RESILIENCE TO COVID-19 THROUGH LEAN CONSTRUCTION

AGANA PARAMESWARAN[1]* & K.A.T.O. RANADEWA[2]
[1, 2]University of Moratuwa, Colombo, Sri Lanka
[1]aganaparameswaran@gmail.com, [2]tharushar@uom.lk

Abstract: COVID-19 pandemic has been an alarming issue from the beginning of 2020 and is a significant disaster that affects each industry. In dealing with the consequences of the pandemic, the construction industry confronts several interruptions for the sustainable delivery of the projects. Many researchers stated that lean construction can minimise this impact. Lean thinking is about engaging everyone, every day in handling interruptions and learning to react better. However, few discussions are there pertaining to how to implement and why to implement lean. Therefore, this paper aims to investigate the impact of COVID-19 on the construction industry and evaluate the ability of lean construction to resilient COVID-19. Therefore, a comprehensive literature review has been carried out. The findings revealed 67 negative factors categorised under resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues for the construction industry due to the pandemic. Continuous improvement for the work under any risks, improvement in project performance, more satisfaction, and better value for the employer were highlighted as the main benefits of lean construction during the new normalcy. The developed conceptual framework unlocked several research arenas on lean in post-COVID implementation for the construction industry.
Keywords: *COVID-19, Impact, Lean construction, resilient*

1. Introduction

The trending topic of recent years, the COVID-19 (coronavirus disease of 2019) outbreak is a major health, social and economic emergency (Bsisu, 2020). Veselovská (2020) specified that the closest example of a worldwide pandemic of Spanish Influenza's such magnitude is seen in the early twentieth century. Lu, Stratton, and Tang (2020) stated that Wuhan City, experienced an unusual pandemic of pneumonia of unknown aetiology was discovered on December 2019 with forty-one cases. Moreover, the World Health Organization (WHO) has announced that the COVID-19 pandemic in china is a global health emergency of international concern on 30th January 2020, posing a high risk to countries due to vulnerable health systems (Sohrabi et al., 2020). Furthermore, in order to prevent the spread of COVID-19, most national governments have imposed unprecedentedly severe measures, including the closing of national borders, restricting public meetings and gatherings, and school, store, and restaurant closures. In addition to that, entire cities and regions have been shut down in certain circumstances (Inoue and Todo, 2020). As a result, the COVID-19 pandemic has triggered healthcare, economic, and social catastrophe that has impacted all demographics and economic sectors. Consequently, Bsisu (2020) stated that the COVID-19 pandemic may have unforeseeable socio-economic implications, as well as affecting the global construction sector. In the Sri Lankan context, new rules and regulations established by the government would have a direct influence on the construction sector (Vithana, Bandara, and Jayasooriya, 2020). Accordingly, Bsisu (2020) stated that, steps should be taken immediately limit the impact of the pandemic as the construction industry is a vital tributary and one of the economy's fundamental foundations. Pathirana (2020) highlighted that due to import restrictions and limitations that have been levied by the Sri Lankan government, will have a significant effect on the construction industry. Depend on imported construction raw materials from India and China, has worsened the current situation in the Sri Lankan construction industry.

Consequently, lack of construction materials (Gamil and Alhagar, 2020; Alsharef et al., 2021; Zamani et al., 2021), delays in project delivery (Gamil and Alhagar, 2020; Ghandour, 2020; Oey and Lim,

*Corresponding author: Tel: +94 77 6165500 Email Address: aganaparameswaran@gmail.com
FARU Journal: Volume 08, Issue 1 DOI: http://doi.org/10.4038/faruj.v8i1.71

2021; King et al., 2021), high cost of constructions (Gamil and Alhagar, 2020; Ogunnusi et al., 2020; Alsharef et al., 2021; Zamani et al., 2021), unprecedented changes to the projects schedules (Alenezi, 2020a; Gamil and Alhagar, 2020; Alsharef et al., 2021; Oey and Lim, 2021) and restrictions to operations (Alenezi, 2020c; Gamil and Alhagar, 2020; Alsharef et al., 2021; King et al., 2021), were considered as noteworthy challenges to the Sri Lankan construction industry due to the pandemic. This has underlined the need of using the resources effectively and efficiently in the project and searching for strategies to overcome the impact of the pandemic.

To resolve the problems due to COVID-19, Yuan et al., (2020) highlighted that lean construction is an approach, which has been used as a project improvement approach aiming to maximise value and minimise non-value-adding activities (NVAA) of a construction project. Even though lean provides immense benefits for a construction project, the use of lean-to minimise the impact of COVID-19 is yet to be researched. Consequently, a need arises to identify the resilience to COVID-19 through lean construction for the construction industry in Sri Lanka. Therefore, this paper is aimed to develop a conceptual framework for the resilience of COVID-19 through lean construction. This paper begins with a literature review on the impact of COVID-19 and consequently discusses the impact to the construction industry. Then, a brief introduction to the lean construction along with the benefits of lean integration to minimise the impact of COVID-19 present. Finally, the developed conceptual framework presents incorporating the literature findings.

2. Research Methodology

This research aims to fill the knowledge gap by answering the research question: "How to overcome COVID-19 impact for the construction industry through lean construction?". Consequently, a systematic literature review was supplemented by journals, conference proceedings, books, and electronic resources to investigate the impact of COVID-19 on the construction industry, and propose strategies through lean construction to overcome the impact of COVID-19 by the construction industry. Subsequently, this paper was intended to develop a conceptual framework for the resilience of COVID-19 through lean construction based on the literature review.

