

Evaluation of measures to prevent the spread of COVID-19 on the construction sites

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ABSTRACT

COVID-19 is the most critical health and safety risk facing the global construction sector. The COVID-19 crisis leads to a reduction in site productivity, has increased compliance costs, delayed projects and increased construction workers' exposure to risk and infections. However, as countries begin to ease lockdowns and restrictions, there is a need to examine the measures that the construction companies can take to ensure workers are "Covid-safe". This research developed a questionnaire instrument that included 24 Covid-preventive measures on construction sites. Isolating sick workers, conducting daily checks for COVID-19 symptoms, preventing hugging/handshaking at the site, displaying health advisory posters and info-graphics, and providing face masks to workers are seen to be the main measures towards keeping sites "Covid-safe". The Principal Component Analysis structured the 24 measures into 4 components. The 4 components explained about 73% of the model, namely hygiene and control, equipment and monitoring, awareness, and incentives. The results found that compliance costs of health and safety regulations to prevent COVID-19 will increase project cost by more than 20%, site productivity will be reduced by up to 50%, and the pandemic will have caused a 40% increase in skill shortages. Cluster analysis was performed to cluster the sites in terms of their exposure to COVID-19 risk. In order to examine the practicability of the findings, the model was validated with 4 case studies. It is asserted that the research findings have the potential to keep sites "Covid-safe", which helps construction companies increase productivity, reduce project costs, reduce claims, and deliver projects on schedule. This research is the first to examine measures to prevent the spread of COVID-19 on construction sites, and the findings hold critical theoretical and practical implications for future research on health and safety management.

1. Introduction

The novel Coronavirus disease (COVID-19) is a contagious disease by a newly found coronavirus caused by the SARS-CoV-2 virus, which usually spreads when an infected person is in close contact with a vulnerable individual. In the long term, this pandemic is predicted to leave lasting scars on the global economy due to lower investments, an erosion of human capital, and fragmentation of global trade and supply linkages. It has been estimated that there will be a 5.2 per cent contraction in the global GDP in 2020. COVID-19 presents great challenges to public health. So far, the pandemic has affected 123, 902, 242

people with confirmed cases and has claimed more than 2, 727, 837 deaths (WHO, 2020a). The virus was initially thought to be "pneumonia of unknown origin" and was linked to a seafood market in Wuhan (Zhu et al., 2020). In fact, on January 2, 2020, WHO informed the Global Outbreak Alert and Response Network partners about the cluster of pneumonia cases in the People's Republic of China and on the 4 January WHO tweeted that there was a cluster of pneumonia cases but with no deaths (WHO, 2020b). Apart from China, the disease was first reported in Thailand based on the report by the Ministry of Public Health in Thailand on January 13, 2020 (WHO, 2020b). On January 14, 2020, in a press briefing, it stated that it is certainly possible that there is limited human-to-human transmission (WHO, 2020b). Moving forward, on

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nomenclature		PCA	Principal Component Analysis
A	Awareness	Q1	First quarter
AGC	Associated General Contractors	Q2	Second quarter
ARI	Average Relative Index	Q3	Third quarter
CIDB	Construction Industry Development Board Malaysia	Q4	Fourth quarter
COVID-19	Coronavirus disease	SARS-CoV-2 virus	Severe acute respiratory syndrome coronavirus
EM	Equipment and Monitoring	SOP	Standard Operating Procedure
HC	Hygienic and Control	SD	Standard Deviation
I	Incentive	UAE	United Arab Emirates
ILO	International Labour Organization	UK	The United Kingdom
KMO	The Kaiser-Meyer-Olkin Measure of Sampling Adequacy	USA	United States
MCO	Movement Control Order	WB	World Bank
MCO	Movement Control Order	WHO	The World Health Organization

January 16, 2020, the Japanese Ministry of Health, Labour and Welfare informed WHO of a confirmed case of a novel coronavirus in a person who travelled to Wuhan (WHO, 2020b). Underpinning the urgency of the infectious diseases, on February 4, 2020, The WHO asked the UN Secretary-General to activate the UN crisis management policy, which held its first meeting on 11 February. On March 7, 2020, to mark the number of confirmed COVID-19 cases surpassing 100, 000 globally, WHO issued a statement calling for action to stop, contain, control, delay and reduce the impact of the virus at every opportunity (WHO, 2020b). On the April 2, 2020, WHO reported evidence of transmission from symptomatic, pre-symptomatic and asymptomatic people infected with COVID-19, noting that transmission from a pre-symptomatic case can occur before symptom onset (WHO, 2020b). On January 30, 2020, four countries had evidence (8 cases) of human-to-human transmission outside China (e.g. Germany, Japan, the United States of America, and Viet Nam). WHO reported on 4 April that over 1 million cases of the virus have been confirmed (WHO, 2020b). Malaysia is placed at 82 with 74,295 cases and 384 death (Worldometers, 2020). Some 80% of the COVID-19 patients experience mild infection, while the infection is severe for the remaining 20% (WHO, 2019). It is a respiratory virus, and the main symptoms are dry cough, fever, and chills. In a relatively small number of cases it can lead to pneumonia and death. It is usually transmitted through droplets and fomites. Fomites are particles that remain on surfaces for a certain period (The World Bank, 2020). For example, if an infectious individual with COVID-19 coughed on their hands and then touched another surface, the particles would remain on the surface for some time. This means that cases of COVID-19 may be caused up to 72 h after that, depending on the nature of the particles. This may make its potential spread on construction sites very high because site operatives often have to work in groups and in enclosed spaces.

Like in other major economic sectors, the impact of COVID-19 on the construction sector is huge, complex, and sophisticated. More than 80% of the human resources in the construction sector that work on sites use dangerous materials and components, are exposed to harsh weather, work at heights, carry or convey heavy materials and components, work in unhygienic conditions, and have poor health and safety practices. Construction projects, except for those considered extremely necessary for national security reasons, were stopped, and construction site operatives were asked to stay at home to works on stage. The post-lockdown presents a great challenge to the global construction sector. The global construction sector will face many challenges such as insufficient site labour, closing of factories, low morale amongst the site operatives, low productivity, shortage of materials, failure to handover projects as stipulated, shortage of plants and materials, border closings, delays or inability to obtain required permits, and changes in the work culture on the sites. The virus has been spreading faster than the reasonable worst-case scenario of scientific estimates and projections

(WHO 2020a). There are multiple dashboards and statistics about the spread and impact of COVID-19 on construction productivity across the world. Although there is no exact estimate on the impact of COVID-19 on construction projects, there is a series of pieces of evidence that it has a great impact on the construction industry in terms of delays, overruns, claims, and insurance. Similarly, report shows that construction sites are major spreaders of COVID-19 in many countries like Singapore, the UK, Qatar, India, the UAE, Malaysia, and the USA. Based on data from 70 medium-sized construction projects in the UK, it was found that COVID-19 will lead to project delays by 32 weeks, and an increase in preliminary costs by £600,000, and will lead to a productivity loss of 15% (Construction Manager, 2020a). Based on a survey conducted by the Associated General Contractors of America, 68% of the survey respondents opined that clients had asked them to halt or cancel projects (AGC, 2020). The AGC's (2020) research revealed that project delays due to COVID-19 are up to 23%. These delays in projects have been due to a shortage of personal protective equipment, materials, equipment, craft workers, and information (AGC, 2020). The Malaysian construction sector incurred a huge loss due to the pandemic (CIDB, 2020 and Department of Statistics, 2020a). The construction sector is one of the industries with little opportunity to work from home, and the sector remains largely labour intensive (Olanrewaju and Abdul-Aziz, 2015). As countries begin to ease the lockdown, this paper reports a study that investigated the measures that construction companies have used to reduce the spread of COVID-19 on sites during and after the lockdown. This is important because construction companies have to reopen and operate alongside a virus that has remained a great threat to the sector and the economies. To achieve this aim, this research identified, prioritized and categorized the COVID-19 preventive measures for construction sites. While prioritisation will help to examine the measures individually, categorizing the measures will help construction companies to streamline and enhance decision making to reduce the impact of the virus on the construction performance. Furthermore the Principal Component model was developed and validated with data from 4 construction sites. Although, there have been limited research on the impact of the COVID-19 crisis on a construction project, the studies are based on simulation (Araya, 2021a), literature (Pamidimukkala et al., 2021). As the impact of the pandemic on the global construction sectors is being examined (Pamidimukkala et al., 2021), there is no systemic and empirical evaluation measure to reduce it spread and impact on construction. Although, Araya (2021a) modelled the impact of the COVID-19 on project duration, they found that COVID-19 could extend project duration by between 30% and 90%. However, the estimation was based on simulation on one site only. Recognizing the inadequacy of the simulation results, in terms of oversimplification of real-life conditions, actual data from construction sites should be used rather than simulation (Araya, 2021a,b). The present research collected primary data through a survey questionnaire that was administered on

construction sites in Malaysia.

2. The construction sites as a main driver of COVID-19 transmission

COVID-19 presents severe health and safety challenge to the construction sector. The vulnerability of construction workers to illnesses, injuries, and deaths are high because site operatives work in unhygienic conditions, use sophisticated equipment, are exposed to harsh weather, use harmful materials, and carry heavy components and are exposed to infectious diseases. Zhou et al. (2015) reviewed safety management policies in the construction industry in 34 economies, from which it was concluded that despite the various measures taken to improve the safety records on sites, accidents and injuries continued to plague the construction industries. The COVID-19 pandemic required a new way of working through strengthened OSH measures, adaption of work arrangements, and management of stress and other psychosocial risks (ILO, 2020 and Occupational Safety and Health Administration, 2020). The main routes of infectious disease transmission on construction sites include contact, droplet, and airborne. Airborne means that the virus can be suspended in the air and linger in the air for a long time. Like most infectious diseases, the COVID-19 virus can be transmitted through direct and indirect contact. Direct contact is when the infectious agent is transferred to a vulnerable individual through physical contact with an infected individual. Indirect contact transmission occurs when a vulnerable individual comes into contact with contaminated items and surfaces such as construction materials, components, equipment, and food that have previously been touched by an infectious individual. COVID-19 can also be transmitted when an infected person coughs, sneezes, or talks and the droplets reach the mucosal surfaces of the eyes, nose, or mouth of a susceptible individual. However, because some of the droplets from COVID-19 are large and can survive for a long time in the air, it is also airborne. Hence, when the small suspended particles are inhaled by a vulnerable person, the droplets will enter the respiratory tract of the vulnerable person and lead to an infection.

