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Effect of COVID-19 pandemic on the productivity of construction projects in Sri Lanka

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Abstract
The COVID-19 pandemic significantly impacted the productivity of construction projects in Sri Lanka and other countries. Research initiatives are required to tackle this issue from the perspective of construction, given that this subject is relatively significant and that individuals are still working to come up with strategies to overcome the pandemic consequences. As a result, this study investigates how productivity fluctuations in Sri Lankan construction projects during the COVID-19 era can be managed. The study applied the Delphi method along with a quantitative methodology. Mean Rating and statistical analyses were used to analyse and validate the empirical data collected during the study. Absenteeism and interference were identified as the main factor that affected production. Other notable factors included prioritising safety over productivity, workforce reduction due to social distancing protocols, inspection and permit delays, and cash flow and payment challenges. Further, the study also discovered eight effective mitigation techniques to deal with production challenges in the construction industry during the pandemic. The findings, which highlight the synergy between the construction industry and productivity increase strategies during COVID 19, would be a useful reference for future studies due to the paucity of literature on the effects of the COVID-19 pandemic on the construction industry in Sri Lanka. Overall, this investigation provides valuable insights into the factors affecting construction productivity during the pandemic and offers potential mitigation techniques for overcoming these challenges in Sri Lanka and other developing countries.

Keywords
Construction projects, COVID-19, Delphi technique, Productivity, Quantitative approach.

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1. Introduction

The coronavirus illness (COVID-19) is the biggest challenge faced by humankind in the 21st century (El-Erian, 2020). Sri Lanka is one of the developing nations that has been badly impacted by the Coronavirus, reporting 671,110 cases, resulting in 16,781 deaths by the end of October 2022 (Sri Lankan Health Promotion Bureau, 2022). Many emergency methods were applied to control the situation (Kawmudi et al., 2021), causing significant negative impacts on the social and economic context globally (Bandara et al., 2021). Further, the effects of the pandemic led to a substantial financial crisis due to the prolonged quarantine, travel restrictions, manufacturing closures, and rapid decline of various services (Boone et al., 2020). The International Monetary Fund (IMF) reports that this global economic recession is far worse than the financial crisis in 2008 (Athias et al., 2020).

Along with the economies of other nations, Sri Lanka's economy experienced a severe recession due to the COVID-19 pandemic (Roshana et al., 2020). Further, the construction sector appeared to be panicking due to the business conditions and was forced to halt operations temporarily (Pathirana, 2020). The COVID-19 pandemic was a severe blow to the construction industry, and the comprehensive closure mandated for months forced the industry to enter into a complete shutdown (Pathirana, 2020).

The epidemic's spread directly affected the construction workers' productivity. For example, people distressed by a virus cannot be productive and put their efforts towards increasing productivity (Kramer & Kramer, 2020). The morbidity caused by the infection implies that no work productivity can occur until after recovery because sick leave or time taken off the job to seek medical attention has reduced productivity (Wren-Lewis, 2020). Additionally, site closures and general shutdowns have a significant impact on productivity.

Low construction productivity thus became the most pressing issue in the Sri Lankan economy (Manoharan et al., 2022). Even when construction activity resumed in late 2020, the effects of the economic crisis persisted because of increases in material prices, exchange rates, and shortages (World Bank, 2021). Various factors influenced construction productivity during the COVID-19 pandemic outbreak (Abeysinghe & Jayathilaka, 2022). However, evidence-based mitigation techniques can ensure construction productivity during the pandemic (Raoufi & Fayek, 2020). The COVID-19 pandemic's effects continue to have a significant operational impact on Sri Lanka's construction industry, creating a compelling need to solve productivity issues in the construction industry (Niroshana et al., 2022). And also, it is clear that there is a pressing need to find extensive measures and techniques that are required to address these issues in the Sri Lankan construction industry (de Silva, 2023). However, the problem is that while several research projects have focused on this issue in the Sri Lankan context, their reach has mostly remained relatively confined. Few studies have specifically prioritised increasing construction productivity, but there is a lack of literature offering practical mitigation techniques to deal with the related difficulties. Therefore, this study aims to investigate the effects of the COVID-19 pandemic on construction productivity in Sri Lankan construction projects with the following research questions:

Q1: What is the productivity fluctuation in Sri Lankan construction projects during the COVID-19 period?

Q2: What the factors affecting the productivity fluctuation in Sri Lankan construction projects during the COVID-19 period?

Q3: What are the suitable mitigation techniques used to reduce the effects of the COVID-19 pandemic for each productivity factor?

Q4: What are the most effective mitigation techniques used in Sri Lankan construction projects?

2. Literature review

This section focuses mostly on the body of literature that has been published about the COVID-19 epidemic in both Sri Lankan and worldwide contexts.

The majority of the literature now in circulation examines how the COVID-19 pandemic has affected productivity in the construction industry from both a global and local standpoint. Additionally, this literature emphasises previously recognised productivity-related factors. The theoretical framework and the necessity for performing this research will be discussed in due time. This will serve to emphasise how important the contribution that this research piece made is.

