**Responses to the COVID-19 pandemic in the Construction Industry: A literature review of academic research**

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# Abstract

Over the past three years, the global construction sector has been severely affected by the noxious coronavirus (COVID-19) pandemic. Visionary construction stakeholders, including governments, practitioners, and academia, all have been actively devising strategies to deal with the crisis caused by the pandemic. Despite the rich contributions by academia, an in-depth review of their research works to understand how the pandemic has been handled to position the construction industry for post-pandemic actions and future pandemics is hitherto lacking. Hence, an up-to-date literature review is conducted in this study to better understand this *terra incognita*. It does so by adopting a six-step thematic analysis of 159 empirical peer-reviewed research articles in relation to COVID-19 on construction. The review discovered a growing research interest from different countries from 2020 to 2022. The existing studies can be put under four major topics, namely the COVID-19 impacts, challenges and opportunities, responding strategies, and post-COVID-19 interventions. A framework consisting of four categories of responding strategies, namely vaccination, personal responsibility of workers, government-instructional practices, and organisation-based approaches, is proposed through the lens of the socio-technical system theory to handle the pandemic crisis in construction. Limitations of the existing studies were further identified. Four pertinent research directions were finally proposed: building upon and testing the proposed COVID-19 response framework, adoption of more advanced innovative strategies to increase productivity amid pandemics and survive the risk of future pandemics, beyond the technological response to COVID-19 in construction, and post-pandemic view of the construction industry. This study contributes to the knowledge body by providing a candid evaluation of the knowledge contributed by academia to deal with the risks of future pandemics in the global construction industry.

**Keywords:** Construction, Construction industry, COVID-19 pandemic, Academic responses; Literature review.

# Introduction

Construction is regarded as one of the world’s oldest and largest industries, with a market size of about US$10 trillion (Barbosa et al., 2017), contributing largely to the modern economic system with 13% of gross domestic product (GDP) per annum (Ribeirinho et al., 2020). However, the global construction industry has been seriously affected by the coronavirus pandemic (COVID-19) endemic since late 2019. The measures and regulations put in place to fight the pandemic, e.g., social distancing, lockdown, travel restrictions, and workplace capacity limits, have impacted construction to an extent that has not been seen before (Organization for Economic Co-operation and Development [OECD], 2020). It led to a fall of 12.5% in construction output in the UK in 2020 compared with 2019 (Office for National Statistics [ONS], 2021). In the US, the real construction GDP in the second quarter of 2020 fell 26.5% (Bureau of Economic Analysis [BEA], 2020). Likewise, a fall of 25.9% in GDP was also reported in March and April 2020 in the Europe Union (EU) (Eurostat, 2022).

Stakeholders, including governments, institutions, practitioners, and academia, have all actively explored the strategies to deal with the COVID-19 crisis in different economic sectors. This is also true in the global construction industry. To date, owing to the orchestrated efforts, the industry is witnessing a steady recovery. In the EU, for example, construction production increased by 20.4% in May 2020 and in January 2022, it increased by 3.9% compared with December 2021(Eurostat, 2022). The construction industry in other countries/regions, including Hong Kong, China, the USA, and South Korea, has also bounced back after the first hit of COVID-19 (Smith et al., 2020). A silver lining of the pandemic could be the rise in socio-technical system (STS) awareness as organisations quickly adopt innovative approaches and digital technologies along with government interventions to manage construction activities in a remote environment. For instance, organisations adopted more virtual meetings, as Zoom saw its February-April 2020 quarter revenue increase over double compared to the same quarter in 2019 (Kastrenakes, 2020). Hence, the construction industry contributes to this increment (Xu et al., 2022) as it strives to ensure business continuity amid the pandemic.

Among the many stakeholders, academia has been crucial in exploring and evaluating the COVID-19 risks, initiating new mitigation strategies, and publishing and sharing knowledge in the global construction community and beyond (Assaad and El-adaway, 2021; Li et al., 2022; Al-Mhdawi et al., 2022). Only a few attempts have been made to comprehend and capture the trends in the study on the pandemic in construction. For instance, Ayat et al. (2021) performed a systematic literature review by using 53 peer-reviewed articles relating to the pandemic’s impacts on the construction sector. Their research remained limited to only the COVID-19 impacts, with no attention to the other topics that are equally relevant. Focusing on the health and safety problems that construction workers experienced during the pandemic, Pamidimukkala and Kermanshachi (2021) reviewed and divided these problems into four categories: heavy loads, lack of a safe environment, concerns about job security, and home situations. Nonetheless, the study was limited to only workforce management, raising questions about why other areas were ignored. On the impacts, Li et al. (2022) comprehensively reviewed the body of research to determine how the pandemic affected the various lifecycle stages of construction projects. Alfadil et al. (2022) reviewed construction research from the perspective of force majeure and environmental risk compared to the pandemic. Still, their study was limited to the effects of the pandemic, including the impacts and changes, with only 20 articles. Kaklauskas et al. (2021) overviewed the research on housing developments during the upsurge of COVID-19 along with limited responses from the green building sector to understand the COVID-19 impacts. To shift the focus slightly from only the COVID-19 impacts, Sierra (2022) reviewed the literature on the major challenges faced by construction as a result of the pandemic to create an evaluation framework. Yet, their work was limited by scope, as the UK was the focal region. These existing review studies are dispersed in a disparate manner, affecting the understanding of the clear picture of the pandemic in the AEC industry. Also, no state-of-the-art review examined the extant research on the response strategies to the pandemic in the construction sector, determined the limitations of prior studies, and proposed effective measures to position the industry for the post-pandemic era and endure the risks of future pandemics. Such a review is needed to better understand the trend and patterns in construction research and recommend effective responses to properly position the industry for the post-pandemic era and endure the risks of future pandemics.

The study, therefore, aims to review the up-to-date academic literature on the COVID-19 pandemic to understand its impacts on the construction industry, including how the industry has responded. It does so by identifying 159 empirical peer-reviewed research articles and reviewing them by adopting a six-step thematic analysis. Consequently, the proposed effective responses are evaluated through the lens of the Socio-Technical System (STS) theory to propose a COVID-19 response framework. As proposed by Emery and Trist in 1960, STS theory describes systems that involve a complex interaction between humans, machines, and the environmental aspects of a work system (Baxter and Sommerville, 2011), similar to construction. This theory has been adopted in construction management research in fields such as improvement of construction industrialisation practices (Jin et al., 2021), construction project management competencies (Ahmadi Eftekhari et al., 2022), management of refurbishment projects (Saurin et al., 2013), and modular construction of cognitive buildings (Ghansah et al., 2022). Hence, the theory’s suitability would help to propose a COVID-19 response framework capable of considering holistically the technical and social (non-technical) responses in positioning the construction industry adequately for the post-pandemic era and also surviving the risks of the future pandemic. However, it is important to acknowledge the limitations of the STS theory, including limited system understanding, complexity outgrowing organisational design, and less control (Gorejena et al., 2016; Lucidchart, 2023). The results are anticipated to provide a clear picture of the recent developments in the COVID-19 pandemic literature and knowledge. It can assist policymakers and practitioners in devising concerted efforts to embrace a post-pandemic recovery and endure future pandemics. Finally, it will help construction researchers in new research directions to deal with the risks of a future pandemic crisis.

This study is organised as follows. Following the introduction are the research method, findings, critical discussion, the limitations of the existing studies and recommended future research directions, and finally, the conclusion.

# Research method

## Collection of relevant publications

Publications were collected from the Scopus and Web of Science (WoS) databases because of their acclaimed reliability in publishing construction-related research (Vieira and Gomes, 2009). The most critical keywords on COVID-19 in construction were searched and chosen from “Google search”. These keywords were divided into two parts. The first part comprised keywords such as “coronavirus” OR “COVID-19” OR “COVID-19 pandemic” OR “Coronavirus pandemic.” The second part included “construction” OR “construction industry” OR “construction management” OR “construction engineering” OR “building industry” or “architectural engineering and construction industry” OR “AEC.” A search query was conducted via the search engine of Scopus and WoS on June 24 2022. The query was facilitated by the Booleans: “AND” and “OR”. As a result, 251 publications were retrieved, including 118 from Scopus and 133 from WoS published from 2020 to 2022.

Subsequently, the results were limited to the English language, peer-reviewed journal articles, and peer-reviewed conference proceedings. The search period was restricted from 2020 to 2022. After removing duplicates and filtering based on relevancy, the number of publications was reduced to 165 (see Appendix A). It is further discovered that the 165 selected articles included 6 review papers and 159 empirical papers. A preliminary review depicted that the six review papers reported separately on the COVID-19 impacts and challenges (Table 1). For instance, Ayat et al. (2021) conducted a systematic literature review by limiting the search to the pandemic’s impact on the construction industry by engaging 53 peer-reviewed articles. Pamidimukkala and Kermanshachi (2021) conducted a similar such on the pandemic’s impact by focusing on the health and safety problems that construction workers experience during the pandemic and categorised them into heavy loads, lack of a safe environment, concerns about job security, and home situations. Other studies have also limited the review to the pandemic’s impact by focusing on different perspectives such as the lifecycle stages of construction projects (Li et al., 2022), force majeure and environmental risk compared to the pandemic (Alfadil et al., 2022), and green housing developments during the upsurge of COVID-19 along (Kaklauskas et al., 2021). With the challenges imposed, Sierra (2022) reviewed the literature on the major challenges faced by the construction sector due to the pandemic to create an evaluation framework. However, there is an issue, which is, none of the existing review studies has reviewed construction research to deal with the pandemic crisis holistically. This should constitute how the existing empirical academic research has reported on handling the pandemic in the construction industry from different perspectives. This review then focused on the 159 empirical articles but referred to the six review papers in terms of analytical structure and searching for publications that might have been omitted. Table 1 summarises the results of the preliminary review of the existing review studies.