COVID-19 affects people in different ways. The virus that causes COVID-19 is mainly transmitted through droplets generated when an infected person coughs, sneezes, or exhales. Most of these droplets are too heavy to hang in the air and quickly fall on the floor or surfaces. Individuals can be infected by breathing in the virus within close proximity with someone who has COVID-19, or by touching a contaminated surface, eyes, nose or mouth. According to the WHO, the spread of COVID-19 can be controlled by taking specific measures, including ensuring physical distancing, wearing a mask, keeping rooms well ventilated, avoiding crowds, cleaning hands, and coughing into a bent elbow or tissue. The symptoms of COVID-19 include dry cough, skin rash, tiredness, fatigue, runny nose, vomiting, aches and pains, sore throat, diarrhoea, conjunctivitis, headache, loss of taste, fever, irritation, or discolorations of fingers or toes. The pandemic has major repercussions on the health outcomes of other diseases as resources and medical staff are diverted to combat the COVID-19 scourge (Wilder-Smith et al., 2020 and Clemente-Suárez et al., 2021). As a result, those with other mental health disorders are not receiving enough attention. In Malaysia, many urology wards were converted to COVID-19 wards (Zhu et al., 2020 and Cleveland Clinic, 2020). In fact, many are scared or advised not to go to hospitals for their regular treatments for fear of contracting the virus. The lockdown and shortened hours of the hospital and health centres pose a great challenge to those with mental health problems.

The construction site is an epicentre of the spread of infectious diseases (Liu et al., 2021; New Straits Times, 2020a, 2020b, 2020c, 2020d; Fadillah, 2020c), with a very high spillover onto adjoining areas. Construction site operatives are occupationally exposed to a variety of infectious diseases on their sites. The delivery of construction projects involves a broad range of workers, including painters, electricians, scaffolders, plumbers, decorators, steel erectors and labourers, clerks of

work, site engineers, site quantity surveyors, site supervisors, and construction managers. The variety of the workers allows occupational exposure to infectious diseases to become challenging, particularly with the limited space and poor hygiene at the sites. The impact of COVID-19 on the sites' activities is extremely high and complicated with severe problems, such as health and safety issues, delays, low profit margins, poor quality work, cost overruns, shortage of skilled workers and disputes. The construction sector is facing decisions about how to continue operation whilst keeping construction labour, especially the site operatives, safe and healthy from the scourge of the COVID-19 disease that is moving fast and is ill-understood. All construction projects, except for those considered extremely necessary for security reasons, have stopped operation and construction site operatives have been asked to stay at home. The Post-lockdown poses a great challenge to the global construction sector as it moves to recover from the effects of the COVID-19 pandemic. In the long term, the post-COVID-19 period will impact the construction industry greatly, the demand on the construction sector will be huge, especially as the government becomes eager to make investments in infrastructure and construction to revise the economy. This could be faced with a shortage of resources, however.

Whilst investments in public projects will increase, it may take some time for the private sector to improve significantly. Whilst the availability and affordability of the vaccine are ongoing, it is strategic to keep the virus under control. Although various vaccines may be available, it could be logistically complicated to administer. It may also take some time to research developing countries. Construction workers may also not be able to procure it. Keeping the virus under control on construction sites requires taking various measures to reduce the infection rate on the construction sites. The remainder of this paper is organized as follows. Section 3 discusses the impact of COVID-19 on costs and time for construction projects across the globe. Section 4 is devoted to the impact of the virus on the Malaysian construction sector. In section 5, the research design and data analytics for this research were explained. Section 6 contained descriptions of the results of the collected data set employed in this study. The discussions of the findings are presented in section 7. The general summaries of the findings are provided in section 8 as a conclusion and limitations.

3. Impact of COVID-19 on construction activities internationally

It has been estimated that there will be a 5.2 per cent contraction in the global GDP in 2020. This is the worst crisis since the greatest economic crisis since the depression 75 years ago, and this is the greatest health crisis since the flu pandemic 100 years ago. The virus has different impacts on the construction sector. For instance, whilst public construction is one of the sectors allowed to operate during the lockdown, the activities in the private sector are still not in full or high operation. However, the operation of both the public and private sectors will be affected. As the supply chain has been disrupted by labour and materials shortages, the termination of contracts by the Government has begun. Many contractors have already been stressed, at least in the short run, and in an effort to minimise losses, many construction companies have already suspended or cancelled contracts and projects. Many construction companies operate with only a small capital base. Hence, the impact of COVID-19 could mean that most construction companies will have to seek alternate means of financing projects and claim management. In fact, according to PwC's survey on COVID-19, 81% of CFOs are considering cost reductions in response to the pandemic, and 60% of the construction companies plan to defer or cancel investments (PwC, 2020). In the long term, construction companies, the contractors, in particular, will be faced with low demand for both private and public projects, especially as the government's deficit and debt increase. Some construction companies may be able to sustain operations due to expertise and the backlog of projects before the COVID-19 crisis. In the longer term, construction companies will be affected by low demand and a shortage of resources. In general, construction companies with high

debt profiles may go bankrupt; subcontractors may stop operations due to a lack of financial support, and construction management practises (especially contract management, contract administration and procurement management, finance management, claim management, etc.) will assume prominent roles. Many of the current contract provisions will be revised to address COVID-19 related matters. Whilst many construction companies may prevent losses or litigation by relying on force majeure; it may not be a sufficient ground to stand on. Therefore, many renegotiations on the part of construction companies, clients, sponsors, legal advisers, and regulatory bodies are required. Furthermore, the pandemic will affect international projects and contracts as countries have enacted various acts and regulations to reduce the spread and impact of COVID-19 in the countries. Most countries have imposed entry restrictions on their citizens, and many embassies and consular offices have closed due to policy requirements. Many site workers have overstayed their visas without the opportunity to renew their visas or work permits. In countries like Singapore, Malaysia, Qatar, and the UEA, many foreign construction workers have been stranded at airports or quarantine centres for months. In fact, the situation has turned the labour camps for the construction workers on the Qatar 2022 World Cup into a “virtual prison”, which has triggered serious health and safety concerns for the welfare of the workers ([Business and Human Rights Resource Centre, 2020](#)). Most of the provisions in the new acts and regulations are different from those that were in operations whilst the contracts were being signed. Even if the construction companies want to abide by them, it would not be immediate. Therefore, a key question is how contractors will ensure the health and safety of their operatives on the construction sites in order to reduce losses, project costs, and project duration, and increase productivity and maximise profits.

The pandemic is affecting the construction processes and phases, including the process of handover of completed and certified projects. For instance, some clients have been unable to take possession of their projects due to movement restrictions. PwC (2020) found that the financial stability, safety, and well-being of site operatives are the main challenges facing construction companies during the pandemic. Imported materials and components may arrive late or may never even arrive because many countries, such as China, the UK, and Italy, have slowed or shut down production of a wide range of key materials, such as steel and cement ([EIC, 2020](#)). Effectively, construction projects that depend on supplies from these countries may face supply chain disruptions. It has been estimated that the construction industries in the Middle East and North Africa (MENA) regions will see a –2.2% contraction in construction output in 2020 due to COVID-19 ([International Construction, 2020](#)). The French construction industry, despite being exempted from the nationwide lockdown, is expected to shrink by 9.4% in 2020 due to the pandemic ([International Construction, 2020](#)). US construction employment declined by 975,000 jobs in April 2020, according to the results of a survey conducted by the Associated General Contractors of America (AGA) and data from the construction technology firm Procore. COVID-19 is also worsening the state of mental health pressure in the construction industry. It is a public health crisis. Construction workers are experiencing more vicarious trauma, depression, anxiety, exhaustion, and lack concentration. The impact of COVID-19 has made 65% of the Indian construction companies lose 40% of their profits ([Global Construction Review, 2020](#)). 14 workers at a 400ha at the LNG Canada Project Site overseen by American engineer Fluor and Japan's JGC tested positive for Covid-19 by Canada's Northern Health Authority ([Northern Public Health Canada, 2020](#)). New Zealand announced a stimulus package amounting to NZ\$12 billion, which is part of the massive infrastructure package for the building and upgrading of roads, rail, schools, and hospitals across the country ([Heights, 2020](#)). The pandemic has reduced construction productivity by 70% even though there has been opening of the sites, and it has lowered the demand for construction around the world by a recorded margin.

Table 1

Value of construction work done, Q1 2010 - Q4 2020.

Quarter	Number of projects	Value of work done RM ' 000	Percentage change (%)	
			(QoQ)	(YoY)
Q4/2020	14,160	31,730,846	1.2	–14.2
Q3/2020	13,598	31,367,003	58.6	–13.1
Q2/2020	12,676	19,780,063	–43.6	–44.9
Q1/2020	11,857	35,040,152	–5.2	–6.3
Q4/2019	11,862	36,978,460	2.5	1.3
Q3/2019	11,018	36,076,604	0.4	–0.6
Q2/2019	10,579	35,919,139	–4	0.8
Q1/2019	9939	37,397,513	2.4	0.7
Q4/2018	9892	36,511,049	0.6	4.1
Q3/2018	9905	36,287,482	1.9	5.2
Q2/2018	9580	35,624,699	–4	5.3
Q1/2018	9259	37,123,931	5.8	5.9
Q4/2017	8747	35,077,956	1.7	7.7
Q3/2017	8844	34,495,002	2	8.1
Q2/2017	9405	33,825,084	–3.5	11.2
Q1/2017	9572	35,053,464	7.7	9.7
Q4/2016	9791	32,559,568	2	8.1
Q3/2016	9725	31,909,993	4.9	10.7
Q2/2016	9983	30,427,274	–4.7	11.7
Q1/2016	10,043	31,941,170	6	11.1

Department of Statistic Malaysia (2020c).

4. Impact of COVID-19 in the Malaysian construction sector

In Malaysia, the outbreak was linked to Chinese tourists that travelled from Singapore to Malaysia through Johor Baru on January 22, 2020. Eight suspected cases were directly linked to the first case ([Abdullah, 2020](#)). Twenty-two positive cases were reported during the first wave, and all were discharged after treatment ([Khor et al., 2020](#)). Various measures were implemented to curb the spread of the virus. Some of the measures include screening travellers at all entry points to Malaysia, increasing the number of hospitals to treat the infected victims, setting up provisional hospitals ([Shah et al., 2020](#)) and creating quarantine centres. By March 2020, five hundred and fifty-three cases were reported. In order to break the spread, the MCO (Movement Control Order) was implemented on March 18, 2020 across the whole country ([Muhyiddin, 2020](#)). The restriction was to last for two weeks, but because of the increase in the rate of infections globally and nationally, the restriction was extended. The Malaysian construction sector is one of the most severely affected sectors by the pandemic ([Department of Statistics, 2020c](#)). The construction sector incurred \$6billion in losses in the first three lockdown ([Fadillah, 2020a](#)). In the first and second phases of the lockdown between March 18 and April 14, RM11.6 billion were losses, and RM6.9 billion in losses were incurred between April 15 and April 28 in the third phase. Twenty-nine per cent of the losses was due to the unemployment of industry workers as construction projects had to be halted ([Lee, 2020](#)). The other losses were due to production and

shortage of materials and supply of machineries. The value of construction work done in the first quarter of 2020 contracted by 6.3 per cent (Q4 2019: 1.3%) year-on-year basis, amounting to RM35.0 billion (Q4 2019: RM37.0 billion) (Department of Statistics, 2020a). Furthermore, the value of construction work done in the second quarter of 2020 contracted by 44.9 per cent (Q1 2020: −6.3%) year-on-year basis, amounting to RM19.8 billion (Q1 2020: RM35.0 billion). (Department of Statistics, 2020b). However, the value of construction work done expanded by 58.6 per cent as compared to the second quarter of 2020, amounting to RM31.4 billion (Q2 2020: RM19.8 billion). However, on year-on-year comparison, the value of construction work done improved −13.1 per cent (Q2 2020: −44.9%) in the third quarter 2020. There is a significant decline based on the year-on year in the fourth quarter of 2020 compared to the fourth quarter in 2019. The quarterly and yearly performance of the Malaysian construction sector is contained in Table 1, from which a 5-year trend can be observed. Although some continuous recovery has been seen, especially on the quarterly basis, there is a decline, but it is high and will be high till the fourth quarter 2020 with the second wave of the crisis, which may extend to the fourth quarter of 2021.