2.1. Effects of COVID-19 on the construction industry

The global economy was severely demobilised due to the COVID-19 pandemic (Chakraborty & Maity, 2020). Investment has been downgraded by international credit rating agencies as a result of the unpredictability of the economy (Faculty of Humanities and Social Sciences, 2020), causing substantial disruptions and suffering across all industries, including construction, dining, retail, and aviation (Alsharef et al., 2021). COVID-19 significantly and negatively impacted the real estate and construction industries, causing projects to stall and their beneficiaries to suffer (Bailey et al., 2020). It is noticeable that the primary elements that had a substantial influence on the construction industry were inflation, the closure of production businesses, shorter and longer workweeks, the economic downturn, decreased demand for sales and projects, and rising material and equipment costs (Chopra, 2020). However, the work had to be carried out in a difficult situation with cautious, restricted movements and accelerated project delivery. They had to commence working under the risk of infection with full scrutiny and awareness (Gamil & Alhagar, 2020). Therefore, construction productivity also significantly declined due to the COVID-19 impacts (Bsisu, 2020).

2.2. Effects of COVID-19 on the Sri Lankan construction industry

The Sri Lankan construction industry employs more than 600,000 people and contributes 7.4% to the nation's GDP (Ranasinghe & Pathirana, 2021). Local supply chain systems became extremely important during the pandemic, taking the brunt of the COVID-19 outbreak and having a significant impact on a wide range of industries (Bandara et al., 2020). As a result, the construction industry was severely hit by the COVID-19 outbreak and the nation's economic slump (Kawmudi et al., 2021). More than 50% of the work was done in the Sri Lankan construction industry, which has a total market value of Rs. 397.77 billion, without the client making any payments to the contractor, and the contractor has not made the majority of suppliers' payments (Pathirana, 2020). According to Chopra (2020), such problems are becoming severe and will cause a serious blow to construction productivity and have adverse effects on the world economy.

2.3. Construction productivity

Productivity is a critical consideration for the construction industry, which contributes between 6 and 7 percent of the GDP and ranks as the fourth-largest sector of the national economy (Karunarathna & Siriwardana, 2019). The current official measures of construction productivity frequently rely on labour productivity; still, it is becoming increasingly evident that such incomplete measures may be deceptive because the output change is frequently caused by changes in all inputs rather than a single input (Navaratna & Jayawardane, 2007). However, the construction industry is currently having trouble maintaining its production due to the COVID-19 pandemic effects (Niroshana et al., 2022). Tools have been developed in practise to gauge the severity of the impact that project-level factors have on the productivity of the construction industry. Such tools can pinpoint the variables that need more attention to boost project productivity (Adi & Kasih, 2019).

2.4. Factors affecting construction productivity

Many researchers have investigated the factors influencing productivity (Ghoddousi & Hosseini, 2012). These

Table 1. *Factors affecting construction productivity.*

Productivity Factors	Romania	Brazil	Egypt	India	Indonesia	Iran	Jordan	Kuwait	Malaysia	Nigeria	Oman	Pakistan	Palestine	Saudi Arabia	Thailand	Trinidad and Tobago	Uganda	Zimbabwe
	A & B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Absenteeism and Interference					•					•					•			
Access Control		•																
Clarity of Technical Specifications								•			•							
Communication and Coordination between Construction Parties							•	•						•		•		
Consumption Reduction	•																	
Delay Drawings				•											•			•
Delay in Material Supply			•	•														
Delay Responses to the Clarifications											•							
Increasing Costs	•																	
Equipment Breakdowns						•												
Equipment Shortages			•		•	•			•	•			•		•			
Errors and Omissions of Designs											•							
Excessive Workload												•						
Financial Incentives							•											
Funding Problems	•																	
Incentive Programmes																		
Labour Disciplines	•																	
Labour Motivation										•			•					
Labour Shortages	•																	
Labour Skills																	•	
Labour Supervision								•			•					•		
Lack of Manpower																	•	
Low Salaries												•						
Material Shortages	•		•	•	•	•			•	•					•			•
Management of Work	•																	
Payment Delays	•		•						•					•		•		•
Political Situation													•					
Poor Construction Methods									•									
Poor Relationships among Labours												•		•				
Project Delays		•																
Revisions of Drawings and Schedules				•		•						•		•				•
Rework					•				•	•								
Site Management													•					
Strikes				•														•
Subcontractor Works								•										
Suitability/Adequacy of Plant and Equipment																	•	
Supervision Delays										•					•		•	
Supervisory Incompetence																•	•	
Supply Chain Problems	•																	
Variations								•			•							
Weather and Site Conditions						•												
Work Experience							•					•	•	•				
Work Suspension for the Long Run		•																
Unrealistic Scheduling and Expectation of Labour Performance																•		

A - Leontie et al., 2022; B - Iqbal et al., 2021; C- Alsamarraie and Ghazali, 2021; D - Gerges et al., 2016; E - Thomas and Sudhakumar, 2014; F - Kaming et al., 1997; G - Zakeri et al., 1996; H - Hiyassat et al., 2016; I - Jarkas and Bitar, 2012; J - Abdul Kadir et al., 2005; K - Olomolaiye et al., 1987; L - Jarkas et al., 2015; M - Tahir et al., 2015; N - Mahamid, 2013; O - Mahamid et al., 2013, P - Makulsawatudom et al., 2004; Q - Hickson and Ellis, 2014; R - Alinaitwe et al., 2007; S - Chigara and Moyo, 2014

productivity-affecting elements vary from project to project, especially from country to country, and even within the same project under various conditions (Jayawardane et al., 1998). Table 1 lists factors that affect construction productivity in different countries as identified by past researchers. The factors were discovered concerning general construction productivity.