Table 1: The existing review studies After a Preliminary Review

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Authors** | **Country** | **Technique** | **Perspective** | **Limitation** |
| Ayat et al. (2021) | Pakistan | SLR (bibliometric and content analysis) | COVID-19 impacts | * Limited to the impacts * Limited to 53 articles |
| Pamidimukkala and Kermanshachi (2021) | USA | SLR | COVID-19 impacts | * Limited to the construction workforce * Limited to the impacts |
| Sierra (2022) | UK | PRISMA | Challenges | * Limited to challenges * Limited to the UK |
| Li et al. (2022) | Australia | SLR | COVID-19 impacts | * Limited to the lifecycle perspective * Limited to the impacts |
| Kaklauskas et al. (2021) | Lithuania | SLR | COVID-19 impacts | * Limited to responses on impacts from the green building sector |
| Alfadil et al. (2022) | Malaysia | PRISMA | COVID-19 impacts | * Limited to the impacts * Limited 20 articles |

SLR=Systematic literature review; PRISMA= Preferred Reporting Items for Systematic Reviews and Meta-Analyses

## Thematic analysis

An inductive-thematic analysis was adopted to examine the 159 articles to identify common themes including topics, ideas, and patterns of meaning that repeatedly appeared in the literature. This was achieved by following the six-step processes, as adapted from Braun and Clarke (2006). Figure 1 shows the six-step processes adopted by this study for the thematic analysis. The authors first browsed the 159 publications thoroughly by reading the publications and taking notes of the topics, the key findings, and the limitations. Secondly, the authors coded the data by highlighting sections of the individual publications and came out with short labels to describe the contents. Thirdly, the authors reviewed the created codes, identified patterns among them, and started generating themes. In the fourth step, the authors ensured that the themes were useful and accurate in representing the data. In the fifth step, the authors had a final list of themes, ready to name and define each succinctly to make them understandable. Lastly, the authors finalised to produce a report based on the defined themes.

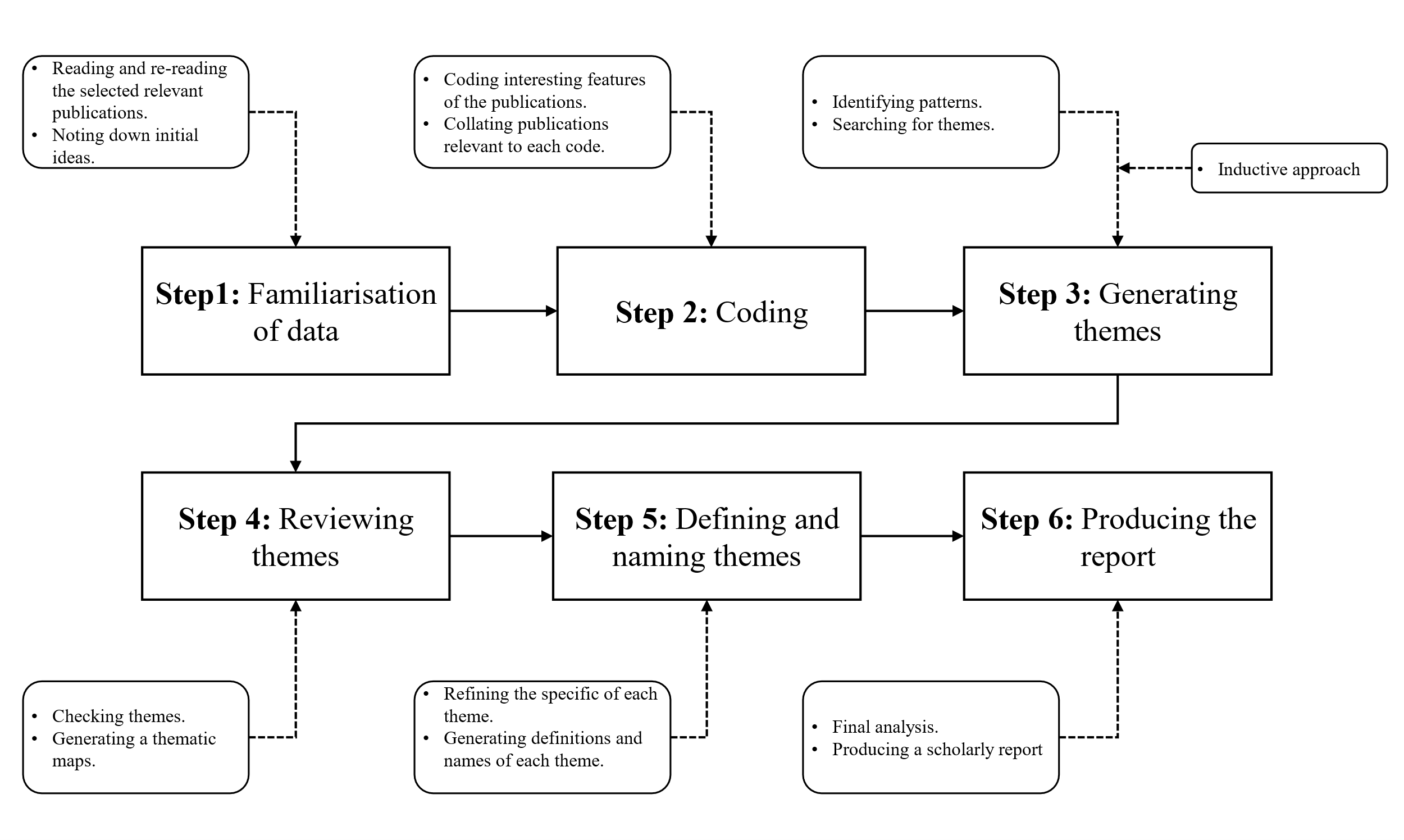


Figure 1 Caption: A six-step inductive-thematic analysis adopted for the study.

Figure 1 Alt Text: The thematic analysis begins with the familiarisation of the data to the last step, which is the production of the report.

# Findings and discussions

## Descriptive analysis

The topics on COVID-19 in construction can majorly be consolidated into four groups, namely (1) the COVID-19 impacts, (2) challenges and opportunities, (3) COVID-19 responding strategies, and (4) the post-COVID-19 interventions. Out of the 159 articles, the report on “COVID-19 responding strategies” has received the most attention with a total number of 84 articles, followed by the “COVID-19 impacts” with 72, then the “challenges and opportunities” recording 29, and finally, the “post-COVID-19 interventions” recording 8 (refer to figure 2[b]). The findings show that while mitigation measures are being implemented, it is still important to comprehend the dynamics of the pandemic by knowing the effects, challenges, and post-COVID-19 interventions. These results also show the extent to which the construction industry has actively dealt with the risk of COVID-19 to ensure business continuity.

Different countries/regions have reported on COVID-19 in the construction industry, which can be related to the major topics identified (Figure 2[a]). Among the countries, based on the literature database for this study, the USA is gaining more attention with reporting on the “COVID-19 impacts” and the “challenges and opportunities” while reporting on the responding strategies with China at an equal contribution rate. The two countries (China and USA) also contribute significantly to the other major topics. Post-COVID-19 interventions have also relatively received equal contribution rates from Australia, Egypt, Malaysia, and Nigeria. Moreover, countries tied to reporting the most challenges and opportunities include the USA, Ghana, and Iraq. Dealing with COVID-19 has been a major responsibility for industries. This befalls the construction industry to perform its part of the responsibilities by first understanding the clear picture and the dynamics of the pandemic, not in a disparate and disorganised form, but in a holistic manner involving the impacts, challenges and opportunities, responding strategies, and post-pandemic interventions. Figure 2[a] illustrates the country-major topic by the selected empirical studies.

Despite the records across various countries, it is important to acknowledge the past and present context of the pandemic’s impact on the construction industry, which can influence studies in specific countries. This study considered China and the USA due to the high attention gained based on the collected data from the literature. In China, the lockdown measure in different cities during the pandemic meant there was no time for delivery. The output value was reduced and the completion date of many projects was delayed, affecting the Chinese construction industry. This encouraged numerous studies reporting on the various impacts of the pandemic on the construction industry (in areas such as international multi-project, health and safety performance of construction workers, see *supplementary material Appendix A*) toward developing responsive strategies. Presently, the Chinese construction industry is gradually improving and being responsive to the pandemic by applying effective strategies, such as e-inspection, BIM, etc., suggested by visionary studies (Wang et al., 2021; Lu et al., 2022; Xiang et al., 2022) and other industry research institutions (FTI Consulting Asia Pacific and others). As the pandemic still wanders, the industry strives to develop effective strategies to ensure responsiveness to the pandemic, including reactive and proactive responses to survive the risks of future pandemics. Similarly, the construction industry in the USA has also been influenced by the pandemic, and this has been reported by various studies (in areas such as construction scheduling, health and safety management, and construction employment, *see supplementary material Appendix A*) toward developing response strategies, such as safety and health management response, smart response systems, and contractual response (Assaad and El-Adaway, 2021). This also includes contributions from other research institutes, such as *Research and Market*. This has currently ensured the continuity of construction activities amid the pandemic. Notwithstanding that, the US construction industry continues to investigate to develop more responsive measures to position the construction industry to be adequate for the post-pandemic era, as well as enduring the risk of future pandemics. This study also acknowledges the efforts of other country-context studies to investigate the pandemic’s impact on the construction industry toward a response framework.