While employment in other sectors improves, there is also a significant increase in the unemployment rate in the construction sector during the outbreak (Mahidin, 2020a). The decline in employment in the construction sector may reflect shortages of labour supply in both sectors (Mahidin, 2020a). Inspections conducted by the CIDB involving 3282 construction sites from April 20 to July 2, 2020 revealed that 84% complied with the COVID-19 SOP on construction sites (The Edge Market, 2020), 15% were warned for violating the guidelines, while 1%, or 19 sites, were closed down. Furthermore, inspections involving 7699 construction sites nationwide from April 20 to June 14 (Fadillah, 2020b). 370 construction sites received a warning for not adhering to the COVID-19's SOP, while another 17 were ordered to close pending further instructions. Some of the offences include not conducting body temperature checks or providing hand sanitiser, not enforcing social distancing and failure to obtain approval to commence work (Fadillah, 2020b). However, legal issues relating to claims due to COVID-19, including extending the completion duration would be resolved via a COVID-19 (Temporary Measures) Bill (Fadillah, 2020b). Many experienced construction workers were laid off due to the pandemic (Rodzi, 2020). Many construction foreign workers have returned to their countries due to the lockdown and have not been able to return to Malaysia (Wahab, 2020) due to various movement restrictions and visa procedures. On April 27, 2020, the (CIDB) published the first guidance documents in relation to the execution of construction works during the lockdown. The SOP outlines measures the CIDB considers will reduce the impact of the MCO and the COVID-19 pandemic on the construction sector. With about 12 months of total and partial lockdown, several weeks or months of productivity have been lost. The implications of these statistics are that in order to clear the backlog of construction projects that were suspended, abandoned and delayed and to meet with new demand pose great challenge and risk to the construction industry. Thus, over the next 2–5 years, the industry will struggle to meet demand amidst a shortage of materials and labour.

Globally, although there is increasing attention to conduct research on the impact of the pandemic (Araya, 2021a), risk mitigation measures (Radulescu et al., 2020) and measures to reduce the impact of the pandemic, there is no empirical research that evaluate the impact of the pandemic on productivity on construction sites. There is no empirical research that evaluated the impact of the virus on the schedule and cost of construction projects and importantly, on the measures to reduce the spread of the pandemic on construction sites. This aims to lay the foundation for an improved understanding of the impact of COVID-19 on construction projects, and possible measures available to construction companies to reduce the spread of the virus on sites in an effort to increase productivity, and reduce loss and claims in Malaysia and globally.

5. Research design and data analytics

The research combined both exploratory and explanatory methods by asking both why and how questions. Although health and safety have received considerable attention in the construction management literature, the literature on the impact of COVID-19 on the construction sector is nascent globally. The constructs on the survey form were based on on-site observations, interviews with site operatives (i.e., project managers, construction, health and safety personnel), and the authors' experiences. The constructs were collated and pretested amongst seven different site operatives. The final survey form was designed based on the consideration of the input of the pretext results. Therefore, this research has not been directed by any sound theories in the literature, but rather, it has been formulated based on practices, experience, and the cross-examination of media reports. Specifically, the questions that this research has sought answers to are: 1) What are the impacts of COVID-19 on the project? 2) What are the measures to reduce the spread of COVID-19 on sites? 3) How can the "Covid-safe" measures be structured for decision making on construction sites? and 4) How can sites be classified in terms of the "Covid safe" measures? The primary data collected were based on snowball sampling. Snowball sampling is a non-probability sampling technique that is used if there is less information on the potential respondents. However, one of the limitations of this technique is that the number of respondents will not be known to the researcher. Also, its findings may not be generalisable; but with large respondents, the findings can be representative. Thus, its basic premise is that if sufficient data are collected and objectivity is maintained, the results will be indicative of the population (Olanrewaju and Idrus, 2020).

The questionnaires were administered to the respondents online. The survey was launched on 6/15/2020 and opened until October 27, 2020. The respondents were asked, based on evidence, to tick the degree to which they agreed with each of the constructs on the survey form. The measures to be Covid-safe on sites were measured on a 6-point continuum scale of 1–6, where 1 denoted not taken at all, 2 least taken, 3 less taken, 4 moderately taken, 5 denoted strongly taken, and 6 denoted extremely taken. The measures were positively worded. Higher scores indicated a higher taken measure. The considerations of the measures were determined by the average relative index (equation (1)) and the standard deviation.

$$ARI = \frac{\sum_{i=0}^6 a_i x_i}{6 \sum_{i=0}^6 x_i} \times 100 \quad (\text{Equation 1})$$

Where a_i was the index of a group; constant, expressing the weight given to the group; x_i was the frequency of the responses; $i = 1, 2, 3, 4, 5$, and 6, and was described as below: $x_1, x_2, x_3, x_4, x_5, x_6$ were the frequencies of the responses corresponding to $a_1 = 1, a_2 = 2, a_3 = 3, a_4 = 4, a_5 = 5, a_6 = 6$, respectively. For interpretation, an ARI score of 1.00–16.67 denoted not taken at all, 16.68–33.33 denoted least taken, 33.34–50.00 denoted less taken, 50.01–66.67 denoted moderately taken, 66.67–83.33 denoted strongly taken, and 83.34–100 denoted extremely taken. There was a pooled difference of 1.0% between each of the scales. The other statistical tests computed were the one-way test, Split-Half Coefficient reliability tests, convergent validity, and mode. The t -test was conducted to test the hypothesis of whether each of the measures could reduce the spread of COVID-19 or not on construction sites. The principal component analysis (PCA) was also conducted to cluster the measures taken to be Covid-safe for effective decision making. The PCA is a form of an unsupervised machine learning algorithm that is used in grouping constructs but without information loss. PCA is the popular form of factor analysis, and it is one of the decomposition libraries in data science. Unlike the factor analysis that aims to develop a measurement model for latent variables, it is a linear combination of related variables in the dataset. It is used to analyse interrelationships amongst a large number of variables in a dataset to cluster the variables into more

Table 2
Respondent's organization.

Organization	Frequency	Percentage	Cumulative Percentage
Main Contractors	75	63.6	63.6
Sub-contractors	24	20.3	83.9
Suppliers	5	4.2	88.1
Others	14	11.9	100.0

Table 3
How many percentage increases will compliance to health and safety regulation due to the COVID-19 have on your project cost?

Cost increase	Frequency	Percentage	Cumulative Percentage
Less than 10%	10	8.7	8.7
10–20%	21	18.3	27.0
20–30%	20	17.4	44.3
30–40%	16	13.9	58.3
40–50%	15	13.0	71.3
50–60%	16	13.9	85.2
60–70%	3	2.6	87.8
70–80%	4	3.5	91.3
80–90%	2	1.7	93.0
90–100%	8	7.0	100.0

meaningful components or factors. It creates new uncorrelated constructs that maximise variance by clustering variables in a large dataset. The clustering can be computed based on the correlation or covariance matrix amongst the variables (Pituch and Stevens, 2016). It is useful in the field of pattern recognition and signal processing and constitutes a fundamental aspect of multivariate data analysis (MVDA) because it is a method of reducing the dimensionality of a multivariate dataset. However, the main uses of the PCA are descriptive rather than inferential (Jolliffe and Cadima, 2016). In addition, cluster analysis using K-means has been performed. K-means is an interdependent technique that is very useful in segmentation. The K-means analysis aims to create groups or

classify objects with many similarities within a group. Thus, within a cluster, there will be many homogeneities, but there will be heterogeneity or dissimilarity amongst the groups. Unlike the factor analysis, the similarities are determined by a distance, not correlation or covariance. All the data gathered adopted the IBM SPSS Statistics Data Editor 25 for the data analytics.

6. Analysing the results of the survey

The online survey form was sent to more than 400 respondents working on different construction sites. The respondents were asked to forward the form to their colleagues/friends working on different sites. However, by the cut-off date, only 120 completed forms were received after several reminders. Missing data could have been addressed by either replacing the missing data with the mode or mean of the construct. However, the missing data were not treated in this way so as not to influence the data.

6.1. Analysing the respondents' profiles

The results of the survey are contained in Tables 2 and 3 and Figs. 1–3. 64% of the responses were from the main contractor organisations, and most of those from “other” organisations were from developers and consultancy firms (Table 2). The data revealed that 68% of the respondents obtained Bachelor's degrees, and 13% had MSc degrees. 17% had diploma grades, whilst the remainder had other qualifications (i.e., certificates). The respondents had their degrees in construction management (45.6%), civil engineering (18.3%), quantity surveying (17.2%), mechanical engineering (4.2%), architecture (2.5%), and others. 40% of the sites were involved in residential construction, and 62% of the sites were involved in industrial, commercial, and infrastructure projects. About 80% of the construction companies were not in full operation during the pandemic (Fig. 1). In fact, for some 50% of the companies, only 20% of their sites were in operation.

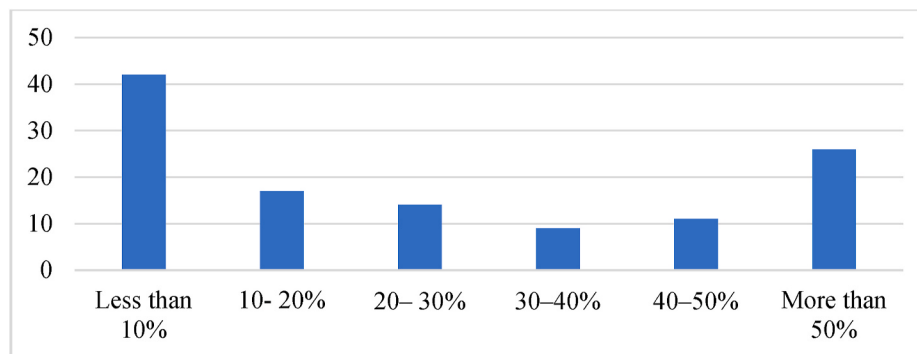


Fig. 1. How many percent of your sites were in operation during the lockdown?