3. Impact on Construction Industry

Considering the global spread of this new virus, WHO has designated COVID-19 of 2019 a pandemic. Furthermore, Nicola et al. (2020) emphasised that the impact of COVID-19 on global healthcare systems has a cascading effect on every area of human existence. In order to halt the spread of COVID-19, governments around the world have implemented a series of preventive steps (Ghandour, 2020), including avoiding unnecessary travel, social distancing, and prohibiting congregations (Nicola et al., 2020). Accordingly, as people, communities, governments, academic institutions, and industrial enterprises grapple with the problems of reducing human life loss in the face of an unseen pandemic, and the practice of social distance has pervaded daily life (Sarkis et al., 2020). Ogunnusi et al. (2020) highlighted that due to those restrictions, the pandemic had an impact not only on human health but also affected all industries including the construction industry. Similarly, Nicola et al. (2020) emphasised the global socioeconomic impact of the COVID-19 outbreak on various sectors such as primary, secondary, and tertiary, which include industries engaged in finished product development, raw material mining, and all service provision industries.

The construction industry is one of the most important economic sectors which contributes significantly to the country's economic development (Apollo and Miszewska-urbańska, 2015). The COVID-19 pandemic has had an impact on the construction sector, as it has on many other industries, in many different ways (Raoufi and Fayek, 2021). Similarly, Ghandour (2020), and Zamani, Rahman, Fauzi, and Yusof (2021) agreed that the construction industry has been impacted by COVID-19. Table 1 presents the impacts faced by the construction industry globally as a result of COVID-19 pandemic.

No	Impacts	Reference
	Resources related issues	
	Material	
1	Scarcity in material	[4],[5],[7],[8],[9],[10],[11],[13],[14]
2	Supply chain disruptions	[2],[4],[7],[8],[9],[10],[11],[12],[13],[14]
3	Difficulties in finding suitable alternative materials	[10],[11]
4	Delay in delivery	[6],[9],[10],[11]
5	Difficulties in storing material	[12]
	Workforce	

No	Impacts	Reference
6	Shortage in workforce	[2],[4],[5],[6],[7],[8],[9],[10],[11],[12]
7	Increased in workload	[2]
8	Unstable mental and physical health of workers	[10],[11],[12]
9	Difficulties in transportation	[6]
	Equipment	
10	Delay in delivery	[5]
11	Shortage in construction equipment	[5]
	Project Management issues	
12	Restriction on operations	[1],[7],[9],[10],[12],[13]
13	Inappropriate site conditions	[5],[9],[10]
14	Difficulties in adapting to the new normal	[12]
15	Lack of experts	[12]
16	Poor decision making	[12]
17	Lack of previous experience on a pandemic	[12]
18	Poor control and monitoring	[2],[11]
19	Continuous changes in project scheduling and planning	[5],[7],[10],[11]
20	Lack of communication between parties	[5]
21	Lack of supervision and site management	[2],[5]
22	Disruption to the progress of work and workflow	[2],[4]
23	Lack of safety conditions	[5]
24	Lack of Coordination	[10],[12],[13]
25	Ineffective work on site	[11]
26	Delay on project completion	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
27	Slowing and suspension of an ongoing project	[7],[10],[12]
28	Delay to start new projects	[10]
29	Project abandonment/stopped/termination	[4],[6],[12],[13]
30	Reduction of per day working hours	[6]
31	Delay from construction-related activities	[6]
	Quality issues	
32	Reduction in quality due to continuous changes	[11]
33	Reduction in quality due to material changes	[11]
34	Reduction in quality due to limited time and delay	[11]
35	Reduction in quality due to lack of coordination	[11]
36	Decrease in productivity	[2],[4],[5],[9],[10],[11],[12]
	Financial issues	
37	Increased in project cost	[4],[7],[8],[9],[10],[11],[13]
38	Increase in exchange rate, and inflation rate	[5],[7],[10],[11],[12],[14]
39	Increase price of materials and equipment	[5],[6],[7]
40	Unstable cash flow and revenue	[2],[4],[10],[11]
41	Lack of funding	[4],[6],[7],[12]
42	Bankruptcy	[13]
44	Employees get payment without work	[13]
	Contractual issues	
45	Delay in payments	[3],[5],[8],[10]
46	Delay due to approval and revising	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
47	Delay from permitting and inspection	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
48	Delay in providing instructions	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
49	Delay due to main contractor	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
50	Delay due to subcontractors	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
51	Changed or unclear standard operating procedures	[9],[11]
52	Increase in claims, disputes, and litigation	[7], [10],[12]
	Safety-related issues	
53	Shortage in personal protective equipment	[10]
54	Quarantining and temporary shutdown	[10]
	Technological related issues	
55	Lack of practices in virtual working	[7],[10],[11]
56	Insufficient support to adopt to new technologies	[7],[10],[11]
57	Issues with work from home	[10],[11]
58	Ineffective transition to remote work	[10],[12]
	Other issues	
59	Challenges to sustainability of future project	[11],[12],[13]
60	Uncertainty of the project	[7],[13]
61	Shrink in market size	[11],[12],[13]
62	Reduction in number of project	[4],[8], [11],[12],[13]
63	Spend more time to review the project	[11],[12],[13]
64	Anxiety for termination	[11],[12],[13]
65	Lack of improvements to the project	[11],[12],[13]
66	Termination of staff employment	[13],[14]
67	Impact on social sustainability	[7],[14]

[1] (Alenezi, 2020c), [2] (Ghandour, 2020), [3] (Alenezi, 2020b), [4] (Ogunnusi *et al.*, 2020), [5] (Alenezi, 2020a), [6] (Osuizugbo, 2020), [7] (Gamil and Alhagar, 2020), [8] (Zamani *et al.*, 2021), [9] (King *et al.*, 2021), [10] (Alsharef *et al.*, 2021), [11] (Oey and Lim, 2021), [12] (Kawmudi *et al.*, 2020), [13] (Vithana, Bandara and Jayasooriya, 2020), [14] (Pathirana, 2020)