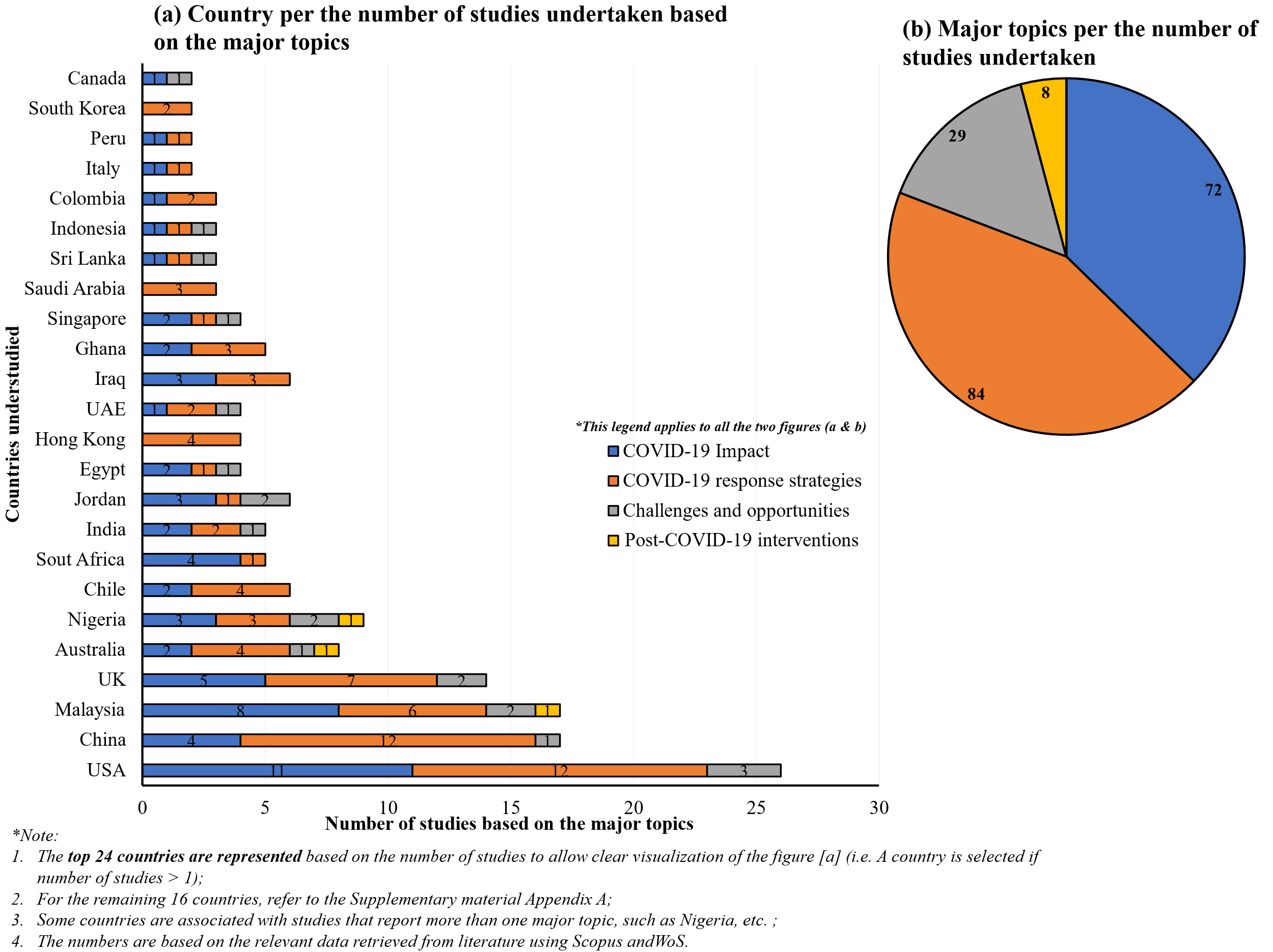


Figure 2 Caption: Country-Major topic detailing

Figure 2 Alt Text: Depicting the countries and their number of studies contributing to the major topics, including the ‘COVID-19 impacts’, ‘challenges and opportunities’, ‘COVID-19 responding strategies’, and the ‘post-COVID-19 interventions’.

## Research methods adopted

Several research methods have been adopted for empirical studies across different countries since the rise of COVID-19 in the construction sector, and these include qualitative, quantitative, and mixed methods. With studies involving the qualitative method, data collection techniques such as interviews have been the predominant approach with content analysis, as they assist in getting high-quality data from respondents on the organisation’s policies and efforts towards managing the implications of COVID-19 in construction. Other qualitative methods adopted for the COVID-19 pandemic research include conceptual analysis, qualitative case study, design science approach, fault tree analysis method, etc. For studies using the quantitative method, surveys have been coupled with various statistical techniques, including structural equation modelling, predictive techniques, and descriptive techniques. The predictive mathematical model has also been engaged to predict the impact of the pandemic on the work activities based on selected parameters, and these stochastic multi-agent modelling, multiple regression, convolutional neural networks, and machine learning and simulation. The mixed method has also been adopted by combining two or more techniques under different categories.

Tying the countries to the research methods adopted denoted that, in the pandemic era, countries have adopted at least one of the research methods. This considers the empirical studies undertaken in the countries, which is important in knowing the trend of research methods that have been adopted in specific countries regarding the impact of the pandemic on the construction industry. The country recording the higher number of empirical studies adopting the qualitative method is the USA (NRM=13), followed by Mainland China (NRM=11) and the UK (NRM=9). A higher number of studies adopting the quantitative method was recorded by the USA (NRM=8), followed by Australia (NRM=5) and Malaysia (NRM=4). With the mixed method, the highest number of studies was recorded by Malaysia (NRM=6), followed by the USA (NRM=5) and UK(NRM=4). It is further inferred that typical countries have adopted all three methods including the USA, UK, Mainland China, Australia, Chile, Hong Kong, Jordan, Malaysia, and Nigeria. However, it is also noted that the number of studies is few as some countries recorded as high as one publication for the methods (see Table 2). As the USA, the UK, and other relatively good-standing countries are contributing more to knowledge and policymaking on the COVID-19 investigations in the construction industry by adopting various research techniques, other countries also need to pick up and adopt various techniques to support the quest. Countries that recorded one or few studies for the research methods may adopt various research techniques to investigate the impact of the pandemic in their specific regions. Others may consider an international perspective. Moreover, it can be inferred that the COVID-19 research is limited in Africa, as less than ten African countries were found among the countries. Among the ten, only Nigeria has adopted all three research methods but with a limited number of studies. Similar inferences and trends can be made for other continents based on the country and the research technique and method adopted. Overall, COVID-19 research is still lacking among specific countries/regions. Therefore, various research techniques should be adopted appropriately to investigate the pandemic towards developing a response framework for the construction industry for the post-pandemic era and endure the risks of future pandemics. Table 2 details the research techniques adopted by the selected empirical studies across different countries. The countries are selected based on the location of where the empirical study was conducted, and this is indicated in all the selected papers, as shown in supplementary material Appendix A.

Table 2: Categorisation of the research techniques and the specific country/region of adoption

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Country** | **Research technique** | **Number of papers** | **Research method** | **NRM** |
| Australia | Survey | 3 | Quantitative | 5 |
| Quantitative case study | 1 |
| Experimental | 1 |
| Conceptual analysis | 2 | Qualitative | 3 |
| Qualitative case study | 1 |
| Survey, thematic analysis of the open-ended responses | 1 | Mixed | 1 |
| Canada | Qualitative case study | 1 | Qualitative | 1 |
| Experimental, field study | 1 | Mixed | 1 |
| Chile | Agent-based modelling | 1 | Mixed | 1 |
| Agent-based modelling | 2 | Quantitative | 2 |
| Interview | 2 | Qualitative | 2 |
| China | Content analysis | 2 | Qualitative | 11 |
| Qualitative case study | 6 |
| Meta-analysis | 1 |
| Focus group, interview, and archival study | 1 |
| Interviews | 1 |
| Qualitative and quantitative case study | 3 | Mixed | 3 |
| Structural equation modelling | 1 | Quantitative | 3 |
| Parametric modelling, Monte Carlo, chaos theory | 1 |
| Survey | 1 |
| Colombia | Qualitative case | 1 | Qualitative | 1 |
| Systematic literature review, content analysis, social network concepts, community detection methods, and snowball procedures | 1 | Mixed | 1 |
| Denmark | Experimental | 1 | Qualitative | 1 |
| Egypt | Theoretical review, interview | 2 | Qualitative | 2 |
| Survey | 1 | Quantitative | 2 |
| Survey, case study | 1 |
| Ghana | Interviews | 2 | Qualitative | 3 |
| Open-ended questionnaire | 1 |
| Hong Kong | Design science approach | 1 | Qualitative | 2 |
| Qualitative case study | 1 |
| Sensitivity analysis | 1 | Mixed | 1 |
| Survey | 1 | Quantitative | 1 |
| India | Quantitative case study | 1 | Quantitative | 3 |
| Expected Value Method | 1 |
| Delphi technique | 1 |
| Qualitative and quantitative case study | 1 | Mixed | 2 |
| Interview, survey | 1 |
| Indonesia | Open questionnaire survey | 1 | Mixed | 1 |
| Survey | 1 | Quantitative | 1 |
| Iran | Survey | 1 | Quantitative | 1 |
| Iraq | Focus group, Analytic Hierarchy Process, survey | 1 | Mixed | 2 |
| Literature analysis, interviews, survey | 1 |
| Content analysis | 1 | Qualitative | 1 |
| Ireland | Interview | 1 | Qualitative | 1 |
| Italy | Simulation, qualitative case study | 1 | Mixed | 1 |
| Multiple regression analysis, supervised machine learning, Monte Carlo simulation | 1 | Quantitative | 1 |
| Jordan | Qualitative and quantitative case study | 2 | Mixed | 2 |
| Literature review, interviews | 1 | Qualitative | 1 |
| Survey | 1 | Quantitative | 1 |
| Kuwait | Interview, survey | 1 | Mixed | 1 |
| Malaysia | Survey | 3 | Quantitative | 4 |
| Partial least squares structural equation modelling technique | 1 |
| Systematic literature review, focus group, questionnaire survey | 1 | Mixed | 6 |
| Systematic literature review, interviews, survey | 3 |
| Interviews, survey | 2 |
| Interview | 2 | Qualitative | 4 |
| Conceptual analysis | 2 |
| Morocco | Fault Tree Analysis method | 1 | Qualitative | 1 |
| Nigeria | Survey | 3 | Quantitative | 3 |
| Interview, content analysis, frequency, percentages | 1 | Mixed | 2 |
| Interviews, survey | 1 |
| Qualitative-based open-ended survey | 1 | Qualitative | 2 |
| Interviews | 1 |
| Oman | Qualitative and quantitative case study | 1 | Mixed | 1 |
| Pakistan | Interview | 1 | Qualitative | 1 |
| Peru | Qualitative and quantitative case study | 2 | Mixed | 2 |
| Philippines | Survey | 1 | Quantitative | 1 |
| Poland | Experimental | 1 | Quantitative | 1 |
| Portugal | Conceptual analysis | 1 | Qualitative | 1 |
| Romania | Interviews, surveys | 1 | Mixed | 1 |
| Saudi Arabia | Qualitative and quantitative case study | 1 | Mixed | 3 |
| Field study, survey | 2 |
| Singapore | Design science approach | 1 | Mixed | 2 |
| Survey, interview | 1 |
| Qualitative case study | 1 | Qualitative | 1 |
| South Africa | Quantitative case study | 1 | Quantitative | 3 |
| Survey | 2 |
| Qualitative-based open-ended survey | 2 | Qualitative | 2 |
| South Korea | Cyclone model and case study | 1 | Quantitative | 2 |
| Survey | 1 |
| Southern Spain | Qualitative and quantitative case study | 1 | Mixed | 1 |
| Sri Lanka | Qualitative case study | 1 | Qualitative | 1 |
| Survey | 1 | Quantitative | 1 |
| Thailand | Qualitative case study | 1 | Qualitative | 1 |
| Turkey | Quantitative case study | 1 | Quantitative | 1 |
| UAE | Qualitative case study | 2 | Qualitative | 3 |
| Interview | 1 |
| Uganda | Qualitative case study | 1 | Qualitative | 1 |
| UK | Qualitative and quantitative case study | 4 | Mixed | 4 |
| Experimental | 1 | Qualitative | 9 |
| Interview | 4 |
| Open-ended survey | 1 |
| Qualitative case study | 1 |
| Observation | 1 |
| Conceptual analysis | 1 |
| Agent-based modelling, Monte Carlo simulation techniques | 1 | Quantitative | 1 |
| USA | Qualitative and quantitative case study | 2 | Mixed | 5 |
| Literature review, interview, survey | 1 |
| Experiment and survey | 1 |
| Qualitative descriptive analysis | 1 |
| Survey | 4 | Quantitative | 8 |
| Visual analysis approach | 1 |
| Granger causality test, structural equation modelling analysis, multivariable prediction model | 1 |
| Quantitative case study | 1 |
| Experimental | 1 |
| Content analysis | 4 | Qualitative | 13 |
| Qualitative case study | 2 |
| Multi-step research approach | 1 |
| Conceptual analysis | 3 |
| Interviews | 2 |
| Interview, case study | 1 |
| Zimbabwe | Survey | 1 | Quantitative | 1 |