Most authors have emphasised that the most important factors affecting construction productivity are payment delays and shortages of materials and equipment. Factors such as communication and coordination between construction parties, revisions of drawings and schedules, work experience, and labour supervision can also be highlighted as important factors affecting construction productivity. In addition, studies have since been performed to determine the mitigation techniques that will enhance the positively impacting factors while lowering the negatively impacting ones.

Table 2. *Mitigation techniques to control construction productivity during the Covid-19 period.*

No.	Mitigation Technique	A	B	C	D	E	F	G
1	Administrative action and policies			●			●	
2	Alternatives for offsite works and virtual					●		
3	Creates opportunities for contractors	●						
4	Daily Attendance Log		●					
5	Emergency Loans		●					
6	Encouraging risk assessment and collaboration					●		
7	Engineering controls			●				
8	Environmental Controls		●		●			
9	EOT Claims	●			●			
10	Fast-track medical transportation					●		
11	Job opportunities for skilled workers					●		
12	Lower Overhead costs				●			
13	Material Planning					●		
14	Monitoring through advanced technology			●				
15	New health guidelines and mandatory vaccination		●		●		●	●
16	Participants limiting/reduction of meetings							●
17	Personal Protective Equipment		●	●	●	●	●	
18	Provide financial aids	●	●			●		
19	Providing on-site accommodation			●	●			
20	Sanitation and hygiene			●	●			
21	Scheduling and planning of work			●	●	●		
22	Site logistics and control			●				
23	Social Distance		●	●				●
24	Splitting in working shifts to reduce contact							●
25	Switching real environment to a virtual one							●
26	Work as groups						●	●

A - King et al., 2021; B - Alsamarraie and Ghazali, 2021; C - Iqbal et al., 2021; D - Hassan, 2020; E - Parameswaran and Ranadewa, 2022; F - Dan-Jumbo, 2021; G - Leontie et al., 2022

2.5. Mitigation techniques used to reduce the pandemic impact on productivity fluctuation in the construction industry

Regardless of the circumstances, technological solutions ensure that contractors function as effectively as possible to tackle the COVID-19 pandemic situation in the construction industry (Alsamarraie & Grazali, 2021). Crisis management frameworks played a vital role, and they have potential impacts on controlling construction productivity during the COVID-19 period (Iqbal et al., 2021). On the other hand, intelligent software can provide mitigation techniques for COVID-19 to planning, ordering, and bidding processes by analysing the data that is now accessible to determine where, when, or how tasks are completed and the expenses involved (Alsamarraie & Grazali, 2021). Table 2 illustrates some mitigation techniques to control construction productivity during the COVID-19 period identified by the previous studies.

Table 2 denotes that new health guidelines, mandatory vaccinations, and personal protective equipment are the most frequent mitigation techniques identified in the previous studies. In addition to that, providing financial aid, rescheduling and planning, and social distancing can be highlighted as some standard techniques to prevent construction productivity during the COVID-19 pandemic.

2.6 The necessity for investigating the effect of COVID-19 on the productivity of construction projects in Sri Lanka

The construction industry is one of the most highlighted industries contributing to socioeconomic growth, especially in developing countries (Cherian, 2020). The Sri Lankan economy also heavily depends on the construction sector (Jayalath & Gunawardhana, 2017). When the island's ethnic strife ended in 2009, revitalising economic activity and leading to a

boom in infrastructure and building construction, significant development initiatives were anticipated in other areas of the country (ICRA, 2011). However, the COVID-19 epidemic, which posed many difficulties for many organisations and businesses functioning globally, including the construction industry, altered the expansion of the construction industry.

The construction industry faced a vast disruption due to the COVID-19 pandemic (Pathirana, 2020). According to Rio-Chanona et al. (2020), six weeks of social isolation caused a 5.6% decline in GDP. The working environment has undergone a radical change, and workers' worries about the economy, their psychological and physical well-being, their loneliness, and the difficulties of working securely and remotely have been voiced (Padimukkala et al., 2021). According to PricewaterhouseCoopers (PwC) Sri Lanka (2020), with this uncertain nature surrounding the crisis, the survival of industries is unprecedented due to the cash pressures, supply chain and workflow disruptions, and long-term consequences of the economy.

Sri Lanka's construction industry was also severely affected by the COVID-19 pandemic. After the Easter Sunday attack, the Central Bank of Sri Lanka anticipated economic growth of 4.5% to 5% but now expects only 2.2% due to the COVID-19 pandemic's effects (Central Bank of Sri Lanka, 2021).

Most academics were seeking answers to address these problems in construction productivity due to the productivity recession in the construction industry. Numerous studies examined what factors impacted construction output before the epidemic (Chigara & Moyo, 2014; Gerges et al., 2016; Thomas & Sudhakumar, 2014). On the other hand, numerous research initiatives have been launched globally to examine construction production during the COVID-19 epidemic period. Nonetheless, the amount of study being done on the COVID-19 pandemic in developing countries is rather modest. Confirming the aforementioned remark, these estimations of the pandemic's effects on the construction sector are incredibly low given the Sri Lankan setting. While some studies have looked at the effects of the COVID-19 pandemic in relation to the Sri Lankan construction industry, the majority of them have skipped looking at mitigation measures in conjunction with productivity-related factors, particularly skipping over the analysis of productivity fluctuation patterns throughout the COVID-19 outbreak. The current study highlights this crucial gap in the literature that exists in this area of inquiry. Therefore, this research is necessary to increase construction production while dealing with the repercussions of the COVID-19 epidemic, especially in the context of Sri Lanka.