Table 1. Impact of COVID-19 in the construction industry

As indicated in Table 1, there are many challenges for the construction industry as a result of the COVID-19 pandemic. Further, negative impacts include resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues. Accordingly, the study identified 67 negative effects with COVID-19 to the construction industry. Consequently, highly agreed impacts form the literature are scarcity in material, supply chain disruptions, delay in delivery, shortage in the workforce, restriction on operations, delay on project completion, continuous changes in project scheduling and planning, project abandonment/stopped/termination, decrease in productivity, increase in project cost, increase in the exchange rate, and inflation rate, increase the price of materials and equipment, unstable cash flow and revenue, lack of funding, delay due to approval and revising, delay from permitting and inspection, delay in providing instructions, delay due to the main contractor, delay due to subcontractors, and reduction in the number of projects

Nevertheless, Table 1 shows that the majority of the problems in the construction sector as a result of COVID-19 pandemic are linked to financial issues (increased project costs and lack of finance), resource shortages, project delays, decreased productivity, and reduced project numbers. In addition to that, Oey and Lim (2021) specify that reduction in cost including salary decreased as the positive impact from the employer perspective. On the other hand, when considering the contractor perspective reduction in other costs has a negative impact (King et al., 2021). It means project suspension and reduction as well as lack and no production directly influence the contractors because the contractor did not entitle to claim without working. Similarly, in the Sri Lankan context, Vithana, Bandara, and Jayasooriya (2020) mentioned that employees' get payment without work has a negative impact due to COVID-19 in the construction industry from an Employer perspective. However, these different perspectives vary between countries legal amendments, and newly amended rules and regulations. Therefore, there is a need to explore suitable strategies to minimise these impacts during the new normalcy by construction industry.

4. Integration of Lean Construction

Lean construction is one of the methods for increasing productivity by the application of a new form of production management to construction (Aziz and Hafez, 2013). "Lean construction" is basically an attempt to adapt lean principles from the Toyota Production System (TPS) to construction, with the aim of handling and optimizing construction operations with the least amount of money and the greatest amount of efficiency while taking consumer needs into account (Gao and Low, 2014). Many researchers indicated the ability of lean implementation in post-COVID to minimise the negative impacts to the construction industry. Although lean is often thought of as a system to solve already-known problems, it is a system to help creating new and better ways to work as a way to 'revitalize' the human spirit, communities, and organizations.

Raoufi and Fayek (2021) initiated 177 measures and categorized them into 16 categories for the mitigation and control of COVID-19 pandemic impacts on construction companies. According to Yuan et al. (2020) construction organisations will be benefitted by implementing lean during the new normalcy. Similarly, Oey and Lim (2021) introduced under the planned 20 action plan, lean construction was offered as a way to combat the COVID-19 pandemic in the construction industry. Accordingly, many argued the ability of lean construction to minimise the negative impact due to COVID-19. On the other hand, even before the pandemic, many researchers signified the ability of lean construction to minimise the NVAA in a construction project and ultimately achieve the expected value. The project participants of a lean implemented project, collaboratively works together achieving one goal (Tzortzopoulos, et al., 2020) which provides the value to the end-customer. In a global pandemic, working towards one goal, with effectively handling interruptions are paramount, confirming the adaption of lean for the post-COVID situation. Similarly, many researchers highlighted the possibility of lean implementation as a means to normalise the situations after any significant interruptions.

Nevertheless, lean construction employs the same principles as lean manufacturing to minimise construction waste and maximize productivity, efficiency and effectiveness in order to produce the greatest amount of value possible in construction projects by reducing NVAA in all phases of project delivery (Aziz and Hafez, 2013; Marhani et al., 2013; Smith, 2015; Khodeir and Othman, 2018; Tezel, Koskela and Aziz, 2018; Mohammadi et al., 2020). In order to become a successful construction firm, the application of lean tools is paramount (Sacks, Radosavljevic and Barak, 2010; Aziz and Hafez, 2013; Muhammad, Ismail, and Hashim, 2013; Sarhan and Fox, 2013). Therefore, not only minimising the impact of the COVID-19 pandemic but also immense benefits will provide for the construction organisations through post-COVID lean implementation as presents in the following Table 2.

No	Benefits	References
1	Decrease the duration of the project	[1],[3],[4],[6],[9],[10],[12],[11],[13],[14],[15],[16]
2	Decrease whole life cycle cost of the project	[1],[2],[3],[4],[6],[9],[10],[12],[13],[14],[15],[16]
3	Increase in quality of the project	[1],[2],[3],[4],[6],[10],[11],[12],[15],[16]
4	Adapting to continuous improvement	[2],[3],[5],[7],[9],[11],[12],[14]
5	Efficient control in inventory	[3],[8],[11],[13],[15]
6	Focus on production control and planning	[5],[8],[11]
7	Minimum impact during sudden risks	[3],[14],[15]
8	Decrease rework and minimise variability of workflow	[3],[6],[9],[13],[14]
9	Increase project performance	[2],[6],[8],[13],[14],[16]
10	Improvement in delivery method of the project	[2],[6],[8],[13],[14],[16]
11	Decrease NVAA	[2],[3],[5],[6],[7],[12],[15],[16]
12	Increase the profit	[6],[12],[16]
13	Improve design and product and process	[8],[16]
14	Improvement in labour performance	[1],[3],[6],[7],[11],[12],[13],[14],[15],[16]
15	More satisfaction and better value for employer	[1],[2],[3],[5],[6],[7],[11],[12],[14],[15],[16]
16	Increase employee satisfaction	[3],[7],[11],[12]
17	Increase innovation at site	[6],[12]
18	Improve relationship with suppliers	[3],[6],[11]
19	Reliability and certainty of project	[3],[6],[9],[12],[14],[16]
20	Improve the cooperation between project participants	[2],[3],[5],[12]
21	Effective increment on control and management	[3],[6],[13]
22	Increase health and safety	[1],[2],[3],[4],[7],[11],[12],[13],[15],[16]