NRM= number of studies that adopted the research method

## Major topics

This section deliberates on the major topics since the emergence of COVID-19 in the construction industry, and these include four major groups after thematic analysis: “the COVID-19 impacts”, “challenges and opportunities”, “the COVID-19 responding strategies”, and “post-COVID-19 interventions” (Figure 2).

### The COVID-19 impacts

The impacts of the pandemic on the construction sector can be categorised into two groups: positive and negative. This is evident in the fact that the pandemic disrupts the construction process and encourages organisations to be innovative in their operations. Figure 3 illustrates the impacts of COVID-19 on construction as reported by the existing selected empirical studies.

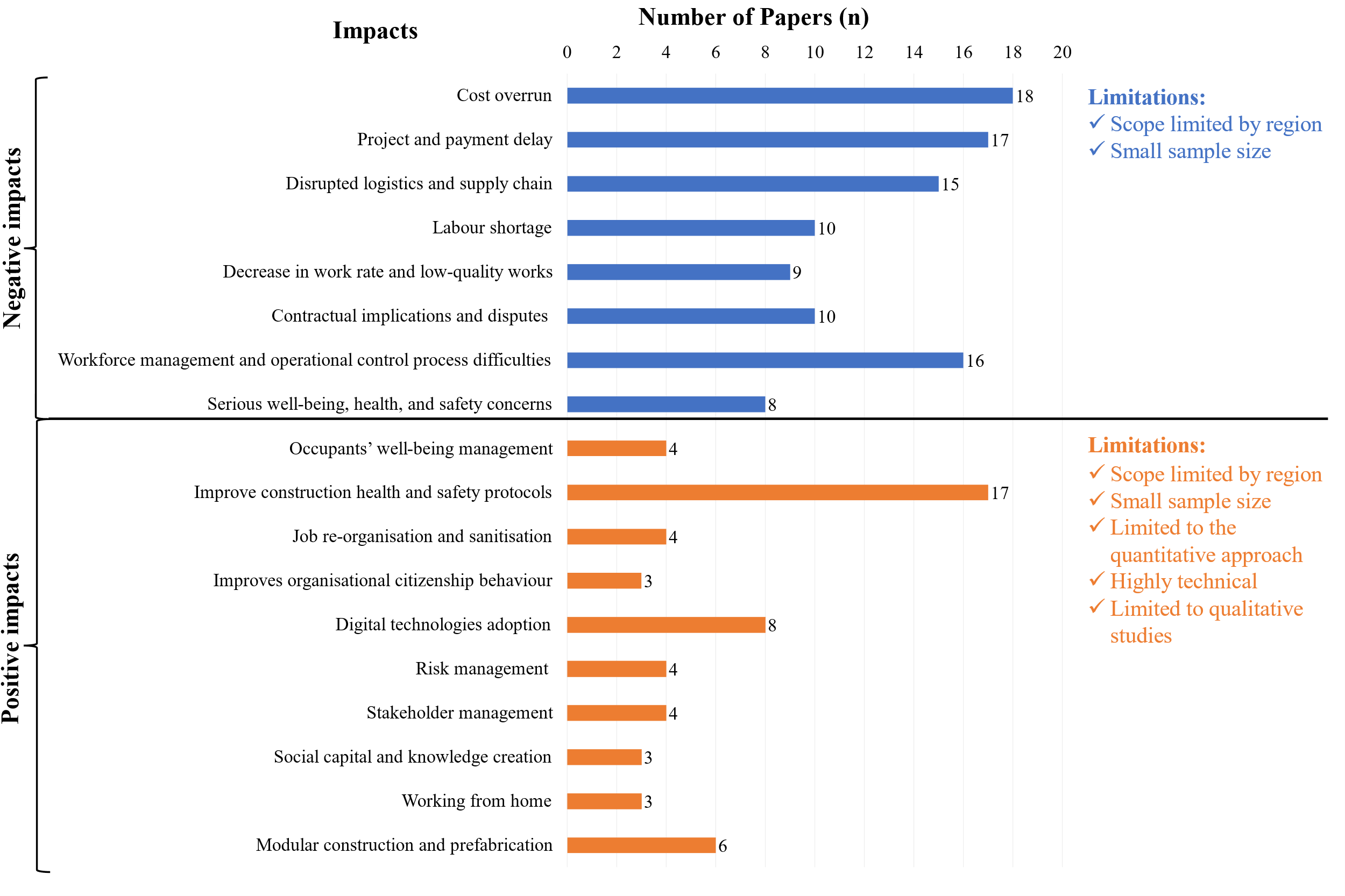


Figure 3: COVID-19 impacts on the construction sector.

Figure 3 Alt Text: Depicting both the positive and negative impacts of the pandemic.

The construction industry has faced disruptions due to the COVID-19 pandemic, causing unprecedented fiscal, social, and healthcare issues in the construction processes. This has also affected the workmanship productivity towards project executions. The major negative impact of the pandemic has been a cost overrun (n=18), followed by project and payment delays (n=17), and then workmanship and operational control difficulties (n=16). With cost overrun as the major negative impact, the firms in the construction industry incur an extra cost for improving the health and safety management system by considering personal protective equipment (PPE), disinfectants, etc., at workplaces and the regular change of use. This causes cost variations requiring extra cost over the budgeted construction project cost. Construction projects are delayed due to the disruptions caused by the COVID-19 protocols including lockdown, the limited number of workers at the workspace, etc. This as well causes delays in payment to workers. It is worth inferring that the impacts of the pandemic may be correlated positively; hence, one impact may lead to another unique impact. Other negative impacts have been the labour shortage, disrupted logistics and supply chain, contractual implications and disputes, and health and safety concerns (Al-Mhdawi et al., 2022; Liang et al., 2022). These cause a new situation where decision-makers strive to promptly respond to the unprecedented crisis to sustain construction operations without compromising the health and safety of workers, implying the presence of an availability heuristic, which has the potential to bring unconsciousness and systematic errors to the construction decision-making process (Liang et al., 2022).

Despite the negative impacts of the pandemic on construction, there seems to be a positive side that needs to be given attention. This appears to be a “blessing in disguise”. The major positive impact is the improvement in the existing construction health and safety (n=17), followed by digital technology adoption (n=8) and then uptake of modular and prefabricated construction (n=6). Organisations now strengthen their health and management systems to mitigate the pandemic risk through training and orientation, providing the best PPE, and ensuring compliance with strict health and safety measures. This creates a safe environment to protect the construction workers at the workplace. The construction industry has now seen the need to increase digital technology adoption amid the pandemic to improve collaboration among workers, monitor and supervise construction works without physical presence, and ensure effective communication among workers at the workplace. Another area of improvement is the uptake of modular and prefabricated construction, which has been effective and productive in the fast delivery of buildings with a smaller number of workers on the construction sites compared to the traditional construction method. Another positive impact is the job re-organisation and sanitisation to meet the pandemic conditions (Onubi et al., 2022; Niroshana et al., 2022). Furthermore, occupants’ well-being is effectively managed as the organisations seek to provide a safe environment and improve health and safety management systems. As strict compliance is ensured in health and safety measures, it also improves workplace citizenship behaviour. Other positive impacts of the pandemic have been in the improvement of construction stakeholder management, risk management, creation of social capital and knowledge for workers, and the use of the “working from home technique”.

### Challenges and opportunities

Given the nature of construction operations and the adoption of labour-intensive techniques, the pandemic has disrupted construction processes and created a number of challenges. The analysis showed that the existing challenges could be categorised into two groups: challenges to the construction work processes and challenges to the COVID-19 implementation guidelines. These challenges also create opportunities that the construction industry needs to identify and harness. Table 3 shows the challenges and opportunities imposed by the pandemic on the construction industry as reported by the selected empirical studies.

