Integrating Green, Lean, Agile and Six Sigma Management Strategies into Construction Supply Chain Management

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ABSTRACT

The construction industry is under constant pressure to maintain the continuous improvement in productivity and hence add value to the construction projects. Despite the introduction of various management concepts, methods and approaches, such as Lean Thinking, Supply Chain Management and Lean Construction Management, an integrated construction supply chain management approach that utilises the strengths of multiple existing methods is lacking. This paper proposes a conceptual model of Lean Construction Supply Chain Management (LCSCM) to fill the above-mentioned research gap. The proposed model shall incorporate integrating Green, Lean, Agile and Six Sigma (GLASS) management strategies with the integration management of Construction Supply Chain (CSC) to minimise waste and to improve productivity. The integration of Construction Supply Chain stakeholders promotes collaboration. The integration of GLASS into Construction Supply Chain Management (CSCM) optimises the combined advantages of Green, Lean, Agile and Six Sigma management strategies in CSCM. This more efficient Construction Supply Chain Management approach helps maintain the continuous improvement desired in the construction industry. The proposed novel approach to CSCM, is a contribution of this paper to the body of knowledge. It provides the construction industry with more confidence to widespread the integration of GLASS into CSCM.

Keywords**:** *Lean Construction Supply Chain Management, LCSCM, Construction Supply Chain Management, CSCM, integrated Green, Lean, Agile, Six Sigma Management, GLASS.*

1 INTRODUCTION

Construction started and learned its lean journey from the manufacturing industry. However, few studies have to date, investigated Lean Construction (LC) in both depth and breadth, especially from the perspective of Construction Supply Chain Management (CSCM) (Meng 2019). While previous construction related studies have focused on how to minimise environmental impacts (Green), reduce waste (Lean), increase productivity (Lean), reduce defects (Six Sigma), there have only been a few researches conducted in the integration of Green, Lean and Six Sigma (Thomas & Khanduja 2022).

Construction processes are project-based and thus, they have a beginning and an end. They are provisional in very nature. Complex temporary Construction Supply Chain (CSC) network is hence, formed to manage the construction project. The main reasons underlying cost increases and low productivity in construction processes, is the inefficiency in managing this complex CSC (Le, Phuoc Luong et al. 2021). Therefore, proper management of the CSC is essential to reduce cost and to improve productivity. Construction Supply Chain Management (CSCM) is defined, as the integration management of key construction processes relating to key stakeholders of the Construction Supply Chain (CSC), including client/owner, designer, contractor, subcontractors and suppliers (Milind & Sachin 2015; Pham et al. 2022; Xue et al. 2007). This suggests the necessity for seeking integration within the CSC (Milind & Sachin 2015). However, it is difficult to achieve integration within the CSC due to the structure and the context of the construction industry (Briscoe & Dainty 2005). The importance of CSCM to improve various construction performance at the operational, tactical, and strategic levels has been commonly documented in the literature. This emphasises the focus shift from the internal structure to the external inter-organisational Supply Chain (SC) processes and the collective learning among organisations (Pham et al. 2022). However, the implementation of CSCM has been partial and scattered (Gadde & Dubois 2010; Pham et al. 2022). Given that, CSCM needs to be formulated, organised, and implemented properly, most contractors should deal with inter-

organisational technological and relational issues to effectively manage their CSC (Palaneeswaran et al. 2003).

Despite the introduction of various management concepts, methods, and approaches, such as, Lean Thinking (LT), Supply Chain Management (SCM) and Lean Construction Management (LCM) into the construction industry more than a decade ago, there remains areas for improvement for research and practice into finding better ways of managing the CSC stakeholders to achieve an overall construction project that is 'Lean', without unnecessary wasteful processes and hence increase the project value and productivity.

2 LITERATURE REVIEW

Lean Construction Management (LCM) has been adopted to manage and improve the increasingly complex construction processes. It is utilised in planning, coordinating, and controlling construction processes. It has also been utilised to maximise value, minimise non-value-added activities and eliminate waste. Nevertheless, LCM is no longer sufficient to cope with the increasingly complex construction processes (Sacks, Girolami & Brilakis 2020). Although, the concept of Supply Chain Management (SCM) has been introduced to the realm of Lean, Lean applications to CSCM has been lacking in theory and insufficiently applied in construction practices. The application of Lean Construction (LC) has been limited to project-specific approaches rather than incorporate Lean into CSCM as a central strategy (Koskela, Vrijhoef & Dana Broft 2020).

Many individual companies that adopt lean concepts quickly realise that, whatever gains that are achieved, are limited unless their immediate respective suppliers and other partners in the Supply Chain (SC) have also become lean (Venkataraman & Pinto 2020). Hence, the construction industry has been challenged to move away from its traditional modus operandi towards more collaborative and integrated approaches. Integrated approaches demand that individuals from various organisations work together to achieve common attainable project goals through the sharing of information. This means that, different companies' processes and organisational cultures have to be aligned in a collaborative manner (Baiden, Price & Dainty 2006).