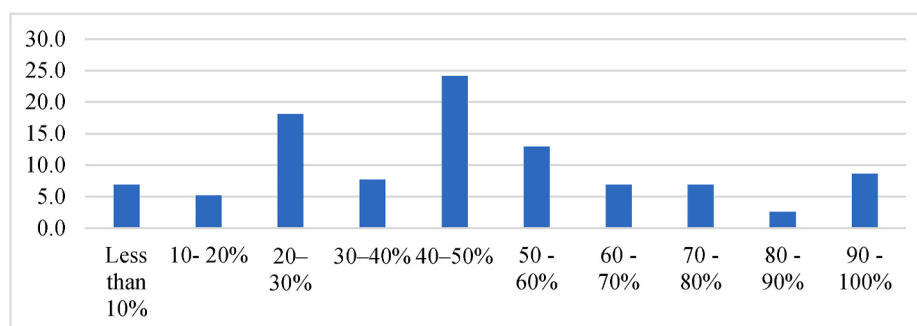


Fig. 2. To what extent will compliance to health and safety regulation due to the COVID-19 reduces the Progress/productivity project on sites?

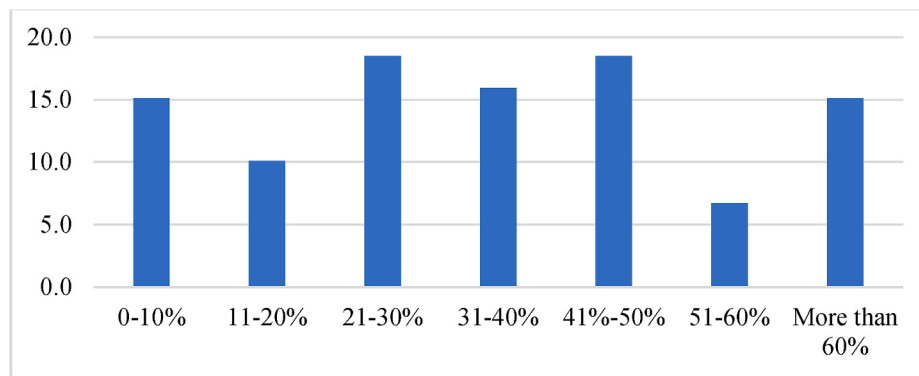


Fig. 3. To what extent has the COVID-19 creates skill shortage to your sites.

6.2. Impact of Covid-19 pandemic on construction projects

The first question that this research seeks answer to relates to the evaluations of the impact of COVID-19 on the project's time and cost. Previous studies (Araya 2021a) simulated that the project's duration can be extended by 30% and 90%. However, because it was based on a simulation of one project involving 100 workers, site data from multiple projects are required to validate the findings. Besides, the research does not include the impact of COVID on the cost of the projects. It is important to evaluate the impact of compliance due to the pandemic on project cost and time, to guide construction companies in claim management. While suspension or shutdown of a project could affect the project cost and schedule, it is the evaluation of the compliance cost that the contractors/subcontractor is most critical in claim management. In most countries, construction companies were allowed to operate but with strict adherence to the COVID-19's SOP. For instance, in some cases, only 50% of the workers are allowed access to enter the sites. Yet, the workers are required to wear a mask, use sanitisers, practise social distance, daily COVID test, site fumigation, among other measures (see the third research question). All these have a significant impact on-site productivity, profit margin, project's cost and duration. As Table 3 contained, the COVID-19' compliance costs have a different impact on the project. The variability may be due to the project's size, location, and types of a project. It may also depend on the stage where projects stood at the time of the shutdown and if a project was suspended or not. However, in the estimation of 70% of the companies, compliance costs

of the health and safety regulations for COVID-19 would increase the project costs by more than 20% (Table 3). The average percentage of the compliance cost is approximately 35% (30%–40%), and the standard deviation is 25%. In other words, complying with the new health and safety on construction sites due to the pandemic could increase the project's cost by 10% to 60% in most of the projects or sites.

The major impact of the pandemic on the construction sector relates to the compliance with regulations. As a result, site productivity is highly affected. Therefore, it is not surprising that productivity is impacted. As Fig. 2 revealed, the impact varies, but in most cases, it is more than 10%. The data revealed that, on average, site productivity had been reduced by about 50%. With the mean score of 5.14 and a standard deviation of 2.445, it is obvious that adhering to the SOP of the pandemic on-site would reduce productivity by between 20% and 70% for most of the projects or sites. The findings are very exciting and have immense practical implications because, in many countries, only about 50% of the site operatives were allowed access to construction sites due to the pandemic. Thus, the findings seem to follow the reality in most countries.

Human capital in the construction sector has been severely impacted by the pandemic. Most of the construction site operatives were foreigners, and many foreign construction workers that returned to their countries could not return to Malaysia due to movement restrictions during the pandemic. Even the movement restrictions within the country restrict the movement of foreign workers from one state to another. Some also contracted the virus, which led to skill shortages.

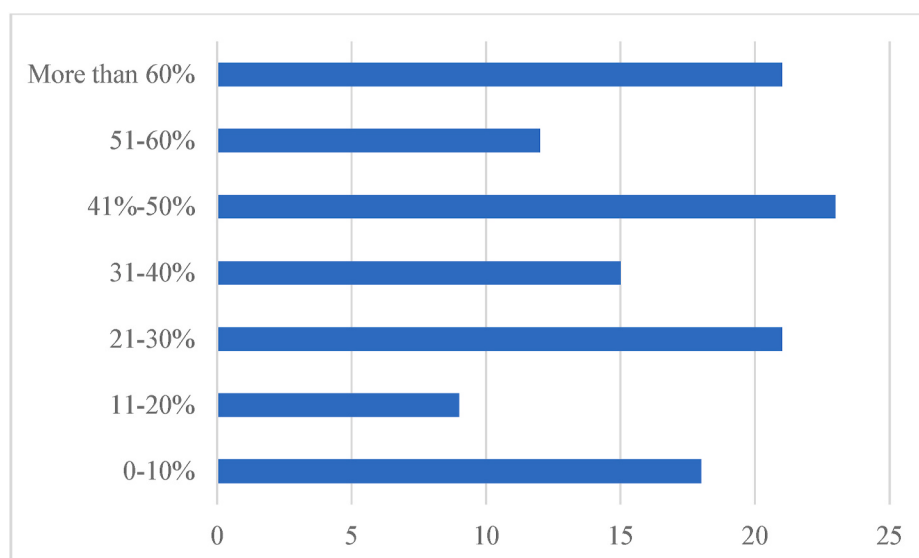


Fig. 4. What percentage of the coming year projects would be delayed/suspended/cancelled due to the COVID-19?

Table 4
Reliability statistics.

Cronbach's Alpha	Part 1	Value	0.924
		N of Items	12
	Part 2	Value	0.932
		N of Items	12
	Total N of Items		24
Correlation Between Forms			0.893
Spearman-Brown Coefficient	Equal Length		0.944
	Unequal Length		0.944
Guttman Split-Half Coefficient			0.942

Therefore, it is not surprising that Fig. 3 revealed that COVID-19 has led to a skills shortage in most construction companies by up to 40%. Only about 50% of the companies have paid their staff fully during the pandemic. 30% advised their staff to take half payment, and the remainder were asked to take unpaid leave. However, foreign workers have only been paid when they work. Effectively, during the lockdown, foreigners have not been paid at all.

Although the condition is improving now, as compared to mid-2020, many projects are still shut down, delayed and many are still in the queue. Governments and public authorities will likely be aiming to advance spending on infrastructure projects as soon as possible. However, the pandemic has led to the delay and suspension of many projects due to shortage of skilled labour and materials, in addition to the movement and work restrictions. Even for the projects that continue

during the pandemic, it is arguable the projects will be delayed. In fact, there are a significant number of scheduled delays globally. Extant simulated data on a project shows that the pandemic can delay the project by up to 90%. However, Fig. 4 displays the extent to which the pandemic has or would delayed projects based on the data from the construction sites. Approximately 85% of the companies estimated that the pandemic will delay projects by upto 90% (Table 4). However, most of the site's projects would be delayed by about between 20% and 65%.

6.3. Results on the measures to minimise the spread of COVID on construction sites

The reliability test results indicated that the Guttman split-half Coefficient and correlation were very high (Table 4). Guttman tests the internal consistency reliability of the measures. In Guttman, it is assumed that the two halves of the test should produce similar accurate scores and error variance. Values of more than 0.60 for both the correlation and Guttman coefficient are recommended. The validity test was based on construct validity. Construct validity may be assessed through the discriminant and convergent validities. Most of the correlation results were more than 0.20 and less than 0.80. If the correlation is more than 0.80, it implies collinearity; if less than 0.2, it implies that the measures are not related (Olanrewaju et al., 2019). The results of the one-sample *t*-test confirmed the ($H_0: U > U_0$) hypotheses that the measures can keep construction sites safe from COVID-19. However,

Table 5
Descriptive statistics of the measures to prevent COVID-19's spread.

Measure	Not taken at all	Least taken	Less taken	Moderately taken	Strongly taken	Extremely taken	ARI	SD	Lower	Upper	Std. Error Mean
Self-isolation for workers who fall ill/sick	1	2	2	21	29	64	87.40	16.92	84.33	90.50	1.43
All workers must be examined for likely COVID-19 symptoms daily	3	2	2	18	29	62	86.50	19.62	83.00	90.00	1.73
No hugging/hand shaking on the site	2	1	6	20	31	59	85.57	17.93	82.33	88.83	1.55
Display health advisory posters and infographics in a language understand by the workers	2	0	6	21	32	54	85.22	18.23	82.00	88.50	1.75
Provide face mask to workers	7	1	1	15	35	59	84.88	22.77	81.00	88.83	1.93
Provide health education to workers regular	0	2	4	22	48	43	84.32	15.90	81.50	87.00	1.50
Abide by government policy	1	1	6	20	47	44	84.03	14.95	81.00	87.00	1.55
Ensure regular supply of sanitiser	4	1	8	18	30	57	83.90	21.47	80.17	87.67	1.75
Keep social distancing	3	3	5	23	36	49	82.63	20.58	79.00	86.17	1.67
No gathering or crowding	6	1	4	20	39	49	82.50	21.03	78.67	86.33	1.82
Ensure regular supply of clean/fresh water	8	1	2	18	43	47	81.93	22.50	77.83	86.00	2.07
Wash hand frequently	6	3	10	18	31	50	80.37	23.12	76.17	84.67	2.05
Suspend non critical activities on sites until condition improve	5	2	8	25	42	37	79.13	20.83	75.33	82.83	1.90
Disinfect surfaces and objects used by others	5	2	10	28	32	42	78.85	22.48	75.00	82.83	1.88
Workers to cover their mouth and nose when they cough/sneeze	7	5	10	18	34	45	78.28	23.53	73.83	82.67	2.20
Company to provide separate accommodation for workers based on the projects works	6	2	10	29	30	42	78.15	23.53	74.00	82.17	1.97
Restrict/stagger access to site welfare facilities	7	2	5	27	43	34	78.10	22.65	74.17	82.00	1.83
Provide incentive to sick worker- with this they will report their medical status	7	5	5	25	39	37	77.55	24.10	73.33	81.83	2.27
Fumigate sites at least once daily – especially at close of day work	5	7	4	27	45	31	77.03	22.83	73.17	81.00	1.97
Wear special safety mask if working in less than 1m apart	7	6	12	24	32	36	75.07	24.00	70.67	79.50	2.23
Workers to work in teams but inter team's interaction is prohibited	9	5	9	27	45	24	73.25	23.85	69.00	77.50	2.05
Foods/drinks should be provided on sites- workers not allowed to eat outside during the working hours	13	5	11	30	35	25	70.17	26.25	65.50	74.83	2.38
Wear gloves	11	5	8	44	35	16	68.90	23.20	64.67	73.00	2.13
While using scaffold, restrict access to one person at a time	12	5	18	29	33	22	68.48	25.52	64.00	73.00	2.32