[1] (Ahmed, Hossain and Haq, 2021), [2] (Albalkhy and Sweis, 2021), [3] (Babalola, Ibem and Ezema, 2019), [4] (Bajjou and Chafi, 2018), [5] (Ogunbiyi, Goulding and Oladapo, 2014), [6] (Locatelli et al., 2013), [7] (Marhani et al., 2012), [8] (Aziz and Hafez, 2013), [9] (Ahiakwo et al., 2013), [10] (Al-aomar, 2012), [11] (Sarhan et al., 2017), [12] (Ogunbiyi, 2014), [13] (Mohan and Iyer, 2005), [14] (Adegbembo, Bamisaye and Aghimien, 2016), [15] (Akinradewo et al., 2018), [16] (Mossman, 2009).

Table 2. Benefits of implementing lean construction

The literature review highlighted the benefits of lean construction as a strategy for overcoming COVID-19's impact on the construction industry. Accordingly, 22 benefits of lean construction were identified pertaining to minimise the impact of COVID-19. The highly noted benefits form the literature are decreasing the duration of the project, decrease the whole life cycle cost of the project, increase in quality of the project, adapting to continuous improvement, decrease the NVAA, improvement in labour performance, more satisfaction, and better value for an employer, and increase health and safety.

Additionally, the implementation of lean in a construction project would improve phases of delivery systems and processes, and lead to value-addition by eliminating wastes, increasing productivity, ensuring environmental sustainability, health, and safety, and optimising overall project, and project delivery practices, improving flow, mitigating delays, financial performance, enhancing performance for the customer at the project stage, as well as enhancing design process cost, concurrent designing, construction, and the application of project control mechanisms to ensure cost and time overruns reduced to a minimum and the required performance level in over the lifecycle of the construction project from initiation to completion, therefore, clients' requirements can be met (Aziz and Hafez, 2013; Muhammad, Ismail, and Hashim, 2013; Pradeepkumar and Loganathan, 2015; Ansah and Sorooshian, 2017; Babalola, Ibem and Ezema, 2019; Mohammadi et al., 2020).

In addition to that, lean construction is a departure from conventional construction approaches which aims to encourage product design simultaneously with the process, maximizing firm or professional performance for employers (Babalola, Ibem and Ezema, 2019). Lean construction and sustainable construction shared several similar goals in terms of resource utilization and reducing waste (Francis and Thomas, 2020; Solaimani and Sedighi, 2020). Even though, based on the numerous evidence, lean practices have been represented through tools, procedures, principles, approaches, and strategies that allow the achievement of lean construction targets (Marhani et al., 2013; Zhang and Chen, 2016; Ansah and Sorooshian, 2017). Considering the literature findings, it is evident that, lean thinking is about engaging everyone, every day in handling interruptions and learning to react better in difficult circumstances. Therefore, not only minimising the impact of the COVID-19 pandemic but also immense benefits will deliver for the construction organisations through post-COVID lean implementation. Therefore, next section presents a conceptual framework developed for the study.

5. Conceptual Framework

Combining all the literature findings of the study, a conceptual framework was developed to represents the resilience to COVID-19 through lean construction (Figure 1). The left side of Figure 1 shows the COVID-19

impacts through a mind map. These impacts have been categorised into 8 as; resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues. These impacts can be overcome through lean construction benefits which are presented in the right side of Figure 1. The identified impacts were then mapped with the benefits of lean construction as shown in the middle of the diagram.

According to the Figure 1, ***resources-related issues*** can be minimised by decreasing the NVAA and efficient control in inventory throughout the project. This allows the effective and efficient use of limited resources with continuous improvement. Furthermore, lean contributes to improving labour performance and increasing employee satisfaction, which means there can be less unstable mental and physical health of construction employees. Further, while decrease in rework and minimise variability of workflow, and improvement in labour performance, employees' workload can be reduced and employees may accomplish their responsibilities within a period. In addition, lean helps enhance supplier connections since supply chain problems can be neutralised. Accordingly, the majority of the resources-related issues may thus be solved through lean construction.

While examining ***project management issues*** such as restriction on-site and inappropriate site conditions, this leads to disruption in the progress of work and workflow, reduction of per day working hours, ineffective work on-site, and lack of experts at the site. These issues can be minimised by lean implementation as lean helps to decrease rework and minimise variability of workflow, decrease the NVAA, improve labour performance and increase employee satisfaction since employees can perform efficiently and efficiently in terms of time. In addition, lean helps to decrease the duration of the project and increase project performance, to resolve project delay and delay between activities. Further, lean will assist to focus on production control and planning, increase project performance, improvement in delivery method of the project, improve design and product and process, provide reliability and certainty of project, and decrease rework and minimise variability of workflow, as these benefit contributes to the management and reduction of continuous project scheduling and planning, and make a better decision. Moreover, Espinoza et al. (2021) explored Choosing By Advantages (CBA) as a lean tool for making choices with transparency and clarity, and it was utilised in this case to facilitate decision-making by taking into account the restrictions of the COVID-19 protocol. Subsequently, lean helps to effectively control and ensure the reliability of the project. Thereafter, improving the cooperation between project participants contributes to maintaining effective interparty communication. Nevertheless, lean helps to improve health and safety since the lack of safety can be remedied on-site. Furthermore, the challenges in adjusting to the new normal can be handled due to an increase in innovation at the site. Accordingly, lean provide more satisfaction and better value for an employer, and provide reliability and certainty of the project, to prevent employers from terminating the project. In addition, the Last Planner System (LPS) one of the lean tools is reliable, and it has served as a foundation for strengthening a production control system used to manage the construction project throughout the pandemic (Mchugh, Patel and Dave, 2021). Consequently, the implementation of lean construction may eliminate most of the problems linked to project management.