On the other hand, the pandemic effects will persist for decades (Bandara et al., 2020). Therefore, Sri Lankan construction companies must select the best tactics to adopt inside their projects to increase construction productivity as the nation transitions to a post-pandemic age (Ranasinghe & Pathirana, 2021). More research initiatives are needed to support and strengthen these operations. Therefore, this research aims to investigate how to manage the productivity fluctuations in Sri Lankan construction projects that occurred during the COVID-19

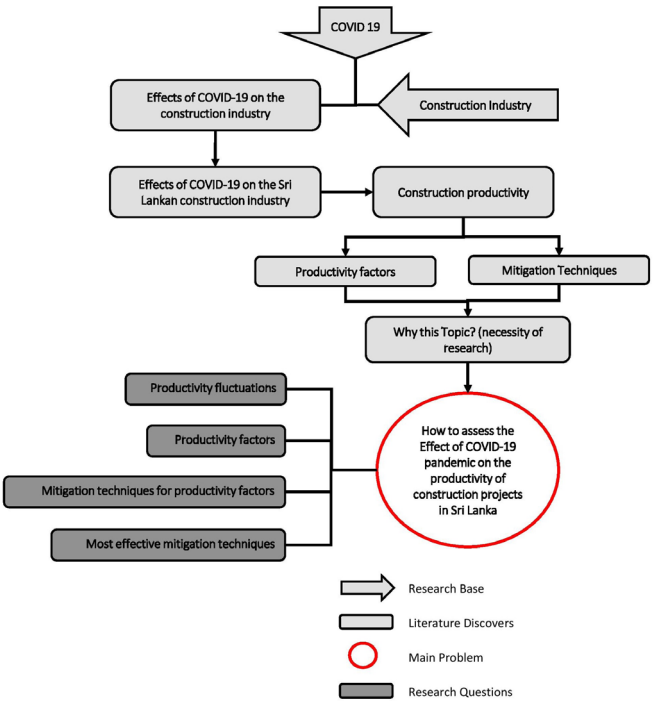


Figure 1. *Theoretical framework of the study.*

Table 3. *Summary of the Delphi Rounds.*

Delphi Round	Phase	Objective	Technique
Delphi Round I	Phase I	Identify the time frame to tank the labour, capital, and material production	Average Acceptance Rate
	Phase II	Validate the factors affecting construction productivity in relation to the pandemic period and identify new factors that had affected construction productivity during the Covid-19 outbreak	Average Acceptance Rate
Delphi Round II	Phase I	Rank the labour, capital, and material production levels relative to predetermined time frames in the pandemic period	Mean Rate
	Phase II	Rank the factors to identify the most significant productivity factors during the Covid-19 pandemic	Mean Rate
	Phase III	Validate the mitigation techniques to reduce the impact of the Covid-19 pandemic and identify new strategies that can enhance or control productivity during the Covid-19 outbreak	Average Acceptance Rate
Delphi Round III	Phase I	Find the most suitable mitigation techniques for each most significant productivity factor	Mean Rate
	Phase II	Rank the mitigation techniques to identify the most effective mitigation techniques to increase productivity during the Covid-19 period	Mean Rate

period, which is a significant need to face future similar challenges as well.

2.7. Theoretical framework

The four initial research questions have been clarified by the theoretical framework presented below, which provides a methodical roadmap for defining the research main problems. The research focuses on the COVID-19 epidemic and the construction industry. Based on that, the literature review discussed the study's backdrop through six subtopics to connect the research's main problem with its four research questions. Please refer to Figure 1 for a visual reference.

3. Methodology

3.1. Quantitative approach

This research looks into questions to make inferences or come to conclusions by carefully gathering data, ranking and analysing it, and discussing the findings. Therefore, this study adopts a quantitative approach as the investigation method. This approach collects data in numerical form and analyses it using mathematical techniques, particularly statistics, to explain an issue or phenomenon (Apuke, 2017). Additionally, it involves various data types that must be gathered to support data analysis. Hence, the quantitative technique is the most suitable approach to collecting more than one type of data to create a better and more comprehensive picture of what is happening in the field (Elkatawneh, 2016). Further, questionnaire surveys can help acquire quantitative data because the study questions require the most important and effective components by ranking them (Bacon-Shone, 2022). When using the Delphi technique, the questionnaire is created similarly to the traditional survey approach, with the researcher selecting a group of qualified experts (Crawford & Wright, 2016).

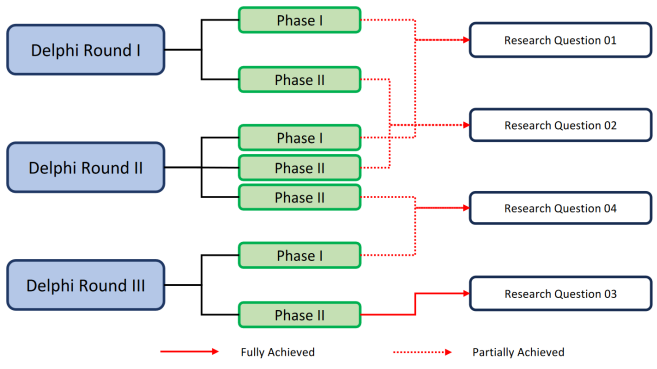


Figure 2. *Research process.*

3.2. Delphi technique

The Delphi approach is functional when group dynamics prevent effective communication and the issue at hand can benefit from collective, subjective evaluations or decisions (Bolger & Wright, 2011). The researcher then creates a second survey based on the results of the first survey and administers it to the same group of respondents. The respondents are asked to examine their initial responses