Table 3: Summary of the challenges

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Sub-categories** | **Challenges/Opportunities** | **Number of papers (n)** |
| Challenges to the construction work processes | Cost and payment-related challenges | Cost estimation issues due to extreme price fluctuations | 4 |
| Rigid payment methods | 3 |
| Project ultimate cost overruns | 5 |
| Salary reduction | 1 |
| Work and workmanship-related challenges | Difficulties with risk assessment due to uncertainties | 3 |
| New design requirements to address health and social distancing concerns | 3 |
| Decrease in work rate | 3 |
| Long approval process and schedule delays | 9 |
| Reworks due to design uncertainties | 1 |
| Collaboration problem | 3 |
| Difficulties with a feasibility study due to lack of information | 3 |
| Increase project duration | 7 |
| Shortage of construction labour | 5 |
| Legal issues due to the breach of contract terms and conditions | 7 |
| Lack of a safe environment in the workplace | 2 |
| Working with masks influences fatigue, productivity, and quality | 2 |
| Lack of control and monitoring owing to COVID-19 protocol | 2 |
| Difficulties with construction work processes | 2 |
| Heavy workloads | 2 |
| Modified project planning (contract addendum, change schedule, and design) | 2 |
| Home situations | 2 |
| Silo-effects due to linear contracting strategies | 1 |
| Procurement and Supply chain-related challenges | Design changes resulting from the shortage of material | 2 |
| Supply-chain disruptions | 8 |
| Shortage of raw construction material | 3 |
| Traveling restrictions | 2 |
| Site accessibility challenges | Site closure resulting from virus outbreak | 2 |
| Halting of business operations | 2 |
| Digital technology-related challenges | Inadequate proper digital platform for design | 1 |
| High costs of technologies | 1 |
| Lack of client support | 1 |
| Readiness in virtual working practices | 1 |
| Challenges to the COVID-19 implementation guidelines | COVID-19-knowledge management-related challenges | Misconceptions about the disease | 1 |
| Lack of adequate information about the virus | 2 |
| COVID-19 safety equipment challenges | Use of COVID-19 personal protective equipment incorrectly | 1 |
| Additional safety equipment usage | 1 |
| Compliance challenges | Lack of compliance | 1 |
| Opportunities | Adoption of advanced technologies | Increased rate of digital technologies adoption | 7 |
| Increased rate of modular construction and prefabrication adoption | 6 |
| Improvement and adoption of innovative approaches | Effective stakeholder management | 3 |
| Improved health, safety, and hygiene programs | 2 |
| Social capital and knowledge creation | 2 |
| Working from home | 2 |
| Effective risk management | 2 |

The existing challenges imposed by COVID-19 on construction work processes can be subcategorised into five groups (Table 3). The pandemic has caused several challenges to construction processes, especially concerning work and workmanship services, which have received the most attention from studies (n=59). As a result, a long approval process and schedule delays affect the entire project duration; hence recorded as the major challenge (n=9). Work-related challenges also include collaboration problems, heavy workloads, shortage of construction labour, etc. Moreover, challenges in the procurement and supply chain of construction projects were identified, and this comprises the travelling restrictions and lockdown, design changes, shortage of construction material resources, and disturbances in supply chain processes (Oey and Lim, 2021; Rankohi et al., 2022; Agyekum et al., 2022). Other challenges discovered include cost and payment challenges, site accessibility challenges, and digital technology challenges comprising high cost, lack of proper digital platform for design, and lack of client support and readiness.

In mitigating the risk of the pandemic, few challenges seem to inhibit effective measures. These challenges can be sub-categorised into three groups (Table 3). In implementing the COVID-19 guidelines, issues of COVID-19 knowledge management have been reported in the literature to be critical. For instance, construction workers have a misperception about the pandemic, which impedes the mitigation rate of the pandemic in construction. This includes those religious thoughts about the COVID-19 vaccine, “only drinking water will prevent the pandemic”, and others. Another issue is the lack of adequate information about the virus among the construction workforces. The analysis depicted the issue of COVID-19 safety equipment, which consists of the organisations buying additional safety equipment to use at workplaces and workers misusing PPE. Compliance with COVID-19 protocols (using nose and face masks, social distancing, etc.) is also a challenge, as workers sometimes intentionally or unintentionally do not follow the protocols due to personal reasons, which may relate to health issues.

Not entirely challenges, the pandemic has also instigated some opportunities to push the construction industry to speed up its adoption rate of innovative approaches and technologies to minimise the risk of COVID-19 and ensure resilience (Table 3). The greatest opportunity is the adoption of digital technologies (n=7) to ensure construction business continuity, followed by management’s innovative approaches, including the uptake of modular and prefabrication construction (n=6) and stakeholder management (n=3). This has caused a breakthrough in the pandemic era as digital technologies have been adopted in construction to ensure continual collaboration, supervision, and data collection from remote positions. Such technologies include smart robotic systems, smart real-time monitoring systems, and others. Management’s innovative approaches include modular and prefabrication construction, stakeholder management, risk management, hygiene programs and working from home (Al Amri and Marey-Perez, 2020; Seagers et al., 2022; Goh et al., 2022). The pandemic has raised industry awareness of the importance of leveraging modular and prefabrication construction methods in the short and long terms since the pandemic required companies to seriously plan for further increasing their capabilities toward modular and prefabrication construction (Assaad et al., 2022; Xiang et al., 2022) with a smaller number of workers at workspace compared to the traditional construction (Lau et al., 2019; Lu et al., 2022a).

### COVID-19 responding strategies

From Table 4, the COVID-19 responding strategies can broadly be categorised into four themes: vaccination of construction workers, personal responsibility of workers, government-instructional practices, and organisation-based approaches. Invariably, there is an overlapping between the responding strategies across all the categories discovered.

Table 4: Summary of the COVID-19 responding strategies

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Responding strategy** | **Number of papers (n)** | **Limitation** |
| 1. Vaccination | Immunisation plans among construction workers and their close contacts | 1 | * More concentration on indoor construction activities |
| 1. Personal responsibility | Personal conviction of the construction workers | 1 | * Scope limited by region |
| 1. Government-instructional practices | Social distancing among construction employees | 8 | * Scope limited by region |
| The use of prescribed nose and face masks | 3 |
| 1. Organisation-based approaches |  |  |  |
| * Adoption of digital technologies | Monitoring technologies | 17 | * Immaturity of technologies * Accuracy issues of the distance * Highly technical * System reliability * Lack of social factors consideration * Scope limited by region * Time limitation |
| Communication technologies | 7 |
| Data transparency technologies | 3 |
| * Contract-based technique | Contract-based technique | 5 | * Scope limited by region |
| * Health and safety management | Updated health and safety guidelines on construction sites | 7 | * Single case study * Unclarity with the resilience activities * Limited to qualitative studies |
| Safety precaution measures | 11 |
| * Workforce management | Use of multi-skilled workers | 1 | * Oversimplification * Lack of diversity in the data |
| Multiple working shifts (night and day shifts) | 1 |
| Working from home approach | 1 |
| * Risk management | Risk response model | 7 | * Scope limited by region |
| Risk assessment | 2 |
| Safety Risk and Safety Behaviour | 1 |
| Modelling the spread of COVID-19 | 4 |
| * Prefabrication construction | Modular composite building | 1 | * Scope limited by region |
| Affordable steel-framed modular building | 1 |
| Fast delivery of COVID-19 quarantine camp | 2 |
| Design for Manufacture and Assembly | 1 |
| * Schedule management | Schedule compression | 3 | * limited to qualitative studies * limited to cross-sectional data |
| * Lean construction technique | Lean construction as a solution | 1 | * Scope limited by region |
| * Recycling | Recycling the face masks to improve the mechanical properties of concrete | 2 | * Unclear process optimisation |
| * Organisational resilience | Resilience enhancement | 6 | * Oversimplification * Not clear about the resilience activities * Scope limited by region |
| Compliance regulations | 1 |

#### (A)Vaccination

COVID-19 vaccines offer hope in ending the pandemic crisis, provided enough population of at least 75%-90% gets vaccinated to attain a basic number R0 (2.5-3.5) (World Health Organisation [WHO], 2021). For construction to keep progressing amid the COVID-19 crisis, construction workers, including the labourers and the top management, must be vaccinated with the right doses of vaccines. Yuan et al. (2022) investigated how vaccination plans could affect the transmission dynamics of COVID-19 among construction workers and their close contacts. This predicts the effectiveness of the vaccination intervention against the pandemic crisis in the construction industry. Next to other undertaken activities in dealing with the pandemic, the vaccination of construction workers along with at least 67% of their close contact can end the spread of the pandemic (Yuan et al., 2022). Therefore, prioritising the protection of construction workers’ health and encouraging them and their close contacts to get vaccinated is an effective method in keeping construction works progressively amid the pandemic crisis.

#### (B)Personal responsibility

Dealing with COVID-19 in construction counts on the personal conviction of the construction workers, including the top management and labourers. It starts with the individual workers being responsible for carefulness during project execution by adhering to the protocols set by the government and the organisations, including wearing masks, using hand sanitisers, and social distancing themselves from potential COVID-19 workers and high-risk areas on site. Personal responsibility can be a basic response to the pandemic crisis in the construction industry as employees can be informed not to report to work if they experience the symptoms of COVID-19: sore throat, fever, runny or stuffy nose, cough, shortness of breath, fatigue, or any respiratory illness symptoms (Assaad and El-Adaway, 2021; WHO, 2021). Thus, construction employees are to seek medical attention if they experience personal feelings of unwellness related to the symptoms.

#### (C)Government-instructional practices

To get over the pandemic crisis, the government plays a significant role in controlling the transmission by setting best practices to be followed by citizens and industries. These practices are supported by advice from legal professionals in every nation. The construction industry follows the best practices set by the government and suggests every firm enforce such practices to ensure the continuity of the construction business (Zamani et al., 2022).

Social distancing among construction employees has been recommended as one of the best practices in the construction industry as issued by the government in response to the COVID-19 crisis. This involves avoiding gathering more than ten construction workers, performing meetings online or via conference calls if possible, keeping a distance of 1.83m (6ft) between construction workers if a meeting is held, not holding large group meetings, and finally discouraging handshaking and other greetings (Assaad and El-Adaway, 2021). The construction workers must be safely apart from one another to avoid latitudinal and longitudinal transmission of the virus. In the construction sector, the latitudinal transmission is controlled when top management ensures their social distancing measures whilst maintaining communication with the lower employees. On the other hand, the longitudinal transmission is controlled when construction workers ensure the social distancing measure among themselves of the same level in the firm whilst maintaining effective communication and coordination.

The construction industry authorises the use of nose/face masks among construction workers, from the management to the labourers in firms. Considering the nose/face mask as a significant part of the PPE ensures safety during project operations (Assaad and El-adaway, 2021). The use of prescribed nose and face masks have also been mandated to minimise the spread of COVID-19, as declared by governments worldwide because construction activities are highly exposed to the risk of the pandemic (Occupational Safety and Health Administration [OSHA], 2020; Assaad and El-adaway, 2021; Zamani et al., 2022) Therefore, construction companies should delay their activities until they can be conducted safely by providing the right PPE, including prescribed nose and face masks.