Thereafter, ***quality issues*** can be overcome through implementing lean, as lean leads to an increase in the quality of the project. Although, reduction in quality due to limited time and delay can be achieved by decreasing the duration of the project and increasing project performance. Furthermore, lean helps to decrease rework and minimise variability of workflow, thereby reduction in quality due to continuous changes and material changes can be minimised. Further, reduction in quality due to lack of coordination can be handled by lean, hence lean improve the cooperation between project participants. Moreover, lean promotes to decrease the NVAA and improve design. Further, Verán-Leigh and Brioso (2021) specified implementing concepts such as lean construction for work planning, control, and execution proved to be a viable choice for maintaining productivity throughout the residential project under consideration, while also meeting the project's deadlines, quality, costs, and safety requirements. Accordingly, the use of lean construction can therefore eliminate most of the problems connected to quality.

Similarly, ***financial-related issues*** can be handled by lean implementation since lean helps to decrease the duration and whole life cycle cost of the project, decrease rework and minimise variability of workflow, and decrease the NVAA. As a result of an increase in exchange rate, price of materials and equipment might increase which leads to unstable cash flows. However, lean ensures the reduction in overall cost of the project and thus the cash flows can be managed. Further, lean provides better value for the employer, so that financial matters can be tackled through lean construction. Furthermore, the lean implementation may alleviate ***contractual related issues*** since lean leads to decrease rework and

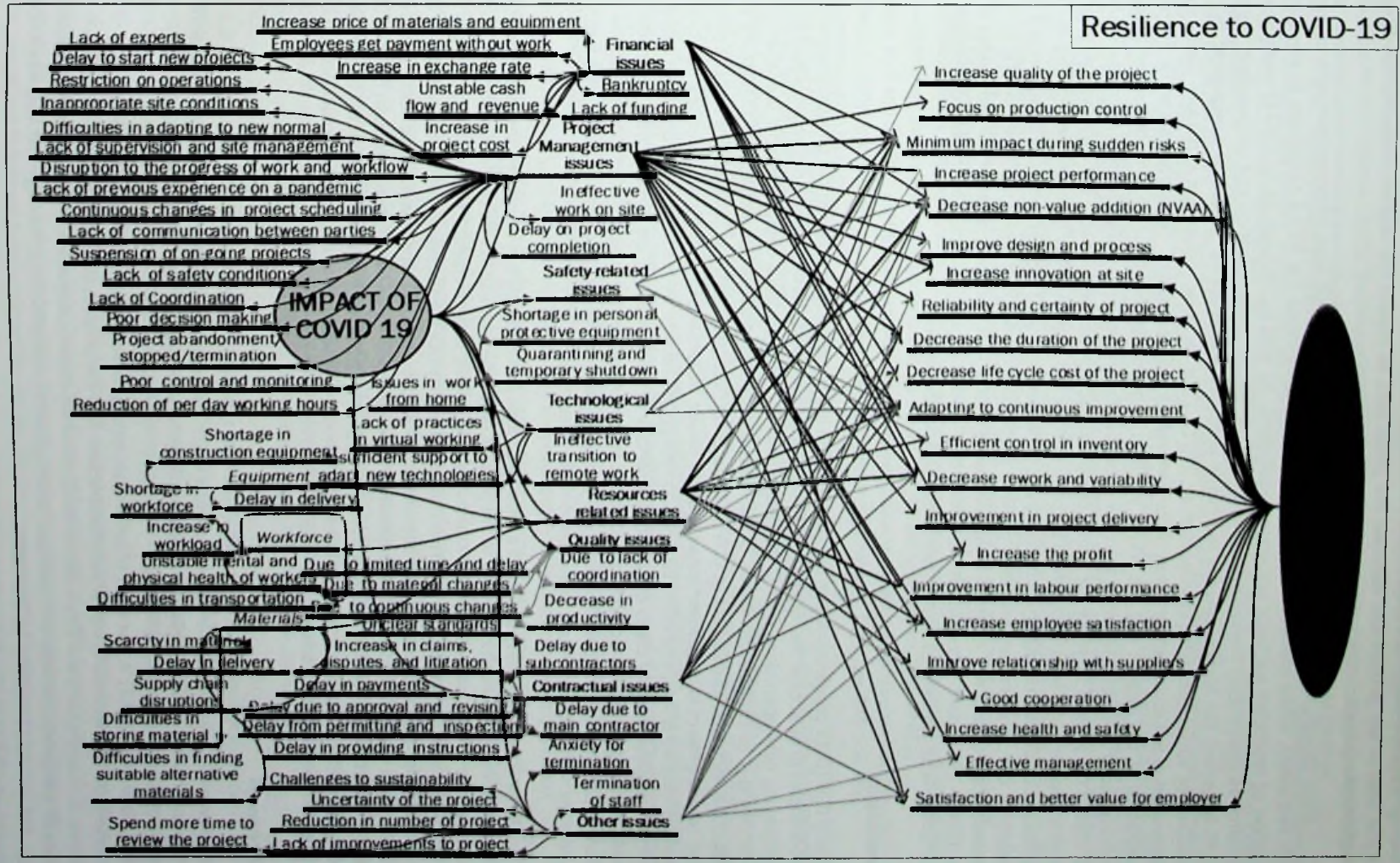

Figure 1. Conceptual framework for resilience to COVID-19 through lean construction

minimise variability of workflow, decreasing the NVAA, and duration of the project. Therefore, delays may be managed at each stage. Moreover, more satisfaction and better value for an employer, decrease whole life cycle cost of the project and increase the profit lead to reduce the claims, disputes, and litigation throughout the project.