Table 4. *Respondents' selection criteria.*

Designation	Experience in the Construction Industry	Criteria 1	Criteria 2	Criteria 3	Round I Nos	Round II Nos	Round III Nos
Construction Managers	10 - 20 Years	4	4	4	4	4	4
	More than 20 Years	8	8	8	8	7	7
Contract Administrators	10 - 20 Years	3	3	3	3	3	3
	More than 20 Years	9	9	9	9	9	8
Senior Engineers	10 - 20 Years	7	7	7	7	7	7
	More than 20 Years	4	4	4	4	2	2
Senior Quantity Surveyors	10 - 20 Years	5	5	5	5	5	4
	More than 20 Years	2	2	2	2	2	2
Total					42	39	37

Criteria 1 - Obtained a Bachelor's Degree in Construction Related Subject, Criteria 2 - Obtained a Master's Degree in Construction Related Subject or Obtained Professional Qualification, Criterial 3 - Experience in dealing with construction productivity (More than 5 Years)

and/or provide more information in response to the first survey's respondent suggestions (Amrouche, 2022). Thus, this study used the Delphi technique. Amrouche (2022) stated that the experts remain anonymous to one another while repeating this procedure until reaching a suitable level of agreement. Most research on Delphi in construction engineering and management suggests that consensus occurs in rounds two or three (Ameyaw et al., 2016). Therefore, this study uses three rounds of the Delphi method to derive its conclusions. Table 3 provides a summary of the Delphi Rounds.

Further, based on the methodology previously provided the research procedure for this study can be further defined as follows. It demonstrates how every component of the Delphi round relates to answering the research questions. For more information, please see Figure 2.

3.3. Data analysis technique

3.3.1. Mean rating

The data collected from quantitative approaches can be analysed using statistical methods (Apuke, 2017). Therefore, in this research, the collected data were evaluated using the mean rating (MR), and the elements were ranked based on a 1–5 Likert scale. The MR of each smart city element was calculated using Equation (1), given below.

$$MR = \frac{\sum_{i=1}^{5}(x_i)}{n}$$

Where xi = rate of the responses (Ranging from 1–5) and n = number of responses

3.3.2. Internal consistency

Internal consistency of the responses is one of the major concerns in data collection. Therefore, Cronbach's alpha (Equation 2) value was employed to validate the findings, which is considered a measure of internal consistency (Tavakol & Dennick, 2011). The Cronbach's alpha value should exceed the 0.700 thresholds, and an alpha value closer to one (1) is considered more reliable (Gunduz & Elsherbeny, 2020).

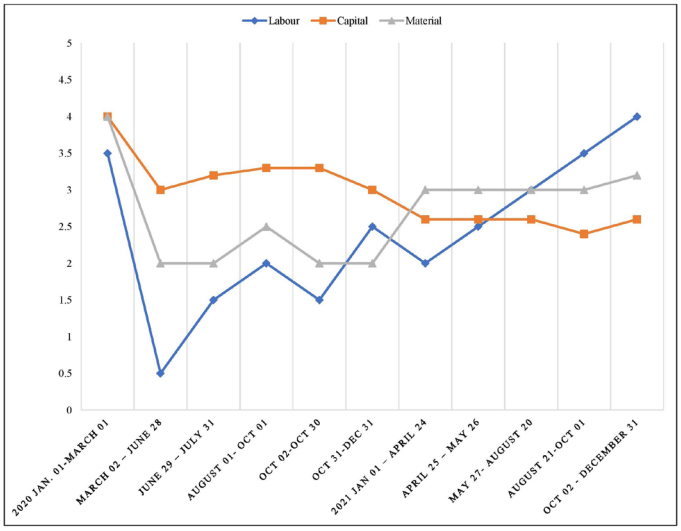
$$\propto = \frac{k}{k-1}\left(1 - \frac{\sum V_i}{V_t}\right)$$

Where k denotes the number of factors, Vi denotes the sum of the risk factor variances, and Vt denotes the variance of the total scores of the Severity Index. The alpha values for the data set were 0.831, 0.845, 0.833, and 0.912, respectively, in phase 1 and phase 2 of rounds two and three. Thus, data sets are considered consistent.

3.4. Expert profiles

Purposive sampling is a technique used by quantitative researchers in which research participants are consciously chosen to test a specific theoretical premise (Agius, 2013). A purposive sample of construction industry professionals with over ten years of expertise was picked for the Delphi rounds, along with three

Figure 3. *Productivity fluctuation during COVID-19 outbreak.*



selection criteria devised to choose the optimal sample for the study. All three requirements must be satisfied to be selected as a respondent for this study. They were contacted via e-mails and phone calls. Similarly, the questionnaires were distributed by hand or e-mail, and the same expert group was considered for all rounds. Table 4 presents the respondent selection criteria. A smaller sample size was used on purpose in this study to maintain the precision and accuracy of the results, adhering to the idea that a well-defined and carefully chosen sample can produce findings with substantial significance despite potential restrictions on statistical generalizability (Lakens, 2022). Furthermore, the senior staff of the construction projects, which includes construction managers, contract administrators, senior engineers, and senior quantity surveyors, is responsible for the management of construction productivity. Therefore, the survey sample size was purposefully limited to a select group of highly experienced senior staff members skilled in coordinating construction production in order to achieve the best productivity results.