Table 6
KMO and Bartlett's test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.910
Bartlett's Test of Sphericity	Approx. Chi-Square	2723.309
	df	276
	Sig.	0.000

there were conflicts amongst the respondents with respect to 'foods/-drinks should be provided at sites as workers are not allowed to eat outside during the working hours; they must wear gloves; and while using a scaffold, access is allowed to one person at a time'. But, the null hypothesis ($H_0: U=U_0$) was accepted for the three measures of keeping sites Covid-safe. Furthermore, the results of the small standard errors were lower at an average of 2%. The practical implication of these results is that the measures can keep all construction sites safe. These results have been confirmed by the results of the confidence interval (at a 95% Confidence Interval). The results of the KMO (0.808) and Bartlett's test ($\chi^2(378) = 1567.206, p < 0.050$) implied that the respondents were drawn from the same population and that the measures taken together would help to keep sites Covid-safe.

Working on sites during the pandemic is expensive and risky to construction companies. Construction companies need to calculate their COVID risk on all projects. This will involve identifying works that could allow Covid transmission, evaluating the categories and the number of workers that may be at risk. This will also involve assessing the level of exposure of the workers to the virus. Then, finally and most importantly, there is a need to evaluate the measures of control that those construction companies can take to reduce the spread of the virus on the construction sites. Construction companies globally have taken multiple measures for the workers to be Covid-safe as they gradually return to sites fully to enable social distancing and comply with new government regulations on COVID-19. Most construction companies have been able to operate at full capacity for most of the Covid lockdown by taking into account some of these measures. The descriptive statistics on the measures are contained in Table 5. The survey found that 67% of the respondents estimated that all the measures were strongly taken and extremely taken. 20% of the respondents evaluated that the measures were moderately taken. Although 5% of the measures were not taken at all, 8% of the measures were less or least taken. The cumulative ARI score for all the measures was 83.14%, whilst the cumulative standard deviation (SD) was 22.73%. Eleven or 48% of the measures scored more than the average score. Taking into account the relationships amongst all the standard deviation values, the results of the ARI imply that nearly all the respondents estimated that the measures were necessary to prevent COVID-19 on sites. The ARI for all the measures was between 68.48% and 87.40%. Based on the index in the research design section,

all the measures were grouped into 2 categories. In particular, eight of the measures were extremely taken. 16 of the measures were strongly taken.

6.4. Results of the PCA on the COVID-19 preventive measures

In this section, results on the answer to the third question, which is "how can the "Covid-safe" measures be structured for decision making on construction sites?" is discussed. For this purpose, the 24 measures were included in the PCA analysis. The eigenvalue technique was used to determine the number of factors to extract. In which case, only factors with eigenvalues of 1.0 or more were retained. Varimax was used for normalisation to reduce the complexity of the factors in order to maximise the variance in the model. KMO test and the Bartlett' Test of Sphericity were conducted to test the validity of the PCA. The analysis returned a Statistical Determinants of 1.838E-11. The commonalities for all the measures ranged from 0.541 to 0.888. The KMO was very high, and the Bartlett Test of Sphericity was significant (Table 6). The anti-image correlation matrix showed diagonal elements greater than 0.5 for most of the measures and all off-diagonal elements were close to 0. The results show that the commonalities for all the measures exceeded 0.54, indicating shared characteristics amongst the preventive measures. The rotations converged in 20 iterations. The results found that the measures to ensure "Covid safety" can be structured into 4 meaningful factors. This was also demonstrated in Fig. 5, as the function compressed out basically after the fourth component. The factors explained 73.01% of the total variance (Table 7). Table 8 contains the distribution of the measures to each of the components.

7. Discussion of the findings

The COVID-19 virus has affected various economic sectors globally. Its impact on the various aspects of the construction sector is huge. There is great urgency in the construction sector to provide information on the impact and measures to keep construction sites COVID-19 safe. In the following sections, the measures that have been taken to reduce its spread are presented. Based on the measures, a framework is also discussed along with the discussion on the validation of the model.

7.1. Discussion on the measures to reduce the spread of the Covid-19 on sites

This section discusses the answer to the second question, which is "what are the measures to reduce the spread of COVID-19 on sites?" Isolating sick workers is the main measure to keep sites "Covid-safe". This finding is stimulating because workers are required to take body temperatures. If the worker's temperature is higher than 37.5 °C, access

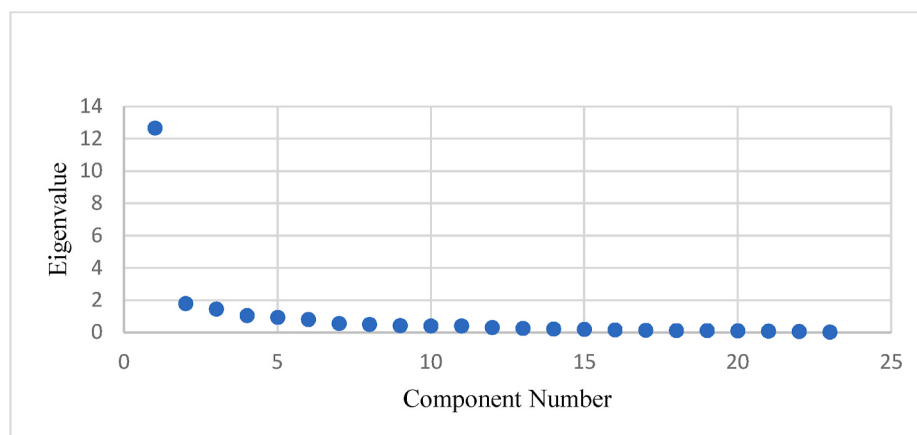


Fig. 5. Scree plot.

Table 7

Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.036	54.315	54.315	13.036	54.315	54.315	6.089	25.371	25.371
2	1.757	7.322	61.637	1.757	7.322	61.637	5.178	21.575	46.946
3	1.511	6.298	67.935	1.511	6.298	67.935	4.194	17.474	64.420
4	1.218	5.076	73.011	1.218	5.076	73.011	2.062	8.591	73.011
5	0.985	4.103	77.114						
6	0.818	3.407	80.521						
7	.615	2.562	83.083						
8	.533	2.219	85.302						
9	0.479	1.996	87.298						
10	0.430	1.792	89.090						
11	0.426	1.776	90.866						
12	0.350	1.459	92.325						
13	0.278	1.158	93.483						
14	0.253	1.054	94.537						
15	0.218	0.907	95.444						
16	0.186	0.774	96.219						
17	0.171	0.713	96.931						
18	0.157	0.655	97.586						
19	0.128	0.533	98.118						
20	0.114	0.476	98.594						
21	0.106	0.441	99.035						
22	0.084	0.350	99.385						
23	0.079	0.329	99.714						
24	0.069	0.286	100.000						

to the site would be denied. The workers will undergo a swap test and report to the nearest health centre for further observation. The Malaysian government has developed applications (i.e., MySejahtera) to monitor COVID-19 incidents. MySejahtera is an application developed by the Government of Malaysia to assist in managing the COVID-19 outbreaks in the country and has helped detect thousands of cases. Some construction companies have also developed their own computer application to trace the movement of workers on sites. Workers are required to scan QR codes when they enter any office. Therefore, it is not surprising that the next measure taken to prevent COVID-19 on the sites is to examine all workers for likely COVID-19 symptoms every day, especially before entering the sites. Apart from the usual temperature, many construction companies will also examine workers for other symptoms like dry cough, skin rash, tiredness, fatigue, runny nose, vomiting, aches and pains, sore throat, diarrhoea, headache, fever, irritation, or discolorations of fingers or toes. The extensive tests are normally conducted periodically by doctors that are engaged by the contractors. One of the main ways that COVID-19 can spread on sites is by direct physical contact. For instance, if an infectious individual touches an uninfected person. Hence, it is not surprising that handshaking or hugging amongst the site operatives is strictly discouraged on sites or even in the hostels. However, while hugging may not be prevalent, handshaking is a normal way of greeting amongst site operatives, especially among those from the same nationality/ethnic workers on sites or at the respective hostels provided by the contractors. Most of the site operatives in Malaysia are foreigners, and are generally from Pakistan, Bangladesh, Indonesia, Myanmar and Nepal. In order to keep everyone informed of the measures to reduce the COVID-19 infection, it is pertinent to display posters and info-graphics in a language understood by the workers. The posters will serve as a reminder to the workers and visitors of the possible Covid risks on site. The Covid posters will help create a high level of Covid consciousness on the sites. Effectively, they will prompt workers to use their personal safety equipment and to be conscious of their environment and co-workers.

The most common form of preventing the virus in most places on construction sites or outside of the workplace is using a face/nose mask. Wearing a mask is an effective measure to curtail the pandemic. In fact, many workplaces are placed under a 'mask mandate'. Contractors provide masks to their workers and the workers are being monitored to

ensure their usage. Penalties are placed on workers who do not use the masks on the sites. Hence, it is expected that wearing masks will serve to prevent the spread of the virus on sites. Health education on construction sites is poorly conducted. In fact, many construction sites are unhygienic. It is making them major breeders of infectious diseases in places like Malaysia and Singapore. Dengue, malaria, and cholera are some examples of common diseases on construction sites. Some contractors provide health education to workers to create awareness amongst the workers on how to keep sites Covid-safe. The government has issued many new regulations to deal with Covid in workplaces. CIDB Malaysia has also embarked on inspections to ensure that workers adhere to the regulations on construction sites. However, only some 50% of Malaysians wear masks (Azlan et al., 2020). Many construction companies have been fined for violating the order. For example, all foreign construction operatives are required to perform a Covid -test before entering the sites and are required to wear a mask and do a daily temperature check.

The nature of construction activities entails carrying materials and components. However, one of the indirect ways that the Covid-19 virus is often spread is if vulnerable workers touch materials/components/items touched by an infected individual. Therefore, to prevent the spread, the use of hand sanitiser is imposed on all construction sites. Workers are required to use the sanitisers provided by the contractors on-site in the morning before their first task and regularly as they change activities or work. As such, it is expected to find that the contractors are required to ensure the availability and accessibility of the sanitisers to the workers on sites. Gathering or crowding, especially in a closed space, which is often the case on most building sites will trigger the rate of the infection directly or indirectly. Therefore, it is important that contractors enforce the no gathering approach as a means of preventing the spread of the virus on the construction sites.