Even though, ***safety-related issues*** can be remedied through lean, whereas lean aids to increase health and safety. While efficient control in inventory and decrease the NVAA contribute to the effective utilization of restricted personal protective equipment. As well as, Mchugh et al. (2021) recognised by integrating all information toward one platform and increasing communication and cooperation, digitising the LPS improved the team's capacity to engage remotely and supplied the social component that was diminished by social distancing (Espinoza et al., 2021). Thus, increase innovation at the site owing to lean implementation assists to support most of the ***technology-related issues***. Nevertheless, while decreasing the duration of the project and the NVAA via lean implementation, it helps to solve ***other issues*** by improving the projects and reducing the time spent on the project review. In addition, decrease whole life cycle cost of the project, increase the profit, more satisfaction and better value for employer, and provide reliability and certainty of project, which helps to achieve the sustainability of future project and minimise the termination of the existing projects. However, termination of staff employment can be addressed leanly as improve the cooperation between project participants, and increase employee satisfaction. The implementation of lean will assist to minimise sudden risks that minimise most of the difficulties arising from COVID-19 impact. Accordingly, the majority of these problems can be resolved through lean construction with continuous improvement throughout the project.

6. Conclusion

The hit of COVID-19 pandemic alarm the construction industries in investigating the process improvement methodologies to minimise the impact to the construction projects. Many researchers emphasised the need of discovering new operations during the new normalcy. Accordingly, a comprehensive literature review was carried out to explore the ability of lean construction to resilient the impacts of COVID-19 on the construction industry. The impact of COVID-19 to construction industry is categorised under resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues. Accordingly, 67 factors were identified under eight categories. Scarcity in material, supply chain disruptions, shortage in the workforce, on project completion, decrease in productivity, increased in project cost, increase in the exchange rate, and inflation rate, reduction in the number of the project considered as highly affecting impacts to the construction industry. The findings of the study mark the ability of lean to minimise those challenges.

Accordingly, the study revealed a total of 22 lean benefits that can be gained through post-COVID implementation. Decrease the duration of the project, decrease whole life cycle cost of the project, increase in quality of the project, increase health and safety, continuous improvement for the work under any risks, improvement in performance, more satisfaction, and better value for the employer were considered as the main benefits of implementing lean in the current scenario. As there are immense benefits that can be gained through post-COVID lean implementation, the developed conceptual framework can be used as the basis to conduct future research. However, the findings have not been empirically tested for the Sri Lankan context. Therefore, empirical investigation of resilience to COVID-19 through lean construction will be the next phase of this research study.

7. References

Adegbembo, F. T., Bamisaye, O. P. and Aghimien, D. O. (2016) 'Assessment of lean construction practice in the Nigerian construction industry', in *Joint International Conference (JIC) on 21st Century Human Habitat: Issues, Sustainability and Development*, pp. 756–764.

Ahiakwo, O. *et al.* (2013) 'A case study of last planner system implementation in Nigeria', in *21st Annual Conference of the International Group for Lean Construction, IGLC*. Fortaleza, Brazil, pp. 699–707.

Ahmed, S., Hossain, M. M. and Haq, I. (2021) 'Implementation of lean construction in the construction industry in Bangladesh : awareness , benefits and challenges', *International Journal of Building Pathology and Adaptation*, 39(2), pp. 368–406. doi: 10.1108/IJBPA-04-2019-0037.

Akinradewo, O. I. *et al.* (2018) 'Benefits of adopting lean construction technique in the South African construction industry', in *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

Pretoria / Johannesburg, South Africa, pp. 1271–1277.

Al-aomar, R. (2012) 'Analysis of lean construction practices at Abu Dhabi construction industry', *Lean Construction Journal*, pp. 105–121.

Albalkhy, W. and Sweis, R. (2021) 'Barriers to adopting lean construction in the construction industry: a literature review', *International Journal of Lean Six Sigma*, 12(2), pp. 210–236. doi: 10.1108/IJLSS-12-2018-0144.

Alenezi, T. A. N. (2020a) 'Covid-19 Causes Of Delays On Construction Projects In Kuwait', *International Journal Of Engineering Research and General Science*, 8(4), pp. 35–39.

Alenezi, T. A. N. (2020b) 'Minimising The Delay Factors On Construction Projects : A Local Case Study In Kuwait City During Covid-19', *International Journal of Engineering Research and General Science*, 8(5), pp. 5–8.

Alenezi, T. A. N. (2020c) 'The Impact Of Covid-19 On Construction Projects In Kuwait', *International Journal of Engineering Research and General Science*, 8(4), pp. 6–9.

Alsharef, A. *et al.* (2021) 'Early impacts of the COVID-19 pandemic on the United States construction industry', *International Journal of Environmental Research and Public Health*, 18(4), pp. 1–21. doi: 10.3390/ijerph18041559.

Ansah, R. H. and Sorooshian, S. (2017) 'Effect of lean tools to control external environment risks of construction projects', *Sustainable Cities and Society*, 32, pp. 348–356. doi: 10.1016/j.scs.2017.03.027.

Apollo, M. and Miszewska-urbańska, E. (2015) 'Analysis of the increase of construction costs', *Advances in Science and Technology Research Journal*, 9(28), pp. 68–74. doi: 10.12913/22998624/60786.