#### (D) Organisation-based approaches

Besides government instructional practices, most construction companies have innovatively enhanced their processes in performing construction activities such as work progress monitoring, inspection, supervision, data collection, and meetings. The construction organisations’ responses to the COVID-19 crisis could be sub-categorised and consolidated into ten areas (Table 4). This study discusses the top three approaches based on the number of articles, including adopting digital technologies (n=27), health and safety management (n=18), and risk management (n=14). The remaining groups are combined and discussed under the sub-section “other approaches”.

The COVID-19 pandemic has developed an urgency in digital technology adoption to significantly reshape the construction industry through collaboration among workers, monitoring, communication, data-driven decision-making, inspection, and supervision. An increasing level of digital technology adoption has been observed from pre-COVID-19 to during COVID-19 and post-COVID-19. For instance, integrating monitoring technologies to propose a smart remote management framework offers the best solution for remote monitoring of workplaces, tracking work progress remotely, enhancing social distancing, supporting the progress on sites, and avoiding delay while maintaining work safety (Goh et al., 2022; Lu et al., 2022b). Also, real-time communication among construction workers using technologies such as building information modelling (BIM) technology and 5G communication networks have been utilised to ensure rapid construction amid the pandemic crisis (Osunsanmi et al., 2020; Wang et al., 2021), whilst guaranteeing data transparency with effective approaches integrated with blockchain technology (Lu et al., 2022).

Health and safety protocols/guidelines are established by construction organisations to minimise the risk of deadly contagion among construction workers at workplaces. Organisations have the responsibility to formulate health and safety policies to enable the smooth execution of building projects amid the COVID-19 pandemic, in addition to the government’s instructional protocols. Organisation-based possible top actions have been recommended to mitigate the spread of the pandemic while ensuring new modes of management and operation for construction organisations (Assaad and El-adaway, 2021; Sherratt and Dainty, 2022). Setting policies to ensure regular monitoring for public/government announcements on COVID-19, updating health policies and protocols to include regulations from public health bodies, and developing safe-work procedures are regarded as part of the top actions to be encouraged in the construction industry. Health and safety policies and regulations have been established to drive the construction industry across different countries to control the contagion. Following these organisation-based health and safety policies and appropriately communicating them to the construction workforce increases the organisation’s dynamic capabilities and resilience amid the pandemic crisis (Chih et al., 2022).

Effectively managing the risk of COVID-19 is critical in construction to ensure the continuity of operations. Risk management in responding to the deadly contagion in construction comprises response modelling, risk assessment, safety risk and behaviour, and infection modelling (Araya, 2021a; Oey and Lim, 2021). Construction organisations have managed risk in this pandemic era by creating a risk response model to understand project delays and determine the critical risk factors. This can be extended to understanding the risks of COVID-19 infections and their dynamics in construction workplaces.

Distinct organisation-based approaches have been adopted in responding to the risk of COVID-19. These comprise workforce management, prefabrication construction, schedule management, contractual-based technique, lean construction, recycling, and organisational resilience (Casady and Baxter, 2020; Khalef et al., 2021; Araya, 2021b; Salami et al., 2021; Borg et al., 2022). In tackling the pandemic’s impacts on construction projects, the terms and conditions of the related contracts need to be carefully evaluated to assess if considerations can impact both the timings and expense of projects currently under construction and in the planning stage. Assaad and El-adaway (2021) recommended the inclusion of -among others- contractual, legal, and insurance aspects, and this addresses the uncertainties regarding the applicability of contractual clauses for the COVID-19 pandemic. Also, prefabrication construction quickly responds to the pandemic’s victims by providing a quick and temporary quarantine facility. Conclusively, the enhanced focus on worker safety due to the pandemic will help accelerate the industry’s move to the modular and prefabrication construction method in the future.

### Post-COVID-19 interventions

Analysing the literature, the study disclosed five post-COVID-19 interventions, as shown in Table 5, namely the change management model, generation of well-being in urban public spaces, sustainability from stakeholders’ perspective, design of new adaptable residential architecture, and business continuity strategies (Ebekozien et al., 2021; Silva et al., 2022; Nassereddine et al., 2021). These interventions are the results of the permanent change caused to the construction processes in the construction industry, and they assure business continuity after the pandemic. The proffered measures to address the challenges of the pandemic need to be directed to a sustainable path in the post-COVID-19 recovery phase. This contributes to achieving sustainable development goals connected to the construction industry (El Khateeb and Shawket, 2022). Also, the residential architecture design must adapt to the new reality that COVID-19 will not be the last pandemic on the planet. Therefore, building designers must continue planning for uncertainties such as pandemics in their designs even after COVID-19.

It is obvious that the construction industry may not look the same as we move beyond the COVID-19 pandemic to the next normal (McKinsey and Company, 2020). Hence, the post-pandemic era consideration is critical for the construction industry, and this depends on how the pandemic is handled and the measures to sustain the response strategies to continue working effectively. As such, the following elements can be considered in sustaining the effectiveness of the construction industry: portfolio diversification, collaborative contracting methods, industrialisation, circular economy, remote working, integrated design management using BIM, staffing and skills training, reversible building design, augmented reality, automation and 3D printing, and lean construction (McKinsey and Company, 2020; Nassereddine et al., 2021). These measures reflect the opportunities created by the pandemic, and if harnessed appropriately, can position the construction industry adequately for the post-pandemic era and endure the risks of future pandemics.

Table 5: Summary of the post-pandemic interventions

|  |  |  |
| --- | --- | --- |
| **Interventions** | **Number of papers (n)** | **Limitation** |
| * Change management model | 1 | * Scope limited by region |
| * Generation of well-being in urban public spaces | 1 |
| * Sustainability from the stakeholder’s perspective | 1 |
| * Design of residential architecture | 2 |
| * Business continuity strategies | 3 |

# Critical discussion synthesising the major topics

Since the emergence of the COVID-19 pandemic, academia has contributed to the efforts to understand the complexities created by the pandemic through empirical research on the impact and the challenges created. This aligns with the complexity theory, reiterating the need to examine the uncertainty and non-collinearity created by external interference (Park, 2017), which can be pandemics, natural disasters, or any “*black swan*” event occurring. From complexity theory, understanding the impact and challenges may improve organisational performance, increase an organisation’s ability to adapt and innovate, and promote quality outcomes (Park, 2017; Turner and Baker, 2019). Understanding the COVID-19 impacts and the challenges assists in identifying effective ways of managing construction activities amid the pandemic and still being effective in the post-pandemic era and enduring risks of future pandemics.

This state-of-the-art review revealed the major topics reported by academia, and these include the impacts, challenges and opportunities, response strategies, and post-pandemic interventions. So far, 40 countries have actively promoted research on COVID-19 by adopting various research techniques to understand and normalise the pandemic’s effects with response strategies that can properly position the industry in the post-pandemic era and endure risks of future pandemics. For instance, in Hong Kong, the Logistics and Supply Chain MultiTech R&D Centre (LSCM) facilitates research in innovations in the construction industry to rise above the COVID-19 challenges (LSCM, 2022). China has also understood the COVID-19 impacts on the Belt and Road Initiatives (BRI) and hence, developed policies to ensure the smooth execution of the projects. These include the New Eurasia Land Bridge, China-Mongolia-Russia Corridor, etc. (Wu et al., 2022). The government of various Asian countries have also set up policies to make the construction industry more resilient to the risks of the pandemic (ADBInstitute, 2021). This affirms that numerous studies are being conducted in various countries, and the outcomes can inform policymaking to ensure the construction industry’s resilience to the pandemic’s effects. Therefore, as COVID-19 spreads at differing rates across countries (Wu et al., 2022), this study recommends other countries, including developing and developed countries, understand the impact of the pandemic on their various economies. This may contribute to developing effective strategies to position the industry to survive the perils of future pandemics.

COVID-19 is also a blessing in disguise because of the sudden increase in innovation adoption in the construction industry. Among other industries, the construction sector has previously been reported to have low innovation adoption (Sahamir et al., 2021), and it is difficult to diffuse innovations for its activities. Although academia has reported the construction industry to be negatively affected by the pandemic, including cost overrun, project and payment delays, workmanship and operational control difficulties, labour shortage, disrupted logistics and supply chain, etc (Agyekum et al., 2022; Elnagger and Elhegazy, 2022), we cannot also refute the fact that the industry cannot be standstill as it plays an essential role in being part of the backbone of an economy. Hence, construction businesses must continue amid the pandemic by adopting innovative management strategies and technologies. The pandemic has pushed the construction industry to improve its health and safety management and increase its innovation adoption by keeping ahead with industry 4.0 by learning from other industries, such as manufacturing and aerospace, on the uptake of digital technologies and modular and prefabrication construction. The pandemic has encouraged the industry to be more strategic in its activities by integrating innovations with management to ensure that workers are safe whilst working to ensure business continuity (Pamidimukkala et al., 2021). Hence, ensuring construction business continuity is an effective step in responding to the pandemic in the construction industry. Therefore, it is worth knowing that the pandemic has not entirely affected the construction industry negatively but also in a positive way that can be harnessed to improve the construction industry’s resilience to the risks of future pandemics.

The challenges created by the pandemic can be related to the construction work processes. The construction workmanship has experienced challenges, including risk assessment difficulties, collaboration problems, lengthy approval processes and delays, heavy workloads, lack of a safe environment, decrease in work rate, etc. “Long approval processes and delays” has been the greatest challenge for many construction organisations. This implies that receiving work-related data and information that may require inspection before continuation takes a very long time. This situation is prevalent for cross-border construction inspection, where quality inspectors may be delayed due to COVID-19 regulations. In most cases, the delay may be due to the quarantine time, requiring completed work to halt to ensure adequate inspection. Other major challenges relating to work include legal issues due to contract breaches and a labour shortage. Challenges may also be related to the procurement and supply chain, site accessibility, digital technology, cost, and payment. Also, challenges are associated with the COVID-19 implementation guidelines, including misconceptions about the disease, lack of adequate information on the virus, incorrect use of nose masks, and lack of compliance. On the other hand, the challenges may create opportunities that can be harnessed by encouraging the uptake of management strategies with innovations. For instance, the pandemic has enhanced industry awareness of the need of utilising modular and prefabrication construction method in the immediate and long term, since the pandemic requires organisations to seriously plan for developing their modular and prefabrication capabilities (Assaad et al., 2022, Xiang et al., 2022), with a smaller number of workers at workspace compared to the traditional construction (Lau et al., 2019; Lu et al., 2022a).