Despite the attention that has been drawn to address the problems in the construction industry's Supply Chain (SC), calling for greater integration of key processes within and among the Construction Supply Chain's (CSC) stakeholders to ensure that better value is delivered to the client, change has been alarmingly slow. Projects are invariably treated as a series of sequential and predominantly separate operations where the individual players have very little stake in or commitment to the long-term success of the resulting construction project (Fearne & Fowler 2006).

2.1 Lack of Integration of Construction Supply Chain Stakeholders

Construction processes are project-based; hence, temporary Construction Supply Chains (CSC) are normally formed to manage the construction projects. The CSC is highly diverse, complex and disjointed (Xie et al. 2022). The construction industry is arguably the least integrated of all the industrial sectors. It is characterised as highly fragmented, lack of trust among clients, main contractors, and subcontractors, having low productivity, cost and time overruns and conflicts. It is widely criticised for its fragmented approach towards the delivery of construction projects and its failure to form effective teams (Le, Phuoc Luong et al. 2021). This has resulted in project delivery inefficiency. Poor performance, delays, errors and process duplications in projects have been attributed to the procurement practices that do not effectively encourage the integration, collaboration, coordination, and communication among the participants or the Construction Supply Chain stakeholders involved (Le, Phuoc Luong, Chaabane & Dao 2022).

Construction teams, also known as the construction project Supply Chain (SC) networks, are usually complex, interdisciplinary, and temporary, and, as such, the need for effective communication and management is crucial, so that the integration and collaboration among the team members could be achieved. The way in which such temporary organisation, is structured and operated and hence its success, is determined by the communication practice employed. The effective and efficient

management of this temporary CSC network to achieve the integration and collaboration of the CSC is of paramount important. Nonetheless, the construction industry has been slow to engage with the developments in CSCM and the associated changes in the CSC relationship. Arguably, the need to engage more participants of the CSC in more collaborative, or at least less adversarial ways of working must be recognised (Burtonshaw-Gunn & Ritchie 2007).

There is little coordination and collaboration among the CSC stakeholders of design professionals, main contractors, subcontractors and suppliers involved during the life cycle of the construction project (Behera, Mohanty & Prakash 2015). These CSC networks are still characterised as having inefficient collaboration (Le, P. L. et al. 2020). In short, CSCM implementation in the construction industry has been scattered and partial (Gadde & Dubois 2010). The CSCM principles, in their current state, are not yielding the full benefits for and are not adapted well into the construction industry (Le, Phuoc Luong et al. 2021)

The lack of integration of CSC's stakeholders can be illustrated and modelled as shown in Figure 1. Each gear represents a member of the CSC (for the purpose of this paper, only the major stakeholders or players in the CSC, such as the client, the client project manager (PM), the architect, the consultants, the structural engineers, the geotechnical engineers, the main contractor, and the sub-contractors who involve directly in the construction project are included). The lack of alignment and synchronisation of the gears represent the lack of integration and collaboration of the stakeholders of the CSC. This results in an inefficient output or poor productivity.

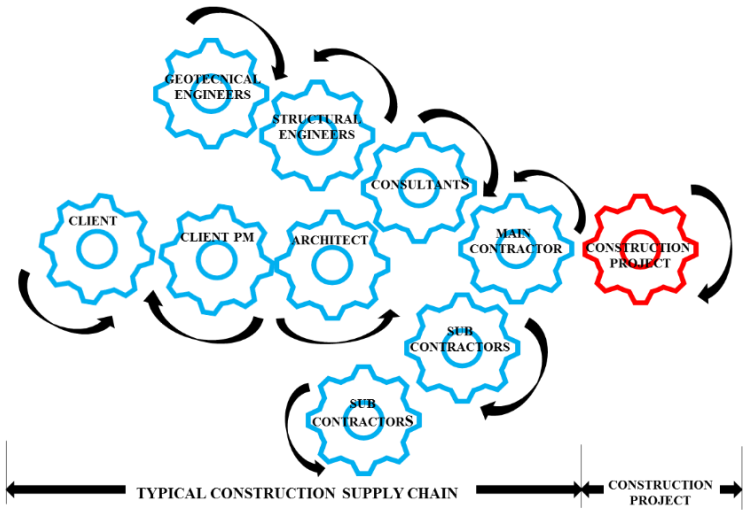

FIGURE 1: ILLUSTRATING LACK OF CSC INTEGRATION (GEARS NOT ALIGNED)

2.2 Lack of Integration of GLASS and CSC

There has been lack of the integration of Green, Lean, Agile and Six Sigma (GLASS) management strategies into the management of Construction Supply Chain (CSC).

Green Construction Supply Chain Management (GCSCM) is about the integration of environmental considerations into all phases of the Construction Supply Chain (CSC) (Carvalho et al. 2020). It aims at reducing the material flows of, and minimising, the inadvertent, detrimental environmental consequences of operational processes, excessive resource consumption, waste generation, improper product disposal and atmospheric emissions**.** The research into Green Construction Supply Chain Management (GCSCM) has lagged behind Green Supply Chain Management (GSCM) in other industries, implying that, GCSCM is an under researched area (Xie et al. 2022).