4. Findings and analysis

4.1. Fluctuation of productivity during the COVID-19 period (Delphi Round I - Phase I, Delphi Round II - Phase I)

During Phase I of Delphi Round I, the time frame for the rating system was finalised using expert interviews. A 1–5 rating system was used to identify the productivity fluctuations during the COVID-19 period in Phase I of Delphi Round II. Respondents were requested to rank labour productivity, capital productivity, and material productivity. Figure 3 was created using the mean rating for each category to give an idea of the productivity levels and to explain the effect of COVID-19 on construction productivity.

According to the analysis of survey data gathered from respondents, construction project productivity in January 2020 was high, with an average rating of 4 out of 5. However, once the government imposed an island-wide curfew from March 2020 to June 2020, a significant drop in labour productivity (more than 90%) was observed. The output of several initiatives suffered as a result. Although labour produc-

Table 5. *Most significant factors affecting construction productivity during Covid-19 period.*

Rank	Most Significant Factors	Mean Rate	Factor from Literature Review	Research Contributions (identified by Experts)
01	Absenteeism and interference	4.12	•	
02	Safety being prioritised over productivity	4.07		•
03	Workforce reduction due to social distancing protocols	3.98		•
04	Delays in materials supply	3.92	•	
05	Communication and coordination between construction parties	3.78	•	
06	Inspection and permitting delays	3.68		•
07	Cash flow and payment challenges	3.44		•
08	Revisions of Drawings and Schedules	3.25	•	
09	Overwhelming work operation	3.16		•
10	Equipment shortage	3.12	•	

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09	Overwhelming work operation	3.16		•
10	Equipment shortage	3.12	•	

tivity slightly increased from June to October and November to December 2020, the second and third waves of the COVID-19 pandemic significantly reduced productivity, with an average rating of 2 out of 5 from October 2020 to April 2021. Furthermore, data analysis showed that public projects in Sri Lanka received the majority of the funds allocated for development projects. The amount of output produced for every dollar spent in capital decreased as a result of delays in funding and allocating funds for new initiatives. Over the whole pandemic period, the productivity decrease that started in the early stages of the outbreak was maintained.

Material productivity data analysis showed a decline from March to October 2020, with an average rating of 2 out of 5. Weather-related material damage and supply chain disruptions were attributed to this reduction. With an average grade of 3 out of 5, material productivity did, however, increase from January to December 2021, showing a stabilisation of the supply chain.

4.2. Most significant factors affecting the productivity fluctuation in Sri Lankan construction projects during the COVID-19 period (Delphi round I - Phase II, Delphi Round II - Phase II)

The literature identified 44 factors, of which 41 had been validated in the second phase of Delphi I. Ten new factors were also added, totalling 51 factors that were carried forward to Delphi round II with the agreement of 75% of respondents (Perera et al., 2023). During Delphi Round II, respondents were asked to rank the factors according to their significance. The elements with a mean rating of over 3.0 were determined to be the most significant in the study after the results were analysed to see how well each component was rated (Hwang et al., 2017; Leontie et al., 2022). As a result, ten factors were identified as significant: five from the literature review and the remaining five from the study findings, which were suggested by respondents and ranked as significant factors. Table 5 highlights the most significant factors that impacted construction productivity during the COVID-19 period in Sri Lanka. Newly identified factors are in italics in Table 5.

The most significant factor impacting the construction industry's productivity during the COVID-19 period has been identified as "absenteeism and interference". The project's progress is significantly obstructed by the construction workers' attendance at the site. However, the pandemic impacts were severely detrimental to worker attendance as a result of workers' reluctance to report to work out of fear of the virus. In addition, factors such as "safety being prioritised over productivity", "workforce reduction due to social distancing protocols", "inspection and permitting delays", "cashflow and payment challenges", and "overwhelming work operations" can be highlighted as new factors derived from the study findings related to the Sri Lankan

Table 6. *Suitable mitigation techniques for each most significant productivity factors.*

No.	Most Significant Productivity Factors	Technique 01	Technique 02	Technique 03	Technique 04
1	Absenteeism and interference	**Work from Home**	Providing on-site accommodation	**Bio Bubble System**	New health guidelines and mandatory vaccination
		MR = 3.27	MR = 3.11	MR = 3.07	MR = 3.03
2	Safety being prioritised over productivity	New health guidelines and mandatory vaccination	Administrative action and policies	Personal Protective Equipment	
		MR = 3.34	MR = 3.01	MR = 3.01	
3	Workforce reduction due to social distancing protocols	New health guidelines and mandatory vaccination	Providing on-site accommodation	**Work from Home**	
		MR = 3.45	MR = 3.23	MR = 3.14	
4	Delays in materials supply	**Use alternative materials**	Material Planning	Monitoring through advanced technology	Monitoring through advanced technology
		MR = 3.78	MR = 3.34	MR = 3.21	MR = 3.14
5	Communication and coordination between construction parties	**Bio Bubble System**	Social Distance	Environmental Controls	
		MR = 3.23	MR = 3.11	MR = 3.07	
6	Inspection and permitting delays	**Use alliterative methods**	Monitoring through advanced technology	Engineering controls	EOT Claims
		MR = 3.15	MR = 3.11	MR = 3.07	R = 3.01
7	Cashflow and payment challenges	Administrative action and policies	EOT Claims		
		MR = 3.41	MR = 3.27		
8	Revisions of Drawings and Schedules	Scheduling and planning of work	Administrative action and policies	Monitoring through advanced technology	
		MR = 3.55	MR = 3.34	MR = 3.21	
9	Overwhelming work operation	Providing on-site accommodation	**Bio Bubble System**	Social Distance	
		MR = 3.21	MR = 3.19	MR = 3.15	
10	Equipment shortage	Engineering controls	Emergency Loans	**Use alliterative methods**	
		MR = 3.19	MR = 3.06	MR = 3.01	