COVID-19 response strategies have become the drive to ensure construction business continuity amid the pandemic. These exist in four forms: vaccination, personal responsibility, government-instruction practices, and organisation-based approaches. First, vaccination is the first point of call to ensure that construction workers are immune to the virus. This decreases their risk of getting infected by the virus. Second, the personal responsibility of workers seeks to conscientise workers to be extra careful of their movement on site and closeness to high-risk victims. This means, in addition to the COVID-19 measures established on construction sites, it is up to each worker to take extra precautions to stay safe. Third, mandated government-instruction practices are significant to ensure business continuity amid the pandemic, including social distancing, wearing nose masks, and regular hand sanitising. Effectively ensuring this on-site may provide a safe environment for workers. Lastly, organisation-based approaches ensure construction business continuity by adopting innovative management strategies and technologies. These include adopting digital technologies, workforce management, contract-based technique, health and safety management, risk management, prefabrication construction, recycling, lean construction technique, and schedule management. Among the approaches, the adoption of digital technology has been the central focus, facilitating activities such as communication, supervision, monitoring, site inspections, etc.

To deal with the pandemic holistically in the construction industry, the response strategies are evaluated with the STS theory, which merges three primary dimensions: social, environment and technology (Abbas and Michael, 2022). The social dimension concerns the human factor, comprising the individual or people that constitute an organisation and their relationship, values, structures, work-related elements and associations that are delivered by an organisational member (Trist and Bamforth, 1951; Emery, 2016). In the pandemic era, these individuals must coordinate and communicate effectively in a safe environment by leveraging digital technologies and technical tools; hence, the technical dimension. The technical dimension reflects the physical and material flows within a transformation process, tasks, control and maintenance functions (Trist and Bamforth, 1951; Emery, 2016). In an organisation setting amid the pandemic, this concerns the innovative tools, techniques, skills, and devices that workers require to ensure the continuity of construction activities. These operate within an environmental system, which influences their function and how they interact. The environmental dimension is the contexts, surroundings, and conditions within which an open socio-technical system operates and is situated, including the internal and external environment (Emery and Marek, 1962; Abbas and Michael, 2022). In the pandemic, the external environment may include government interventions that require social distancing, mandatory vaccination, and wearing of nose/face masks, whilst the internal environment may also include the organisational policies on health and safety regulations and restrictions at construction workplaces. The three primary dimensions are interdependent, viewing the integration of digital technologies, such as BIM, zoom virtual meetings, smart technologies, etc., into the societal system in an organisation to support productivity, social connection and team continuity amid the pandemic. This approach may raise the cost of development but results in complex systems, like social networks, that have far more performance potential in effectively handling the pandemic in the construction industry.

Based on the review of the existing academic responses to the pandemic in the construction sector, a COVID-19 response framework is proposed (Figure 4) by holistically combining the four categories of COVID-19 response strategies and then strengthened by the STS theory. This makes the four categories of the COVID-19 responsive strategies interdependent toward achieving an effective framework for the post-pandemic era and surviving the risks of future pandemics, as seen in Figure 4. This is called joint optimisation (Appelbaum, 1997; Gorejena et al., 2016). For instance, being vaccinated, which is a mandatory external policy, may empower a construction worker to be effective at the workplace throughout the workflow process, which may involve using digital technologies and other technical tools. Adhering to organisation mandatory safety policies may also create a safe environment, ensuring the effectiveness of construction workers at the workplace using technical tools throughout the workflow. This assures the good health of the construction worker. The interdependent nature of the response strategies could help position the construction industry for the post-pandemic era and also survive the risks of future pandemics. Hence, the COVID-19 response framework could allow an effective understanding of the pandemic response strategies to ensure business continuity amid pandemics. These are significant as they are derived from the lessons-learned reported by empirical studies (see supplementary material Appendix A). Applying these response strategies can help practitioners to keep on with their construction activities whilst the pandemics hover around. Hence, the proposed COVID-19 response framework can properly position the construction sector for the post-pandemic era and survive the risks of future pandemics.

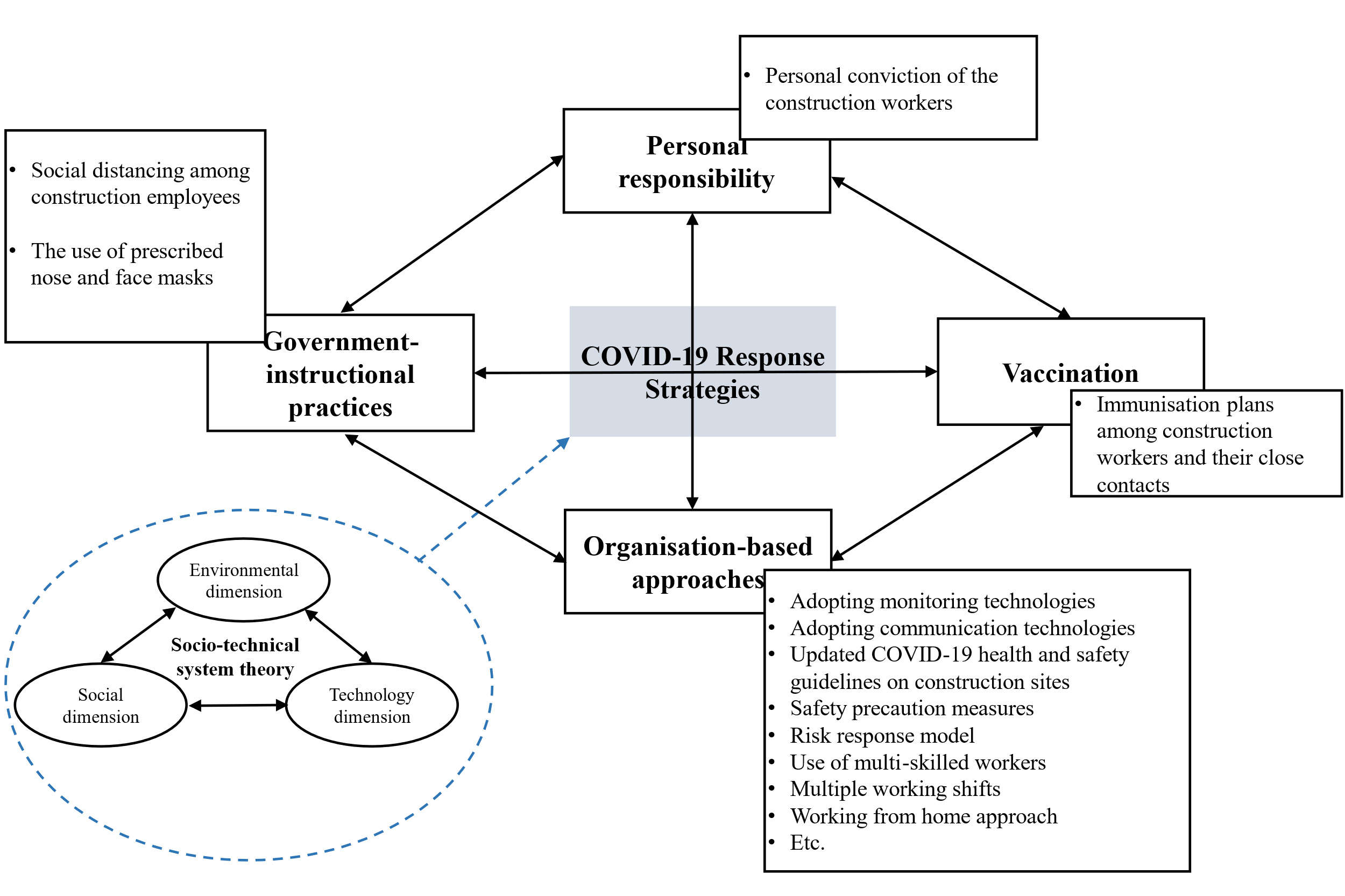


Figure 4: COVID-19 Response Framework in the construction industry.

Figure 4 Alt Text: Depicting framework based on combining the categories of the COVID-19 response strategies via the socio-technical system theory.

# Limitations and future research

Previous studies probably had a narrow focus in order to collect data quickly and publish in rapid response mode. An intriguing perspective would be to look at the trends in the scope of studies in the literature since the initial study in 2020. Knowing these trends contributes to the knowledge body and informs potential future pathways for further academic research. This study investigated the trend to identify the major topics covered. However, limitations of the previous studies are identified and discussed to propose future research pathways in the field.

## Limitations of Previous Research

While embracing the results of the previous studies as strengths, limitations were encountered. Thus, the strengths have been rigorously discussed towards a conceptual COVID-19 response framework. An overview of the current limitations of existing studies is presented in Table 4, Table 5, and Figure 3. Three main limitations of the existing studies are noted, which are discussed further in this section.

First, most studies are country-specific and subjected to the host countries’ government policies and regulations; hence, the studies are limited by scope due to region/location. Though policies on the pandemic may be similar among countries, there is a difference in the execution processes depending on the economy of a specific region/country. This may affect the reports on the impacts of the pandemic, making the result different from one country to the other. This becomes an issue with the result generalisation due to the region specificity. Therefore, responses may vary from region to region, though there may be few commonalities. This denotes a great “limitation by scope” of the existing studies. Also, reviewing the research techniques and methods across countries/regions also denoted a significant limitation. Many studies across countries are limited by research methods, and this does not lead to in-depth investigations of the pandemic in the construction industry. The study reviewed that the number of studies is few as most countries recorded as high as one publication adopting one of the research methods (quantitative, qualitative, mixed). For instance, it is inferred that the COVID-19 research is limited in Africa, as less than ten African countries were found among the countries. Among the ten, only Nigeria adopted all three research methods but with a limited number of studies. Similar inferences and trends can be made for other continents based on the country and the research technique and method adopted (see Table 2). As the pandemic still wanders around the globe, there is a need for other countries/regions also to investigate and highlight their findings using various research techniques to add up to the overall results to mitigate the risks of the pandemic in construction effectively. Also, a cross-border study is recommended to consider views from different countries to determine the best practices that can position the industry for post-pandemic actions and endure the risks of future pandemics by adopting various appropriate research techniques.