Aziz, R. F. and Hafez, S. M. (2013) 'Applying lean thinking in construction and performance improvement', *Alexandria Engineering Journal*, 52(4), pp. 679–695. doi: 10.1016/j.aej.2013.04.008.

Babalola, O., Ibem, E. O. and Ezema, I. C. (2019) 'Implementation of lean practices in the construction industry: A systematic review', *Building and Environment*, 148, pp. 34–43. doi: 10.1016/j.buildenv.2018.10.051.

Bajjou, M. S. and Chafi, A. (2018) 'Lean construction implementation in the Moroccan construction industry: Awareness, benefits and barriers', *Journal of Engineering, Design and Technology*, 16(4), pp. 533–556. doi: 10.1108/JEDT-02-2018-0031.

Bsisu, K. A. (2020) 'The Impact of COVID-19 Pandemic on Jordanian Civil Engineers and Construction Industry', *International Journal of Engineering Research and Technology*, 13(5), pp. 828–830.

Espinoza, L. R., Brioso, X. and Herrera, R. F. (2021) 'Applying CBA To decide the best excavation method : scenario during the COVID-19 pandemic', in Alarcon, L. F. and González, V. . (eds) *29th Annual Conference of the International Group for Lean Construction (IGLC29)*. Lima, Peru, pp. 870–879.

Francis, A. and Thomas, A. (2020) 'Exploring the relationship between lean construction and environmental sustainability : A review of existing literature to decipher broader dimensions', *Journal of Cleaner Production*, 252. doi: 10.1016/j.jclepro.2019.119913.

Gamil, Y. and Alhagar, A. (2020) 'The Impact of Pandemic Crisis on the Survival of Construction Industry : A Case of COVID-19', *Mediterranean Journal of Social Sciences*, 11(4), pp. 122–128.

Gao, S. and Low, S. P. (2014) 'Impact of Toyota Way Implementation on Performance of Large Chinese Construction Firms', *Journal of Professional Issues in Engineering Education and Practice*, 140(3).

Ghandour, A. (2020) 'The impact of COVID-19 on project delivery : a perspective from the construction sector in the united arab emirates', *Humanities & Social Sciences Reviews*, 8(5), pp. 169–177.

Inoue, H. and Todo, Y. (2020) 'The propagation of economic impacts through supply chains : The case of a mega-city lockdown to prevent the spread of COVID-', *PLoS ONE*, 15(9), pp. 1–10. doi: 10.1371/journal.pone.0239251.

Kawmudi, W. N. *et al.* (2020) 'Identification of the Challenges Imposed by COVID-19 Pandemic on Sri Lankan Construction Projects', in *13th International Research Conference of General Sir John Kotelawala Defence University*, pp. 35–44.

Khodeir, L. M. and Othman, R. (2018) 'Examining the interaction between lean and sustainability principles in the management process of AEC industry', *Ain Shams Engineering Journal*, 9(4), pp. 1627–1634. doi: 10.1016/j.asej.2016.12.005.

King, S. S. *et al.* (2021) 'Mechanisms for addressing the impact of COVID-19 on infrastructure projects', in *IOP Conference Series: Earth and Environmental Science*. doi: 10.1088/1755-1315/682/1/012047.

Locatelli, G. *et al.* (2013) 'Improving Projects Performance With Lean Construction : State Of The Art , Applicability And Impacts', *Organization, Technology & Management in Construction: An International Journal*, 5, pp. 775–783. doi: 10.5592/otmcj.2013.2.2.

Lu, H., Stratton, C. W. and Tang, Y. W. (2020) 'Outbreak of pneumonia of unknown etiology in Wuhan , China : The mystery and the miracle', *Journal of Medical Virology*, 92(4), pp. 401–402. doi: 10.1002/jmv.25678.

Marhani, M. A. *et al.* (2012) 'Lean Construction : Towards enhancing sustainable construction in Malaysia', *Procedia - Social and Behavioral Sciences*, 68, pp. 87–98. doi: 10.1016/j.sbspro.2012.12.209.

Marhani, M. A. *et al.* (2013) 'Sustainability Through Lean Construction Approach: A Literature Review', *Procedia - Social and Behavioral Sciences*, 101, pp. 90–99. doi: 10.1016/j.sbspro.2013.07.182.

Mchugh, K., Patel, V. and Dave, B. (2021) 'role of a digital last planner ® system to ensuring safe and productive workforce and workflow in COVID-19 pandemic', in *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC29)*. Lima, Peru, pp. 87–96.

Mohammadi, A. *et al.* (2020) 'Applying lean construction principles in road maintenance planning and scheduling and scheduling', *International Journal of Construction Management*, 0(0), pp. 1–11. doi: 10.1080/15623599.2020.1788758.

Mohan, S. B. and Iyer, S. (2005) 'Effectiveness of lean principles in construction', in *13th International Group for Lean Construction Conference: Proceedings*. Sydney, Australia, pp. 421–429.

Mossman, A. (2009) 'Forum essay Why isn ' t the UK construction industry going lean with gusto ?', *Lean construction journal*, 5(1), pp. 24–36.

Muhammad, W. M. N. W., Ismail, Z. and Hashim, A. E. (2013) 'Exploring Lean Construction Components for Malaysian Construction Industry', in *Business Engineering and Industrial Applications Colloquium (BEIAC), 2013 IEEE*, pp. 7–9. doi: 10.1109/BEIAC.2013.6560091.

Nicola, M. *et al.* (2020) 'The socio-economic implications of the coronavirus pandemic (COVID-19): A review', *International Journal of Surgery*, 78(April), pp. 185–193. doi: 10.1016/j.ijsu.2020.04.018.

