19 exit strategy: Transitioning towards a new normal. Annals of Medicine and Surgery, 59, 165-170. https://doi.org/10.1016/j.amsu.2020.09.046
28. Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., & Vaish, A. (2020). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. Diabetes & Metabolic Syndrome: Clinical Research & Reviews, 14(4), 419-422. https://doi.org/10.1016/j.dsx.2020.04.032
29. Jung, J., Hong, S., Yoon, S., Kim, J., & Heo, J. (2016). Automated 3D wireframe modeling of indoor structures from point clouds using constrained leastsquares adjustment for as-built BIM. Journal of Computing in Civil Engineering, 30(4), 04015074. http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000556
30. Karimi, H., Taylor, T. R., Dadi, G. B., Goodrum, P. M., & Srinivasan, C. (2018). Impact of skilled labor availability on construction project cost performance. Journal of Construction Engineering and Management, 144(7), 04018057. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001512
31. Kavanagh, B. (2021). Virtual Site Visits - a necessity borne of COVID-19. HKA. https://cdn.hka.com/wp-content/uploads/2021/04/31-March-2021- Virtual-Site-Visits-Bart-Kavanagh-AMENDED-TITLE.pdf
32. Kazado, D., Kavgic, M., & Eskicioglu, R. (2019). Integrating building information modeling (BIM) and sensor technology for facility management. Journal of Information Technology in Construction (ITcon), 24(23), 440-458. https://www.itcon.org/2019/23
33. Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmström, J. (2019). Digital Twin:

vision, benefits, boundaries, and creation for buildings. IEEE access, 7, 147406-147419. http://dx.doi.org/10.1109/ACCESS.2019.2946515
34. King, S. S., Rahman, R. A., Fauzi, M. A., & Haron, A. T. (2021). Critical analysis of pandemic impact on AEC organizations: the COVID-19 case. Journal of 95 Engineering, Design and Technology, Vol. 20 No. 1, pp. 358-383. https://doi.org/10.1108/JEDT-04-2021-0225
35. Kong, L., Peng, X., Chen, Y., Wang, P., & Xu, M. (2020). Multi-sensor measurement and data fusion technology for manufacturing process monitoring: a literature review. International Journal of Extreme Manufacturing, 2(2), 022001. http://dx.doi.org/10.1088/2631-7990/ab7ae6
36. Koster, E. (2020). COVID-19 and the impact on construction risk and insurance. Willis Towers Watson. https://www.wtwco.com/en-NL/Insights/2020/04/COVID-19-and-the-impact-on-construction-risk-and-insurance
37. Lee, F.C. (2020). Malaysia's construction sector has lost up to RM11.6b monthly since MCO. MalayMail. https://www.malaymail.com/news/money/2020/09/18/malaysias-constructionsector-has-lost-up-to-rm11.6b-monthly-since-mco-says/1904449
38. Leng, J., & Jiang, P. (2019). Dynamic scheduling in RFID-driven discrete manufacturing system by using multi-layer network metrics as heuristic information. Journal of Intelligent Manufacturing, 30(3), 979-994. https://doi.org/10.1007/s10845-017-1301-y
39. Li, X., Wu, P., Shen, G. Q., Wang, X., & Teng, Y. (2017). Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. Automation in Construction, 84, 195-206. https://doi.org/10.1016/j.autcon.2017.09.011
40. Lim, J. (2021). Cover Story: Digital twins IoT and AI. The Edge Markets. https://www.theedgemarkets.com/article/cover-story-digital-twins-iot-and-ai
41. Megahed, N. A., & Ghoneim, E. M. (2021). Indoor Air Quality: Rethinking rules of building design strategies in post-pandemic architecture. Environmental Research, 193, 110471. https://doi.org/10.1016/j.envres.2020.110471
42. Memon, A. H., & Zin, R. M. (2010). Resource-driven scheduling implementation in Malaysian construction industry. International journal of sustainable construction engineering and technology, 1(2), 77-90. https://penerbit.uthm.edu.my/ojs/index.php/IJSCET/article/view/65
43. Nawi, M. N. M., Ibrahim, S. H., Affandi, R., Rosli, N. A., & Basri, F. M. (2017). Factor affecting safety performance construction industry. International Review of Management and Marketing, 6(8), 280-285. https://econjournals.com/index.php/irmm/article/view/4061
44. Osunsanmi, T.O., Aigbavboa, C.O., Thwala, W.D.D. and Molusiwa, R. (2022), "Modelling construction 4.0 as a vaccine for ensuring construction supply chain resilience amid COVID-19 pandemic", Journal of Engineering, Design and Technology, Vol. 20 No. 1, pp. 132-158. https://doi.org/10.1108/JEDT-07-2021-0384
45. Othman, I., Al-Ashmori, Y. Y., Rahmawati, Y., Amran, Y. M., & Al-Bared, M. A. M. (2021). The level of building information modelling (BIM) implementation in Malaysia. Ain Shams Engineering Journal, 12(1), 455-463. https://doi.org/10.1016/j.asej.2020.04.007
46. Pamidimukkala, A., & Kermanshachi, S. (2021). Impact of COVID-19 on

field and office workforce in construction industry. Project Leadership and Society, 2, 100018. https://doi.org/10.1016/j.plas.2021.100018