Arguably most construction sites are unhygienic. According to the Business and Human Rights Resource Centre (2020), immigrant construction workers in Gulf countries are highly at Covid risk because the workers live in tightly cramped labour camps and often in unsanitary conditions, some without access to running water. Similarly, in fact, in the USA, many construction sites lacked clean or freshwater on sites during the COVID-19 pandemic. This research has found that ensuring the regular supply of clean/freshwater will go a long way towards

Table 8
Rotated component matrix.

Measure	Component			
	Hygienic and Control (HC)	Equipment and Monitoring (EM)	Awareness (A)	Incentive (I)
Workers to cover their mouth and nose when they cough/sneeze	0.768			
While using a scaffold, restrict access to one person at a time	0.760			
Workers to work in teams but inter team's interaction is prohibited	0.744			
Wear a special safety mask if working less than 1m apart	0.723			
Wash hand frequently	0.703			
No gathering or crowding	0.679			
Foods/drinks should be provided on sites- workers not allowed to eat outside during the working hours	0.630			
Wear gloves	0.602			
Keep social distancing	0.555			
Provide face masks to workers		0.822		
Ensure regular supply of sanitiser		0.757		
Disinfect surfaces and objects used by others		0.693		
Restrict/stagger access to site welfare facilities		0.680		
Fumigate sites at least once daily – especially at the close of day work		0.672		
All workers must be examined for likely COVID-19 symptoms daily		0.588		
No hugging/ handshaking on the site		0.574		
Company provides separate accommodation for workers based on the projects they are working on		0.472		
Display health advisory posters and info-graphics in a language understood by the workers			0.780	
Provide health education to workers regular			0.737	
Abide by government policy			0.632	
Suspend non- critical activities on sites until conditions improve			0.625	
			0.605	

Table 8 (continued)

Measure	Component			
	Hygienic and Control (HC)	Equipment and Monitoring (EM)	Awareness (A)	Incentive (I)
Self-isolation for workers who fall ill/sick				
Provide incentive to a sick worker- with this, they will report their medical status				0.797
Ensure regular supply of clean/freshwater				0.533
Eigenvalue	13.036	1.757	1.511	1.218
Variance explained (%)	54.315	7.322	6.298	5.076
Internal consistency	0.685	0.657	0.676	0.665
Bartlett's Test of Sphericity	0.902 χ^2 (36) = 909.458	0.887 χ^2 (28) = 743.530	0.8327 χ^2 (10) = 213.761	0.500 χ^2 (1) = 7.297
p for second order component analysis	<0.001	<0.001	<0.001	<0.001
Variance explained for second order component analysis (%)	67.96	67.50	60.707	62.27
Cronbach's alpha for second order component analysis	0.939	0.930	0.832	0.679

reducing the spread of the virus, and it is remarkable that the next measure, supplying freshwater, is to ensure that workers wash their hands frequently. Hands should be washed with soap carefully, ensuring that all areas of the hands and forearms are well cleaned. To reduce congestion on the sites, many contractors have suspended none critical activities until the Covid curve has flattened to decrease the spread of the virus, especially due to physical contact. Therefore, it is interesting that this research found that the suspension of non-critical activities on sites is being implemented on construction sites. In Malaysia, during the first wave, construction companies were ordered to reduce site activities by up to 50% until the condition improved. Most construction companies have not returned to sites fully even after 6 months of the lock-down being suspended.

It was anticipated that disinfecting surfaces and objects used by others will greatly reduce the scourge of the virus. Therefore, if the particles fall on a surface or if an infectious individual touches a surface, the virus will be there for some time. Depending on temperature and humidity, the virus remains active for up to 72 h on surfaces and materials (Van Doremalen et al., 2020). The droplets could remain airborne for around 8–14 min in a confined space (Stadnytskyi et al., 2020). Therefore, apart from using hand sanitiser, it has been recommended that surfaces and objects that were previously used by others should be disinfected. However, because the virus is also airborne, the virus may be transported for some distance before it falls onto surfaces. Therefore, even if the materials or objects have not been used or touched by others, it is highly recommended that surfaces/materials/components should be disinfected if left for a long time as may be determined by the site safety manager or construction managers. Mouth and nose coverings were also found to be a practical measure to reduce the spread of the virus. This is very necessary, especially if the other workers are not using the mask during eating/drinking times or when alone. Workers may not use the masks when in isolation or far from other people. Wearing masks is not comfortable for most site operatives due to obstructions to breathing. Many of the workers carry heavy materials and components and need to move fast so that they can complete the assigned tasks. Most

Table 9
Additional measures listed by some of the respondents (Listed verbatim).

Strict control on health and safety Workers are restricted to visit other places (only to work site & quarters) unless necessary Scheduled working hours Alternate working days for workers and staff to avoid too much of close contact. And some staff can work from home and only go to site for important issues. Company should follow the government SOP all the time and educate all the staff and workers at site. No just talk on paper only. Don't work	Strick compliance levels Follow "SOP" which created and agreed by government in the future. Works in zoning. Send safety or engineers go for safe distancing officer course and safe management officer course which relating to covid 19 Alternate working days for workers and staff to avoid too much of close contact. And some staff can work from home and only go to site for important issues. Reduce the number of workers working on site
No visitors allowed at site at all	Doing disinfection to the site 3 times a day
Separate the workers to different cluster according to their trade and position, to keep to workers in one group	Work from home unless necessary, smart use of technology, strictly follow SOP
Frequently give check up	Good staff & work rotation
Social distance and work from home	Force leave for everyone
Work from home unless necessary, smart use of technology, strictly follow SOP	Ensure the worker in fit condition for everyday and no symptom of covid-19
Close the site for a while to prevent Covid 19	Always stay hygiene.
Follow sop	Body temperature check and self-declaration
Worker work only 3 days per week	No visitors allowed at site at all
Make sure all the sop rules had been done	Stop works
Take shift to avoid overcrowded and always follow sop	Work under sop
Reduce the import of foreign labor at this period	Provide mask and safety distance
Adopt sop & new normal, monitor & proper practical enforcement at project site is the ultimate risk control. stay safe practice the new normal requirements set by MOH and the construction industry like MBAM & CIDB guidelines	Time slots for workers to minimise number of people on site at one time while working 24 h a day to compensate reduction of manpower.
Every worker should be provided with a basic set of tools needed for the tasks they are assigned to. Using of the same tool by multiple workers should be avoided. If tools are shared or stored for later use by another person, they need to be disinfected/cleaned	To continue on critical project with time frame for completion & delay other non-critical project kickstart. Manpower efficiency to increase with the limited resources available so that site would not be overcrowded.

SOP = standard operating procedures.

of the sites have workers working under the rain or sun with high humidity which is accompanied by a lot of sweat. Under such onerous conditions, wearing masks may not be easy for most of the construction site operatives. However, because the virus is airborne, it is important that they cover their noses and mouths to prevent the spread of the virus.

The contractors should provide separate accommodation for workers based on the projects they are working on to curtail the surge of the virus on sites. This would also minimise efforts on contact tracing in case a member of the gang/team is infected. Restricting or staggering access to site welfare facilities will reduce the workers' vulnerability to the virus because it will reduce overcrowding and congestion. The research further found that to reduce the spread of the virus, the contractors should provide incentives for sick workers. This is a strategic approach because it will prompt the workers to reveal their true medical status. The previous research found that construction workers engage in unhealthy behaviour to retain their jobs. They fear that if they reveal their medical status, they may be denied entry to the site if unwell. This is a very serious consideration for foreigners, as it may lead to their deportations. In fact, many patients in Malaysia lied about their COVID risks (Zhu et al., 2020) by not disclosing their movement and exposure to

COVID-19. Hence, patients were requested to sign the "COVID-19 Risk Declaration Form" (Zhu et al., 2020). Whilst many contractors will disinfect surfaces and objects that have been touched by others, most of the contractors will fumigate the entire site at the end of the work day. With this, it is believed that the virus that fell on the surface or was suspended in the air will be destroyed before the start of work on the following day. The normal mask is required to be worn on. However, if the distance between the workers and other workers is less than 1 m, the contractors should provide a special safety mask for the workers to keep the virus under control. Working in teams but discouraging inter-team interaction will help to reduce the scourge of the virus, according to the surveyed construction companies. This is necessary in a case where someone in a team has contracted the virus. The rate of the spread will be confined to the team as workers in the other teams will not be infected with the COVID-19 virus as there is no interaction between teams. Rather than allowing workers to eat outside the sites, as is normally the case during the break period, contractors are now taking the initiative to either provide the food themselves to workers or engage the services of an external caterer. The contractors also provide workers with individually packed meals and utensils. This approach will ensure that the workers are not exposed to the public outside of the construction companies. Although the virus is transmitted by droplets, wearing hand gloves will help to reduce the spread of the virus in case the virus has fallen on the surface of the materials or the clothes of other workers. Using scaffolds during construction is prevalent on construction sites. The scaffolds are designed to maximise space but yet be able to provide the required access and support for the workers. Many operatives could be using the scaffold at the same time. However, to prevent contact whilst using the scaffold. It is required that contractors control access to the scaffold, even if the use of masks and gloves is strictly enforced.

Apart from the measures on the survey form, the respondents were asked to include other applicable measures they had taken or will take to break the chain of the transmission. Table 9 contained the list of qualitative data on other measures aside from those on the survey form. The measures are presented unedited.

Based on the qualitative data presented by some of the respondents in Table 6 above, many of the suggested measures revolve around those in the survey. Some of the respondents recommended that basic tools and masks should be provided. It is interesting to know that the respondents emphasised strict adherence to the SOPs (standard operating procedures) on Covid prevention. Many also suggested staggering work. For instance, some of the respondents opined that scheduling working hours and zoning of work will help in preventing the spread of the Covid virus. Some also said the movement to sites should be restricted. It is interesting to find that some suggested working from home. Where work to perform depends on many factors, including the nature and stage of the projects. It also depends on investment in technology. However, whilst this is commendable, most construction workers can not work from home. But, this does not imply that technology has no role to play in combating the spread of COVID-19 on sites. In fact, one of the respondents suggested that contractors should use innovative technology. In fact, Covid is a driver to change in the construction sector. Many contractors have moved to virtual ways of working. Drones and robotics can be used to perform some tasks. However, the major limitation of the adoption of technology is the cost implications. Investment in technology is very expensive, and many contractors may not be able to afford it considering the low-profit margin in the industry. Most of the contractors belong to the category of small and medium-sized enterprises with a low capital base and low-profit margin of less than 10%. It is exciting to note that many of the respondents stressed the need to enforce the implementation of the latest health and safety guidelines and SOPs on the measures to control the spread of the COVID virus. However, in support of this, one of the respondents wrote "Make sure they follow government rules to test for Covid-19 for every worker; not only foreign workers but local workers also". Another one wrote, "Ensure every person working at the site has to get a Covid-19 test". Many of the

respondents also suggested that the work duration be shortened. This is a good approach as this will also reduce congestion on the site. In many of the sites, workers are allowed access to sites in batches or teams. For instance, if the workers are divided into two teams, team A will allow access to the site on the alternative days (i.e. Monday, Wednesday, Friday and Sunday) while team B will take alternative turns. In fact, in an effort to reduce the spread of the virus, the Qatar government has restricted construction workers' hours to a maximum of 6 per day (Business and Human Rights Resource Centre, 2020). Respondents also suggest conducting disinfection periodically. This suggestion is in accordance with the government policy (Yaakob, 2020)

7.2. Discussion of the PCA framework

The discussion of the answer to the third question is presented in this section. Using the principal component analysis as a tool in preventing the spread of COVID-19 on construction sites will help to facilitate systemic decision making to interrupt the spread of COVID-19 on sites. This will inform policy, programmes, and interventions aimed at ensuring "Covid safety" and increasing productivity.