Oey, E. and Lim, J. (2021) 'Challenges and action plans in construction sector owing to COVID-19 pandemic – a case in Indonesia real estates', *International Journal of Lean Six Sigma*. doi: 10.1108/IJLSS-09-2020-0149.

Ogunbiyi, O. (2014) *Implementation of the Lean Approach in Sustainable Construction : A Conceptual Framework by Oyedolapo Ogunbiyi*. University of Central Lancashire, Lancashire, UK,.

Ogunbiyi, O., Goulding, J. S. and Oladapo, A. (2014) 'An empirical study of the impact of lean construction techniques on sustainable construction in the UK', *Construction Innovation*, 14(1), pp. 88–107. doi: 10.1108/CI-08-2012-0045.

Ogunnusi, M. *et al.* (2020) 'COVID-19 Pandemic : The Effects and Prospects in the Construction Industry', *International Journal of Real Estate Studies*, 14(November), pp. 120–123.

Osuizugbo, I. C. (2020) 'Disruptions and Responses within Nigeria Construction Industry amid COVID-19 Threat.', *Covenant Journal of Research in the Built Environment*, 8(2), pp. 37–48.

Pathirana, L. P. D. S. (2020) 'Effect of COVID -19 and Strategic Response : A Review on Sri Lankan Construction Industry', *SSRG International Journal of Economics and Management Studies (SSRG-IJEMS)*, 7(6-june), pp. 73–77. doi: 10.14445/23939125/IJEMS-V7I6P110.

Pradeepkumar, C. and Loganathan, S. (2015) 'A Study on Minimization of Construction Waste through Lean Construction Principles in Tirupur District , Tamilnadu', *International Journal of Advanced and Innovative Research*, 4(4), pp. 289–292.

Raoufi, M. and Fayek, A. R. (2021) 'Identifying Actions to Control and Mitigate the Effects of the COVID-19 Pandemic on Construction Organizations : Preliminary Findings', *Public Works Management & Policy*, 26(1), pp. 47–55. doi: 10.1177/1087724X20969164.

Sacks, R., Radosavljevic, M. and Barak, R. (2010) 'Automation in Construction Requirements for building information modeling based lean production management systems for construction', *Automation in Construction*, 19(5), pp. 641–655. doi: 10.1016/j.autcon.2010.02.010.

Sarhan, J. G. *et al.* (2017) 'Lean Construction Implementation in the Saudi Arabian Construction Industry', *Construction Economics and Building*, 17(1), pp. 46–69.

Sarhan, S. and Fox, A. (2013) 'Barriers to Implementing Lean Construction in the UK Construction Industry', *The Built & Human Environment Review*, 6(1), pp. 1–17.

Sarkis, J. *et al.* (2020) 'Resources , Conservation & Recycling A brave new world : Lessons from the COVID-19 pandemic for transitioning to sustainable supply and production', *Resources, Conservation & Recycling*, 159(April), p. 104894. doi: 10.1016/j.resconrec.2020.104894.

Smith, J. P. (2015) 'A case study on design science research as a methodology for developing tools to support lean construction efforts', in *Proceedings of IGLC 23 - 23rd Annual Conference of the International Group for Lean Construction*, pp. 517–526.

Sohrabi, C. *et al.* (2020) 'World Health Organization declares global emergency : A review of the 2019 novel coronavirus (COVID-19)', *International Journal of Surgery*, 76(February), pp. 71–76. doi: 10.1016/j.ijsu.2020.02.034.

Solaimani, S. and Sedighi, M. (2020) 'Toward a holistic view on lean sustainable construction : A literature review', *Journal of Cleaner Production*, 248. doi: 10.1016/j.jclepro.2019.119213.

Tezel, A., Koskela, L. and Aziz, Z. (2018) 'Current condition and future directions for lean construction in highways projects: A small and medium-sized enterprises (SMEs) perspective', *International Journal of Project Management*, 36(2), pp. 267–286. doi: 10.1016/j.ijproman.2017.10.004.

Tzortzopoulos, P., Kagioglou, M. & Koskela, L., 2020. Lean construction: Core concepts and new frontiers.. 1st ed. s.l.:Routledge.

Verán-Leigh, D. and Brioso, X. (2021) 'implementation of lean COVID-19 impacts in residential construction projects In Lima , Peru', in *Proc. 29th Annual Conference of the International Group for Lean Construction*. Lima, Peru, pp. 923–932.

Veselovská, L. (2020) 'Supply chain disruptions in the context of early stages of the global COVID-19 outbreak', *Journal of Problems and Perspectives in Management*, 18(2), pp. 490–500. doi: 10.21511/ppm.18(2).2020.40.

Vithana, N. D. I., Bandara, K. and Jayasooriya, S. D. (2020) 'Impact of Covid -19 Pandemic to Construction Industry in Sri Lanka', in *13th International Research Conference General Sir John Kotelawala Defence University*, pp. 161–166.

Yuan, Z. *et al.* (2020) 'Cause Analysis of Hindering On-Site Lean Construction for Prefabricated Buildings and Corresponding Organizational Capability Evaluation', *Advances in Civil Engineering*. doi: https://doi.org/10.1155/2020/8876102.

Zamani, S. He. *et al.* (2021) 'Effect of COVID-19 on building construction projects : Impact and response mechanisms', in *4th National Conference on Wind & Earthquake Engineering*. doi: 10.1088/1755-1315/682/1/012049.

Zhang, L. and Chen, X. (2016) 'Role of Lean Tools in Supporting Knowledge Creation and Performance in Lean Construction', *Procedia Engineering*, 145, pp. 1267–1274. doi: 10.1016/j.proeng.2016.04.163.