47. Pérez, L., Rodríguez-Jiménez, S., Rodríguez, N., Usamentiaga, R., & Garcia, D. F. (2020). Digital Twin and virtual reality based methodology for multi-robot manufacturing cell commissioning. Applied Sciences, 10(10), 3633. http://dx.doi.org/10.3390/app10103633
48. Ren, X. (2020). Pandemic and lockdown: a territorial approach to COVID-19 in China, Italy and the United States. Eurasian Geography and Economics, 61(4-5), 423-434. https://doi.org/10.1080/15387216.2020.1762103
49. Rafee, H. (2021). ConTECH Talk 2021: Local construction industry embraces tech advances. The Edge Markets. https://www.theedgemarkets.com/article/contech-talk-2021-local-construction-industry-embraces-tech-advances
50. Rodzi, N. H. (2020). Coronavirus: Some laid off Malaysians competing with migrant workers over 3D jobs-dirty, dangerous and difficult. The Straits Times. https://www.straitstimes.com/asia/se-asia/coronavirus-some-laid-off-malaysians-competing-with-migrant-workers-over-3d-jobs-dirty.
51. Rooshdi, R. R. R. M., Abd Majid, M. Z., Sahamir, S. R., & Ismail, N. A. A. (2018). Relative importance index of sustainable design and construction activities criteria for green highway. Chemical Engineering Transactions, 63, 151-156. https://doi.org/10.3303/CET1863026
52. Sierra, F. (2021), COVID-19: main challenges during construction stage, Engineering, Construction and Architectural Management. https://doi.org/10.1108/ecam-09-2020-0719.
53. Simpeh, F., Bamfo-Agyei, E., & Amoah, C. (2021). Barriers to the implementation of COVID-19 safety regulations: insight from Ghanaian construction sites, Journal of Engineering, Design and Technology. Vol. 20 No. 1, pp. 47-65.http://dx.doi.org/10.1108/JEDT-03-2021-0153
54. Tang, S., D. R. Shelden, C. M. Eastman, P. Pishdad-Bozorgi and X. Gao (2019). A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. Automation in Construction, 101: 127-139. https://doi.org/10.1016/j.autcon.2019.01.020
55. Tao, F., Zhang, H., Liu, A., & Nee, A. Y. (2018). Digital Twin in industry: State-ofthe-art. IEEE Transactions on Industrial Informatics, 15(4), 2405-2415. https://doi.org/10.1109/TII.2018.2873186
56. Thabet, W. and Lucas, J. D. (2017). A 6-step systematic process for model-based facility data delivery, Journal of Information Technology in Construction (ITcon), pp. 104–131. http://www.itcon.org/2017/6.
57. TheMalaysiaReserve. (2021). Damanlela construction site records 630 new cases. The Malaysia Reserve. https://themalaysianreserve.com/2021/07/06/COVID-19- 7654-new-cases-detected/
58. To, Alex & Liu, Maican & Hazeeq, Muhammad & Hairul, Bin & Davis, Joseph & Lee, Jeannie & Hesse, Henrik & Nguyen, Hoang. (2021). Drone-based AI and 3D Reconstruction for Digital Twin Augmentation. In: Meiselwitz, G. (eds) Social Computing and Social Media: Experience Design and Social Network Analysis. HCII 2021. Lecture Notes in Computer Science, vol 12774. Springer, Cham. https://doi.org/10.1007/978-3-030-77626-8_35

59. Tobias, M. (2020). Why a Digital Twin Is the Best Way to Start a Building Project, Part 2. Nearby Engineers. https://www.ny-engineers.com/blog/why-a-digitaltwin-is-the-best-way-to-start-a-building-project-part-2
60. Vithana, N. D. I., Bandara, K. P. S. P. K., & Jayasooriya, S. D. (2020). Impact of COVID-19 Pandemic to Construction Industry in Sri Lanka. 13th International Research Conference, General Sir John Kotelawala Defence University, Ratmalana, Sri Lanka, pp 161-166. http://ir.kdu.ac.lk/handle/345/3267
61. Wahab, A. (2020). The outbreak of COVID-19 in Malaysia: pushing migrant workers at the margin. Social Sciences & Humanities Open, 2(1), 100073. https://doi.org/10.1016/j.ssaho.2020.100073
62. Wang, L., Zhao, D., & Zhong, Y. (2021). Sustainable Allocation Model of Construction Workforce for Work Resumption during COVID-19. Sustainability, 13(11), 6481. https://doi.org/10.3390/su13116481
63. Wang, W., Guo, H., Li, X., Tang, S., Xia, J., & Lv, Z. (2022). Deep learning for assessment of environmental satisfaction using BIM big data in energy efficient building Digital Twins. Sustainable Energy Technologies and Assessments, 50, 101897. https://doi.org/10.1016/j.seta.2021.101897
64. Yeoh, L. & Pua, J. W. (2020). Penjana: 'Making Malaysia Great Again', with low unemployment. MalaysiaKini. https://www.malaysiakini.com/letters/530257.
65. Zamani, S. H., Rahman, R. A., Fauzi, M. A., & Yusof, L. M. (2021). Effect of COVID-19 on building construction projects: Impact and response mechanisms. In IOP Conference Series: Earth and Environmental Science (Vol. 682, No. 1, p. 012049). http://dx.doi.org/10.1088/1755-1315/682/1/012049
66. Zhou, Y., Wei, X., & Peng, Y. (2021). The Modelling of Digital Twins Technology in the Construction Process of Prefabricated Buildings. Advances in Civil Engineering, 2021, 2801557. https://doi.org/10.1155/2021/2801557