7.2.1. Component 1 – hygiene and control

There is a high positive correlation amongst the measures. More than 50% of the model was represented by this component. The component comprised nine measures to reduce the Covid scourge. The second-order analysis combined the nine measures into one component. Based on the WHO's guidelines, the COVID-19 virus can be contracted when it enters the mouth, nose, or eyes of a vulnerable person, which is more likely to happen when people are in direct or close contact (less than 1 m apart) with an infected person (WHO, 2020b). One of the primary means of interrupting the spread of the virus is through social distancing. Social distancing is keeping a distance of about a meter from the other workers. Many construction sites have been shut down because the workers cannot work "shoulders to shoulder" (Global Construction Review, 2020). However, the 1 m rule predates the COVID-19 but hinges on the principle that the droplet can be observed within 1-metre. However, there are still some significant chances that the virus can be transmitted within 1 meter. Hence, 2 m or more apart has been suggested. Furthermore, since the epidemic transmission of COVID-19 is driven by population densities (Rocklov and Sjodin, 2020), cramped accommodations and building sites mean social distancing is impossible for these workers. Research in the UAE also found that cramped accommodations and building sites mean social distancing may not be possible for construction workers (Business and Human Rights Resource Centre, 2020). It may not always be possible to keep a social distance of up to 1 meter on construction sites. If the workers require working at an interpersonal distance of less than 1 m and other organisational solutions are not possible, it is then necessary for all workers to use masks. These measures should be combined with wearing hand gloves and reducing overcrowding and congestion on the sites. Additionally, these measures are conducted along with making sure that workers wash their hands regularly with soap. For all these to be more effective, workers should be restricted from eating outside of the sites once they have entered the site in the morning. Food vendors may be contracted to supply foods and drinks to the site during the lunch period on-site rather than allowing the workers to eat outside, as they may expose the workers to the virus in the markets. Along the same path, workers should be informed or reminded to close their mouths and noses when they cough or sneeze. Equally, it is very important that these measures ensure that, where applicable, the use of the scaffold is closely controlled so that it will not be congested.

7.2.2. Component 2-protective equipment and monitoring [personal and companies]

This component has eight measures that were closely related and collectively contributed 7.32% of the model. Contractors are required to

provide face masks to workers and ensure that sanitisers are regularly or always provided. These measures should be provided along with the disinfection of surfaces, tools, plants, and materials that have been used by others or left for a long time. Hand sanitiser and masks alone may not be enough to control the spread of the virus to vulnerable workers. Furthermore, to be more effective, regular fumigation of the sites should be conducted to ensure the whole site is not at Covid risk. Welfare facilities like toilets, bathrooms, and canteens on sites are normally few and small and are used by everyone regardless of the team/gang or location of the work. Visitors also use these facilities. Because of the wide and heavy usage, welfare facilities could be a secondary epicentre for the spread of the virus on a site. Additionally, a high level of restriction or monitoring is required with the use of the welfare facilities. Hand sanitiser should be provided at the entrance of the welfare facilities. Workers must use hand sanitisers before they enter and leave the facilities. Where possible, visitors should not be allowed to use the welfare facilities on the sites during the pandemic. The facilities should be regularly disinfected and fumigated. Depending on the size of the site and the number of workers, it could be disinfected and fumigated twice a day. Masks should be worn at all times, most especially when workers use the welfare facilities. Providing sanitiser and masks by the contractors will be more effective if their use are closely monitored. Notwithstanding, even if sites are fumigated, and masks and sanitiser are provided, daily examinations of the workers for possible COVID-19 is necessary. Whilst activities can be controlled on sites, to further break the chain of the transmission, contractors should provide separate accommodations for workers based on the projects they are working on. However, cramped accommodations in the UAE for construction workers and construction sites make it very impossible for workers to practice social distancing (Business and Human Rights Resource Centre, 2020). Contractor should ensure that workers do not hug each other or shake hands whilst on the site. Universal personal protective measures need to be applied at all times to prevent unintentional COVID-19 transmission on the construction sites. Construction companies need to develop innovative and suitable personal protective equipment for their workers and ensure its implementation in the companies.

7.2.3. Component 3 – awareness

Keeping workers informed on the status of the Covid virus and on the government guidelines and regulations on ways to reduce the spread and impact of Covid on construction sites and the health of the workers themselves is important. Contractors should provide updated health information to workers regularly on Covid and display health advisory posters and info-graphics for the workers on the sites. To avoid being fined/penalised and to be Covid risk-free, contractors should ensure that all government guidelines and regulations on safety protocols for construction sites are strictly implemented. Providing information on the Covid-risk and abiding by government regulations should be combined with suspending noncritical work on sites. Effectively, the number of workers on sites will be reduced, which will ultimately reduce the rate of infections. This approach in tandem with government regulations to reduce the spread of various diseases by reducing the size of the workforce on sites and by reducing the number of days to work on sites in many countries. This is also in tandem with the government policy for isolating unwell workers pending a medical examination. Some measures taken by the government and the contractors were to postpone construction activities that are not critical because of the requirement of social distancing and providing Covid tests for workers. The contractors need to ensure that workers are examined every day, especially for temperature, cough, and sneezing, and workers that are sick should be kept under observation. Health education for workers and displaying infographic information on sites can break the transmission of Covid and should be combined with information on the government regulations and guidelines.

Table 10
ANOVA.

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
Zscore: Provide an incentive to a sick worker- with this, they will report their medical status	6.124	3	.867	116	7.059	0.000
Zscore: Provide health education to workers regular	11.971	3	.716	116	16.714	0.000
Zscore: Provide face mask to workers	19.888	3	.512	116	38.882	0.000
Zscore: Keep social distancing	27.198	3	.322	116	84.347	0.000
Zscore: Suspend non-critical activities on sites until conditions improve	13.295	3	.682	116	19.494	0.000
Zscore: Ensure regular supply of clean/ freshwater	18.609	3	.545	116	34.169	0.000
Zscore: Ensure regular supply of sanitiser	26.186	3	.349	116	75.106	0.000
Zscore: All workers must be examined for likely COVID-19 symptoms daily	17.308	3	.578	116	29.933	0.000
Zscore: Fumigate sites at least once daily – especially at the close of day work	21.019	3	.482	116	43.585	0.000
Zscore: Foods/drinks should be provided sites- workers not allowed to eat outside during the working hours	19.097	3	.532	116	35.898	0.000
Zscore: Abide by government policy	21.895	3	.460	116	47.637	0.000
Zscore: Restricting or staggering access to site welfare facilities	27.623	3	.311	116	88.687	0.000
Zscore: Self-isolation for workers who fall ill/ sick	13.383	3	.680	116	19.687	0.000
Zscore: No gathering or crowding	25.366	3	.370	116	68.585	0.000
Zscore: Wear a special safety mask if your distance from other people is less than 1 m	20.583	3	.494	116	41.703	0.000
Zscore: Wear gloves	9.244	3	.787	116	11.750	0.000
Zscore: While using scaffold access allowed to one person at a time	18.678	3	.543	116	34.411	0.000
Zscore: Wash hand frequently	26.628	3	.337	116	78.966	0.000
Zscore: Workers to cover their mouth and nose with a tissue when they cough/sneeze	23.616	3	.415	116	56.892	0.000
Zscore: No hugging/ handshaking on the site	22.725	3	.438	116	51.866	0.000
Zscore: Disinfect surfaces and objects used by others	29.353	3	.267	116	110.053	0.000
Zscore: Company provides separate accommodation for workers based on the projects they are working on	18.909	3	.537	116	35.224	0.000
Zscore: Display health advisory posters and	16.091	3	.610	116	26.390	0.000

Table 10 (continued)

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
info-graphics in a language understood by the workers						
Zscore: Workers to work in teams but inter team's interaction is prohibited	19.725	3	.516	116	38.246	0.000

7.2.4. Component 4 – incentive

The framework shows that in order to accelerate breaking the chain of transmission of the virus, contractors need to encourage workers to make their medical status known. This is because workers, especially those who are not Malaysian, will be reluctant and scared to make their health status known. Infectious workers may be deported and required to pay for the cost of medical examinations, which is very high. The foreigners who constitute more than 80% of the site operatives are not entitled to health subsidies afforded to Malaysians and permanent residents. However, as the data revealed, this measure must be combined with the supply and availability of clean and fresh water that should be provided by the contractors on the sites. This is not peculiar. Immigrant workers working in the Qatar construction sector, especially those working on projects related to the Qatar 2022 World Cup, were found to be at high risk and particularly vulnerable to the virus ([Business and Human Rights Resource Centre, 2020](#)). Construction companies in many countries are now taking concerted steps to educate workers on the disease and carry out awareness-raising programmes, including those relating to hygiene.

Based on the data in [Table 7](#), the efficacy of the measures to keep sites Covid-safe (CS) is:

$$CS = 54.315HC + 7.322 EM + 6.298 A + 5.076I . \quad (2)$$

The Covid risk of a site can be determined with this equation (equation (2)). By comparison, a site with a lower score will be considered high Covid risk, whilst a site with a higher score has a low Covid risk. In this context, a high Covid risk implies penalties for violating Covid policies, cost and time overruns due to low productivity and shortage of resources, and low-profit margins due to low productivity and shortage of resources, work suspension, and high medical costs.