constriction industry. The remaining elements, including "delays in material supply", "communication and coordination between construction parties", "revisions of drawings and schedules", and "equipment shortages", may together have an adverse effect on construction productivity, leading to delays, higher costs, and other problems that adversely affect the construction process. Therefore, effective management of these factors is vital to ensure the smooth and efficient operation of construction projects, which leads to higher productivity.

4.3. Suitable mitigation techniques used to reduce the pandemic impact on productivity fluctuation in the Construction Industry (Delphi Round I – Phase III, Delphi Round III – Phase I)

Phase II of Delphi Round II discovered 33 mitigation techniques (26 from the literature and six new techniques identified by the experts) with a 75% response rate and advanced them to Round III. During Delphi Round III, respondents were asked to identify the mitigation techniques for each most significant productivity factor. The techniques with a mean rating of more than 3.0 were determined to be the most suitable mitigation techniques for each most significant factor. Table 6 shows suitable mitigation techniques for each most significant productivity factor. The table below features some mitigation techniques that are fresh additions from this study

Table 7. *Most effective mitigation techniques of the study.*

Rank	Most Effective Mitigation Techniques	MR Score
1	New health guidelines and mandatory vaccination	4.01
2	Providing on-site accommodation	3.89
3	EOT Claims	3.87
4	**Bio-Bubble System**	3.65
5	**Work from Home Concept**	3.54
6	Monitoring through advanced technology	3.40
7	Administrative action and policies	3.25
8	Social Distance	3.11

and are denoted in bold. The experts recognised these and chose them as appropriate strategies for some of the important aspects.

Out of 33 mitigation techniques, 15 were selected to manage construction productivity during the COVID-19 outbreak in the Sri Lankan context. "New health guidelines and mandatory vaccination", "monitoring through advanced technology", "administrative action and policies", and "the Bio Bubble System" were the most frequently used mitigation techniques presented in the table. Those techniques can mitigate the three or more most significant factors affecting construction productivity. In addition, some techniques can be used to mitigate two other productivity factors. However, techniques such as "emergency loans", "environmental controls", "EOT claims", "material planning and scheduling", and "work planning" can be considered unique techniques in this context because they can only be used to mitigate one productivity factor in the study.

4.4. Most effective mitigation techniques used to reduce the impact of the pandemic on productivity fluctuation in the Sri Lankan Construction Industry (Delphi Round II – Phase III, Delphi Round III – Phase I and II)

After identifying mitigation techniques for each of the most significant factors affecting construction productivity, the selected techniques were further ranked based on their effectiveness to identify the most effective mitigation techniques for the Sri Lankan context. Thus, respondents were asked to rank the mitigating techniques according to their effectiveness in the Sri Lankan context. Techniques with an MR score above three (3) are considered the most effective techniques for this study. Accordingly, as illustrated below, eight techniques were chosen as the most effective mitigation techniques for the Sri Lankan context. Newly discovered mitigating strategies are highlighted in bold.

Based on the table outcomes, "new health guidelines and mandatory vaccination" can be considered the most effective mitigation technique that can enhance productivity during the COVID-19 outbreak. Further, "providing on-site accommodation" and "EOT claims" has a similarly significant impact on increasing construction productivity during the COVID-19 outbreak. Maintaining "social distance" is the last and most important mitigation action used throughout the epidemic, as it significantly slows virus spread. However, maintaining social distance can be difficult when working on a construction site because worker interconnectedness is hard to control. Therefore, social isolation works with bio-bubble systems to improve adaptation and efficiency.

5. Discussion

The study results identified ten factors significantly affecting construction production during the COVID-19 outbreak. It can also be deduced that these particular factors are of the utmost importance based on their perspectives given the scope of the study, which primarily centres on productivity factors examined from the perspective of project productivity governance (involving construction and contract managers, senior engineers, and quantity surveyors). One of these, "absenteeism and interference", has been identified as having the greatest potential impact on the construction industry's productivity. The COVID-19 pandemic significantly disrupted and interfered with the Sri

Lankan construction industry because the bulk of the sites had to close as a result of the disease's rapid spread (Bandara et al., 2020). This factor was also noted during the literature assessment of various countries. Specifically, this factor significantly affected labour productivity in the Nigerian construction sector during the 20th century (Olomolaiye et al., 1987). However, in the contemporary building sector, Asian countries like Thailand have also elevated that as a productivity factor in their studies (Makulsawatudom et al., 2004). Additionally, the two most commonly observed factors throughout the COVID-19 period are "delays in material supply" and "equipment shortages". It's also vital to remember that the majority of material and equipment shortages were brought on by unstable market prices. Due to a lack of supply, those costs were also rising rapidly day by day. For instance, the unit cost of sand (price per 100 cubic feet) climbed by over 8,000 LKR to approximately 22,000 LKR within the past two years (Nilar, 2022). However, before the emergence of the COVID-19 epidemic, these factors had a significant impact on the construction output in several countries, such as Egypt, India, and Zimbabwe (Chigara & Moyo, 2014; Gerges et al., 2016; Thomas & Sudhakumar, 2014). However, since it is essential for planning and procurement throughout all construction activities, it is possible to say that "coordination and communication between parties" is a factor that extends beyond the COVID-19 outbreak. Numerous studies have identified this factor as a productivity indicator for the entire construction industry in different countries during the past two decades (Hiyassat et al., 2016; Jarkas & Bitar, 2012; Mahamid et al., 2013). The study concluded with five additional factors that were previously not identified as influencing productivity during the COVID-19 outbreak in the construction industry.