Second, oversimplification and unclarity with resilient activities were noticed as limitations of existing studies due to the weaknesses of the research methods adopted. Oversimplification may occasionally work well, but the intricacies should not be overlooked. Upon the review, it is made clear by Araya (2022) that the proposed framework based on the agent-based modelling approach is a simplification of real-life conditions in construction projects, and no specific set of skills was discussed in the proposed model. This imposes a limitation that needs to be acknowledged in their study, though it is necessary to simplify real-life conditions by making assumptions about agents’ behaviours. This oversimplifies real-life conditions, such as the process of contagion among workers regarding the modelling of multiple working shifts and the use of multi-skilled workers in construction organisations (Araya, 2021ab). This causes obscurity in understanding the detailed dynamics of the working practices of the workforce in construction firms. Another limitation relates to the unclear and lack of specificity regarding the multi-skilled workers in their model (Araya, 2021ab). The proposed model did not refer to any clear and specific set of skills for construction workers, which may be reduced to the specificity of findings. Given the international scope of the pandemic, it is important to develop models and tools that can improve the management of the construction workforce against the pandemic by providing clear, specific, adaptable, and transferrable solutions to multiple construction contexts. Hence, robust methodologies/research methods with a high precision rate to real-life conditions can be engaged further to investigate and analyse the dynamics of workforce activities in construction firms without missing the clarity of actions in ensuring resilience amid the pandemic crisis.

Lastly, the studies involving digital technologies in dealing with the COVID-19 crisis in construction exhibited limitations, such as the immaturity of technologies, accuracy issues of distance, high technicalities, system reliability, and lack of social factors consideration. A low level of maturity in digital technologies was noted among the selected empirical studies compared to studies from other fields, such as aerospace, manufacturing, etc. (Ebekozien and Aigbavboa, 2021). This is reflected in the level of detailed research reports by the studies on the use of digital technologies for COVID-19 response in construction. Hence, cross-interdisciplinary research engaging construction experts and experts from the computing field may be encouraged in future research studies. In addition, there are associated issues that need to be further investigated, though the pandemic has impelled the construction industry to adopt digital technologies to ensure business continuity. For instance, with smart real-time monitoring systems based on computer vision developed, the system was diagnosed with an issue of distance accuracy since it depended on the images from existing CCTV cameras (Goh et al., 2022). This led to the occlusion effects of computer vision-based systems. Therefore, the system needs to be improved by testing other cases. The issue of digital system reliability is noted as a limitation in developing a smart robotic system for mask recognition and autonomous navigation during construction to mitigate the spread of the pandemic. The accuracy of locating and identifying workers to ensure they are properly wearing masks was unreliable due to system bugs and anomalies. Therefore, tackling the challenges regarding the bugs and anomalies created by surrounding environments should become the focus of future research. Moreover, the studies regarding the digital technology adoption in construction amid COVID-19 were noted to be highly technical, lacking the components to understand the social factors, the roles, and operable features of the technologies to ensure successful implementation (Seagers et al., 2022; Lu et al., 2022b). Hence, the selected empirical studies were limited to the technical aspect of digital technology. Thus, more efforts are required to understand the social aspects, including roles, organisational culture, and institutional mutual enhancement policies and regulations, in order to balance the concerns regarding the technicalities of digital technology adoption in the construction industry amid the pandemic.

## Future research direction

The forgoing results and analysis have summarised and depicted previous research on COVID-19 in the construction industry. Several research gaps have been identified based on the study findings, and future research directions are proposed. The suggested areas are based on evaluating the future works proposed in the existing studies and on the untapped strategies identified from the analyses that can position the construction industry for post-pandemic actions and endure the risks of future pandemics. As such, four pertinent research areas must be considered for future research.

#### Direction 1: Building upon and testing the proposed COVID-19 response framework in the construction industry

This study proposed a COVID-19 response framework that has the potential to position the construction industry adequately for the post-pandemic era and endure the risks of future pandemics. However, the response framework is based on the literature review of existing empirical studies; hence, lacking empirical data to prove the effectiveness of the framework. Therefore, future studies are encouraged to test and build upon the proposed framework by adopting robust research methodologies. This could be considered by taking empirical data from country-specific contexts, case study contexts, specific field contexts, international perspectives of the framework, and so on. Also, this framework could be developed further by incorporating temporal elements, including short-term, medium-term, and long-term responses, as well as pro-active and reactive responses. In the end, an effective COVID-19 response framework will be developed to ensure the effectiveness of construction activities in the post-pandemic era and also survive the risks of future pandemics

#### Direction 2: Adoption of more advanced innovative strategies to increase productivity amid pandemics and survive the risks of future pandemics

As the construction industry follows government instructions and organisation-based policies regarding COVID-19 mitigation, more advanced innovative strategies can be deployed to ensure resilience. The industry is still immature with innovation adoption practices, such as digital technology integration into the management loop. However, limited studies have considered this investigation, especially in the construction industry amid the pandemic. Applying more advanced innovative strategies by integrating digital technologies in construction management can offer promises to ensure construction business continuity amid the pandemic crisis and position the industry to endure the risks of future pandemics. Aside from engaging digital technologies, the industry can also be innovative about its traditional construction management through various means of enhancements. More innovative efforts are required. Therefore, future research is encouraged to report on the feasibility of more advanced innovative management strategies, engaging digital technologies or not, in ensuring resilience in the local and international construction business amid the pandemic, taking lessons from other industries.

#### Direction 3: Beyond the technological response to COVID-19 in construction

Digital technology implementation in this research domain by existing studies has been centred on technical solutions (Lu et al., 2022) with less focus on social concerns, operability, the institutional culture, policies, and the roles of management. Digital technologies, such as BIM, smart monitoring systems, blockchain, etc., are adopted in society and, therefore, can be designed to conform to society by considering managerial solutions. No study has positioned the digital response to COVID-19 from the perspective of the Socio-technical system. This is highly significant during the pandemic wave, where digital technology is adopted to ensure resilience in construction activities with the help of human resources and management. Besides, future research could investigate integrating digital technologies with managerial solutions considering institutional policies, operability, and management roles to ensure resilience in the construction business amid the pandemic.

#### Direction 4: Post-pandemic view of the construction industry

It is about how the construction industry will work after COVID-19, the so-called “new normal”. There is a need to understand the post-COVID-19 situation in the construction industry after the digital technology adoption and other innovative approaches. Reviewing the existing studies denoted a few post-COVID-19 interventions, including a change management model, sustainability, new adaptable residential architectural design, and construction business continuity strategies. However, more intervention ideas may demonstrate the projects the construction industry will embark on after the COVID-19 crisis. Thus, future research is encouraged to explore possible post-COVID-19 interventions to keep the construction industry more active and innovative after the pandemic crisis.

# Conclusion

The study reviews the up-to-date academic literature on the COVID-19 pandemic to understand its impacts on the construction industry, including how the industry has responded. The review involves 159 publications from 2020 to 2022 selected from the WoS and Scopus database. The key findings and conclusions are provided next.

The review articles show an increasing trend of research interests related to the COVID-19 pandemic in the construction industry with diverse research methods and techniques since 2020 across different countries. Four major topics could be deduced from synthesising the previous research studies on the pandemic in the construction sector. These include the COVID-19 impacts, challenges and opportunities, COVID-19 responding strategies, and post-COVID-19 interventions. Despite the negative impacts and the challenges imposed by the pandemic, positive impacts and opportunities are found to exist, causing construction industries to be innovative with the existing managerial strategies. Four categories of responding strategies exist in handling the risks of the pandemic in construction, namely vaccination of construction workers, personal responsibility of workers, government-instructional practices, and organisation-based approaches. With the response strategies, it was also observed that early construction studies have focused on enforcing government instructional practices at workplaces and encouraging construction workers to vaccinate with the right doses. Also, organisation-based health and safety measures have been established to ensure a safe working environment for construction workers. Moreover, adopting digital technologies in the construction industry has shown great promise in the pandemic era in ensuring construction business continuity. Based on the review of the response strategies from previous studies, a COVID-19 response framework is proposed to ensure construction business continuity amid pandemics through the lens of STS theory. This is significant as the framework is developed based on the lessons learned reported by empirical studies and can position the construction industry for the post-pandemic era and endure the risks of future pandemics. This study concludes that there are various outcomes of studies that can inform the decisions on responding to COVID-19 in the construction industry, but previous studies have been limited, requiring more efforts to contribute to positioning the industry for post-pandemic action and endure the risks of future pandemics.

In examining insights from and synthesising previous studies, four main research direction was recommended for future studies: (1) building upon and testing the proposed COVID-19 response framework in the construction industry, (2) adoption of more advanced innovative strategies to increase productivity amid pandemics and survive the risk of future pandemics, (3) beyond the technological response to COVID-19 in construction, and (4) post-pandemic view of the construction industry. The four directions in union depict a reasonably predictable future that can position the construction industry for post-pandemic actions and endure the risks of future pandemics.

By synthesising prior research and offering critical insights into future explorations in handling pandemics in construction, the study significantly adds to the knowledge about pandemic impacts and responses in the construction industry. The study contributes to theory by applying the lens of STS theory to propose a COVID-19 response framework capable of positioning the construction industry to be adequate for the post-pandemic era and survive the risks of future pandemics. The study demonstrates the concerted efforts of the construction industry in dealing with the impacts of the pandemic, along with response strategies, such as the adoption of digital technologies. The findings should cultivate research interest and support the industry for deeper and frontier research into handling pandemics in the construction industry. However, there are limitations associated with this review. The analysis was based on two databases, namely Scopus and WoS, published in English. Therefore, one can advise a more thorough assessment by expanding the selection of papers to other databases such as PubMed, JSTOR, ScienceDirect, IEEE Xplore, Academic Search Complete, etc. The pattern of the findings, nevertheless, should remain the same. Also, the research was limited to journal articles and conference proceedings. Future studies may combine with other different databases and document types. Furthermore, the study was restricted to the construction industry; hence, findings may differ from other industries. Finally, the literature search was conducted based on selected keywords. This might not accurately represent the whole field of study. As a result, future research may use more keywords.

# Data availability statement

Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

# Disclosure statement

“No potential competing interest was reported by the authors.”

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