7.3. Results and discussion of the clustering

In this section, the results and discussion of question 4 are presented. Specifically, it provides the answer to “How can sites be classified in terms of the “Covid safe” measures?”. To answer this question, first, a hierarchical cluster analysis was carried out to determine the number of the cluster-based Agglomeration schedule. The analysis observed 4 meaningfully differentiated cluster solutions. On that basis, the K-means cluster analysis was performed using 4 clusters. The K-Means algorithm grouped the 120 sites into Cluster 1, Cluster 2, Cluster 3, and Cluster 4 of sites 5, 33, 78, and 4, respectively. Based on the characteristics of the clusters, the clusters were named Lower-level intervention, High level intervention, Very-level intervention, and Medium level intervention. The data revealed that there were statistical differences amongst all the sites with respect to each of the measures to ensure “Covid safety” on the sites and that they are Covid risk-free. For this reason, the null hypothesis was that each measure did not have any significant effect on which group it would be classified in ($H_0: U=U_0$), and the research hypothesis was that each of the measure had a significant effect on the class it would be grouped into ($H_1: U \geq U_0$). The ANOVA results imply that each of the measures had a significant impact on which group it

Table 11
Final cluster centres.

	Cluster			
	Lower-level intervention	High level intervention	Very high-level intervention	Medium level intervention
Zscore: Provide an incentive to a sick worker- with this, they will report their medical status	-.22394	-.52051	.31000	-.46604
Zscore: Provide health education to workers regular	-1.14714	-.51894	.40932	-2.23965
Zscore: Provide face mask to workers	-2.37001	-.50098	.45954	.71293
Zscore: Keep social distancing	-2.62541	-.54755	.54985	-2.48501
Zscore: Suspend non critical activities on sites until condition improve	-1.12954	-.51464	.41595	-3.00098
Zscore: Ensure regular supply of clean/fresh water	-1.31111	-.66496	.51243	-2.94214
Zscore: Ensure regular supply of sanitiser	-2.70908	-.57956	.52934	.79520
Zscore: All workers must be examined for likely COVID-19 symptoms daily	-2.31971	-.41580	.40830	.74406
Zscore: Fumigate sites at least once daily – especially at the close of day work	-2.14499	-.62937	.51711	.29542
Zscore: Foods/ drinks should be provided sites- workers not allowed to eat outside during the working hours	-1.88171	-.57815	.50022	-2.09987
Zscore: Abide by government policy	-1.39713	-.64745	.52608	-4.12325
Zscore: Restricting or staggering access to site welfare facilities	-2.70400	-.50098	.53556	-2.83246
Zscore: Self- isolation for workers who fall ill/sick	-1.05578	-.67636	.44699	.75884
Zscore: No gathering or crowding	-2.45612	-.50703	.52236	-3.11459
Zscore: Wear a special safety mask if your distance from other people is less than 1 m	-1.96486	-.67234	.51553	1.04908
	-.94781	-.53466	.35223	1.36096

Table 11 (continued)

	Cluster			
	Lower-level intervention	High level intervention	Very high-level intervention	Medium level intervention
Zscore: Wear gloves				
Zscore: While using scaffold access allowed to one person at a time	-1.74594	-.60801	.50516	-2.08063
Zscore: Wash hand frequently	-2.02624	-.72752	.60282	-2.74776
Zscore: Workers to cover their mouth and nose with a tissue when they cough/sneeze	-1.85857	-.70200	.57234	-2.54907
Zscore: No hugging/hand shaking on the site	-2.08962	-.63828	.54804	-1.93765
Zscore: Disinfect surfaces and objects used by others	-2.61669	-.71364	.59263	.98367
Zscore: Company provides separate accommodation for workers based on the projects they are working on	-2.37401	-.30452	.39961	-2.74689
Zscore: Display health advisory posters and info-graphics in a language understood by the workers	-.37490	-.67170	.45108	-3.81150
Zscore: Workers to work in teams but inter team's interaction is prohibited	-2.06835	-.51262	.48412	-2.42599

should belong to (Table 10). The data revealed that disinfect surfaces and objects used by others, and workers must cover their mouths and noses when they cough/sneeze, wash hands frequently, no gathering or crowding on site, and keep social distancing contributed more to the cluster solution. However, wearing gloves, self-isolation for workers who fall ill/sick, provide an incentive for a sick worker, suspend non-critical activities on sites until the condition improves, and provide health education to workers regularly provided less impact on the separation in the cluster solution. However, all the measures were found to be important, with different impacts (Table 11). The sites in cluster 2 were similar to those in cluster 3 (Table 12). The sites in cluster 2 were also similar to the sites in cluster 4. The sites in cluster 1 were dissimilar to the sites in cluster 3.

Cluster 1 – Lower-level intervention. This segment consisted of 5 sites representing 4.17 per cent of the sample. The segment consisted of sites, that showed more commitment to creating awareness. However, they did not have high levels of commitment toward implementing and enforcing hygienic principles on sites. The welfare of the workers was not very important to the companies in this cluster. Cluster 2 – High-level intervention. About 28% of the surveyed site belonged to this cluster, and comprised 33 sites all together. The cluster was dominated by construction sites that were conscious of the Covid risk. They were

Table 12
Distances between final cluster centres.

Cluster	Lower-level intervention	High level intervention	Very high-level intervention	Medium level intervention
Lower-level intervention	1	7.020	11.849	9.817
High level intervention	7.020	1	5.271	9.624
Very high-level intervention	11.849	5.271	1	12.869
Medium level intervention	9.817	9.624	12.869	1

Table 13
Results of validation of the PCA framework.

	Site 1	Site 2	Site 3	Site 4
Respondent's Position	Project Manager	Quantity Surveyor	Health & Safety Officer	Site supervisor
Respondent's working experience	5–10years	5–10years	11–15 years	Below 3 years
Type of project	Residential building	Residential building	Residential building	Residential Building
The average number of workers in your site	400 to 600	Less 50	400 to 600	50–200
Class of company	G7/Developer	G7	G7	Developer
Location of project	Johor	Selangor	Penang	Perak
Measure:				
1 Our company takes extensive steps to prevent the spread of the virus with hygiene programmes and control (54.315HC)	5	4	5	4
2 Our company takes inclusive steps to prevent the spread of the virus by providing all equipment to workers and with effective monitoring in their implementations (7.322 EM)	5	3	5	5
3 Our company takes extensive steps to prevent the spread of the virus with awareness-raising and hygiene programmes (6.298A)	5	5	5	3
4 Our company takes extensive actions to prevent the spread of the virus by motivating and encouraging workers economically and socially (5.076I)	5	4	5	4
Overall measures	365.06	291.02	365.06	293.07
Ranking (1- most safe site)	1	3	1	2

concerned about educating and creating awareness of Covid among the workers. They have recognised the importance of hygiene in the workplace. Cluster 3 – Very high-level intervention. It is apparent that this cluster comprised 65% of the surveyed sites and fully aware of the impact of the Covid pandemic on the sites and took all measures to curtail its spread. They provided all the necessary equipment and support to the workers on the sites. The sites in this cluster also implemented and enforced all the safety measures to be “Covid safe”. Cluster 4 – Medium level intervention. This cluster had only 4 sites, or 3.33% of the surveyed sites. Although, the companies paid less attention to the welfare of the workers. Moreover, implementing measures to reduce the spread of the virus on the sites was not organized.

7.4. Validation of the PCA proposed framework

There is no similar model for construction sites. The only existing models were based on the impact of the pandemic on project duration (Araya, 2021a) and were based on simulation only. To assess the efficacy of the developed model for preventing the spread of COVID-19 on sites was applied to 4 case studies to determine its practical application by building contractors. The cases involved were not involved in the development of the framework. The participants were selected based on their willingness to participate in the validation. The respondents were asked questions based on their experiences during the pandemic to evaluate the frequency at which they agreed with each of the following statements on a scale of 1–6 on their sites. Where 6 = Extremely frequent, 4 = Very frequent, 3 = Frequent, 2 = Less frequent, 1 = Least frequent, and 0 = Not applicable. The CS for the construction companies was computed as a product of the evaluated Likert scale point with the percentage of variance explained as shown in the equation (2). Subsequently, all the products were summed together for the sites. Finally, the sites were ranked in terms of the extent that they would be exposed to Covid risk or to be “Covid safe”. A site with a high score on the Covid risk would be comparatively safer. Table 13 contains the summary of the case studies investigated. Sites 1 and 3 were the most “Covid-safe”. The two sites applied the measures immensely on sites. However, despite

taking the measures remarkably, the respondents still believe that the sites are not entirely “Covid-safe”. For instance, the respondents were asked to indicate the extent to which the workers on their site were vulnerable to the virus. The respondent on-site 1 chose “Exposure to covid risk” and the respondent on-site 3 opined that the site is “Medium exposure risk”. These evaluations could be accounted for by the 27% variance in the model.

8. Conclusion, implication and limitations of the study

This is the first comprehensive research that investigated the impact and validated measures to reduce the spread of COVID-19 on construction sites. This research has provided rich insight into simple and practical measures to reduce the rate of transmission of COVID-19 on sites. With respect to the first question, generally, the cost implications of Covid on the project are approximately 20%. However, this depends on the nature of the project. Big projects, projects that are at the critical phase and experiencing resource shortages, will experience up to 70% increased costs and could delay projects by up to 60%. With respect to the 2nd-second question, to combat the virus, both the contractors and the workers need to work together as the requirement to keeping the sites “Covid-safe” is multi-faceted. The contractors need to ensure that workers work in hygienic conditions and are provided with protective equipment to work safely. Workers also need to educate other workers on the Covid risk. Thirdly, for systemic decisions, the measures can be classified into 4 components including, clear control and monitoring techniques of the company and government policy should be enforced and implemented. Contractors also need to create awareness by providing the necessary information on government regulations and guidelines, and at the same time, incentivise the workers to comply with the company policy. Fourthly and finally, the extent to which the “Covid-19 safe” measures are taken on sites varies. A PCA model was developed and validated with raw data. The results show that the model is practical. Looking at the findings of this research from a practical point of view, the analyses and grouping of the preventive measures and sites have several implications. The first major practical contribution of

the present research is that it provides much needed empirical data on how contractors can keep sites "Covid-safe". The data shows that contractors should offer a duty of care technique to the frontline site workers. Such practical and straightforward techniques during the pandemic would include ensuring the availability and provision of clear water, and sanitary fittings, and appliances. The contractors should also provide hand gloves, masks, and medical facilities. This information is important given that there has been no comparative study as of yet. This will allow projects to be completed within budget and on time. A second important implication of this study derives from the findings on the uniqueness of the knowledge and information on keeping the sites clean and safe being posited within the data. Furthermore, whenever a new worker is engaged, or suppliers/visitors enter the site, precaution is required. Although the primary data for this research was collected in Malaysia, the findings have global implications. The measures that were explained are applicable on most construction sites outside of Malaysia. Similarly, the measures discussed have multiple implications for the control of many diseases because they can be used to reduce the spread of other types of infectious diseases like malaria, Ebola, and dengue on construction sites. However, whilst this research has provided insight into the approach to keeping sites Covid-safe, it has some limitations. In particular, though the respondents in this research provide a comparatively large sample, there is a need to increase the response rate. The number of measures may be increased in future research by looking at the qualitative data in Table 9. In addition, a similar survey may be administered outside of Malaysia, taking into account some possible country-specific conditions.

Conflict of interest

There is no any conflict of interest appertaining to the data in presented in this article and the authors have not received any financial support from companies, government or organization to conduct this study.

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