Over the past few years, numerous studies have developed methods to reduce the COVID-19 epidemic's impact on global construction output. Despite these various investigations, the circumstances in Sri Lanka are quite different. Alsamarraie and Grazali (2021) conducted a study and concluded that there were six mitigating strategies to deal with the effects of COVID-19 in the construction sector. The above study and this research have shown that using social distance, bio-bubble systems, and offering accommodations on the construction site significantly affect construction productivity. These strategies were also derived from this study since the biobubble system and accommodation provision on construction sites were among the techniques most frequently employed by Sri Lankan construction workers during the COVID-19 outbreak. Further, Alsamarraie and Grazali (2021) and this study have further emphasised the need for vaccines. With the introduction of vaccinations, this preventative measure could become an essential requirement for every person in Sri Lanka, resulting in a mandate for all construction sector workers to receive a vaccination prior to beginning work, significantly lessening the impact of the COVID-19 pandemic on the construction industry (Ranasinghe & Pathirana, 2021). Although only a few of these strategies are in line with the results of this study, the majority of them contradict them. King et al. (2021) provided a list of mitigation strategies to deal with construction industry productivity during the pandemic period. Here, methods have been developed in many categories, including legal, financial, production, and environmental. The authors have, however, highlighted the ongoing supply and the avoidance of labour shortages as a mitigation strategy in the production category—in this study, it came from the other components, too. For instance, offering onsite accommodations and bio-bubble systems can help reduce the labour shortage. Additionally, a continuous material supply may be guaranteed by adopting alternative resources. Therefore, the findings of King et al. (2021) align to some extent with this study, which is based on the Sri Lankan context. Iqbal et al. (2021) have stated that mitigation strategies such as physical distancing, a one-worker, one-task policy, monitoring through advanced

technology, scheduling, and site logistics and control can overcome issues in construction productivity during the COVID-19 pandemic. However, the effects of these strategies may differ depending on the Sri Lankan setting. For instance, the Sri Lankan construction industry employs a novel and uncommon approach to monitoring construction activity with advanced technology. The one-worker, one-task concept and the ideas of a bio-bubble and social distancing are identical. Though the overall outcome differs in the study of Iqbal et al. (2021), the two studies are equivalent to a certain extent. However, considering that the general components of project productivity are largely controlled by seasoned and experienced experts within the construction industry, the mitigation measures used in this study are primarily centred around project productivity governance.

Further, the effects of the COVID-19 epidemic have also been closely examined in a variety of international contexts (Şeker, 2022). However, depending on specific regional and demographic characteristics, the consequences of these studies can vary significantly (Khan et al., 2021). As a result, the focus of this study was limited to the Sri Lankan setting due to the fact that developing countries like Sri Lanka have been severely impacted by the COVID-19 pandemic and are currently working to establish effective responses. Also noteworthy is the thorough examination of productivity aspects from the perspective of the entire project, which included project productivity as a whole rather than isolating it into distinct categories like labour or party productivity.

6. Conclusion and recommendations

The COVID-19 effects during the previous two years have severely reduced the contributions of the construction industry to an expanding economy. Due to these combined effects, productivity in the construction industry as a whole has significantly decreased. As a result, one of the crucial challenges in the economic recovery of Sri Lanka is to examine the effect of COVID-19 on the productivity of construction projects.

The present analysis identified ten factors as having an impact on construction productivity during the COVID-19 pandemic period. Absenteeism and interference were the top factors that impacted construction production during the epidemic. Additionally, safety being prioritised over productivity, workforce reduction due to social distance protocols, inspection and permit delays, cashflow and payment challenges, and overwhelming work operations can be highlighted as highly distinctive factors derived from this study related to the Sri Lankan context. The study also identified a set of mitigation techniques to deal with production challenges in the construction industry during an epidemic. Among them, eight techniques were highlighted as the most effective mitigation techniques in the Sri Lankan context. The main priorities were the EOT claims, establishing health guidelines, and providing on-site accommodation.

Ultimately, the study contributes to the industry by finding the factors affecting construction productivity and mitigation techniques to overcome the issues in productivity and thereby enhance the quality of the construction industry. Overall, this study gives important new insights into the difficulties that pandemic construction productivity encounters, as well as workable answers to these difficulties. It will serve as a crucial reference for construction experts and decision-makers in order to navigate and reduce the difficulties of the upcoming pandemic or other disruptions.

On the other hand, it is worth evaluating how the COVID-19 outbreak would affect the construction sector in modern society. Other countries have already conducted numerous research projects connected to this topic, though Sri Lankan research incentives are drastically insufficient to address this issue in the future. Therefore, this study can contribute to the theory by examining the impact of COVID-19 on construction productivity. The ultimate conclusions, however, can vary among nations. Therefore, the final findings apply to countries with a sim-

ilar setting to the Sri Lankan context. This study can also benchmark further research in a different context.

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