Lean Management (LM) is also known as Lean Project Management (LPM), which adopts lean fundamentals in Project Management (PM) (Xing et al. 2021). Lean Management (LM) refers to the use of methods, techniques and tools that leads to process improvement by reducing waste and add value to the end customer. Lean Management (LM) is known as Lean Construction (LC) in the construction industry (Nowotarski, Pasławski & Dallasega 2021). Lean Construction (LC) is focused on minimising

waste and in favour of creating maximum value for the client (Di Domenico 2020). Lean Construction (LC) is also about the continuous improvement in pursuit of excellence and perfection throughout the construction process. Few studies to date provide evidence for the integration of Lean Construction (LC) and Construction Supply Chain Management (CSCM), namely, Lean Construction Supply Chain Management (LCSCM). As a result, there is a doubt about Lean Management (LM) in the context of Construction Supply Chain (CSC) (Meng 2019).

Agile Management serves to creating the possibility for fast, effective response to non-expected changes, (Pasławski & Rudnicki 2021). Whereas, Agile Project Management (APM) is the ability of the project team to modify the plan of a project in response to clients' requirements, technological changes and market conditions to achieve better project performance within an innovative and dynamic project environment (Conforto et al. 2016).

The journey for an organisation to achieve greater agility is dynamic and ongoing. It is a transformation that engages people, enhances culture and improves processes so to enable the organisation to adapt rapidly and be nimbler to new opportunities and challenges (Chia, Tung & Yong 2022). Although different frameworks have been proposed over the years for the adoption of agile methodologies in construction projects the scale of adoption has been extremely limited. (Chathuranga et al. 2023).

Six Sigma is about reduction or elimination of defect and continuous improvement. Its aim is to achieve less than 3.4 defects out of a million opportunities, almost perfection. Six Sigma has been applied to various industries, such as, information system, finance, legal, human resource, public affairs, research and development, environmental, health and safety. It could also be applied to the construction industry.

The Six Sigma methodology is to achieving and maintaining quality which has massively grown over the years and which is also an ongoing process (Salih, Mahmoud & Khalaf 2020). Although a large number of studies have successfully addressed the concept of quality (Six Sigma) in construction, the research on the use of Six Sigma as a strategy for process improvement in construction is limited (Siddiqui et al. 2016).

Agile supply networks emphasise on responsiveness and flexibility to changes while lean supply networks emphasise on efficiency (Slack, Brandon-Jones & Burgess 2022). According to Lalmi et al 2022, few studies of the concept of combining Traditional, Agile and Lean approaches in the construction industry have been discussed in the literature, suggesting it is a new concept in construction projects.

Lean, Six Sigma (LSS) is a holistic methodology that maximises value by achieving the fastest rate of improvements in customers' satisfaction, cost, process speed, invested capital and quality. It is based on systems approach and considers the whole supply chain. LSS is utilised to eliminate waste and deliver products and services of high quality. LSS incorporates the principles of Lean and the defect free principles from Six Sigma (Nascimento et al. 2020)

While green and lean approaches have gained momentum as vital concepts in effective business processes, less attention has focused on the integration of Green Construction Process (GCP), Lean Construction Process (LCP) and Six Sigma Construction Process (SSCP) (Hussain et al. 2019). The concept of Green, Lean and Six Sigma (GLSS) have already been known to the academics. The concept of Integrated sustainable Green, Lean, Six Sigma and Agile manufacturing system (ISGLSAMS) has also been known to the manufacturing sector (Hariyani & Mishra 2024). However, the concept of GLSS has only gained momentum in the construction industry recently all over the world (Thomas & Khanduja 2022). Literature reviews that, researchers have focussed on applying Green practices, Lean practices and Six Sigma practices (Salih, Mahmoud & Khalaf 2020) individually in the construction processes. The integration of GLSS is beneficial to overcome the limitations of individual application of GLSS. It combines the benefits of Green, Lean and Six Sigma to mitigate the environmental impacts by reducing carbon footprint, rejection rates and producing high quality products and profits (Kaswan & Rathi 2020a). Although, several benefits in terms of waste reduction, performance improvement and productivity have been achieved via Green, Lean and Six Sigma (GLSS) individually, there have been very few pieces of literature, report on the combined benefits and integration of GLSS (Thomas &

Khanduja 2022). The compatibility of the integration of Green and Lean (GL), and the integration of Lean and Six Sigma (LSS) to improving the environmental, operational performance, and further maximising the profit and competitiveness of the business have been proven in numerous studies. This proposes the compatibility of the combined approaches of Green, Lean and Six Sigma (GLSS) (Gholami et al. 2021).

The studies of the integration of Green and Lean (GL) and the integration of Lean and Six Sigma (LSS) to improve environmental and operational performance, were mainly applied (if any, on the construction industry) on the construction project levels, rather than on the Construction Supply Chain Management. The purpose of this paper, is to propose the application of these integration strategies, more specifically, the integration of Green, Lean, Agile and Six Sigma management strategies into the integration of Construction Supply Chain (CSC). If their combined benefits could be realised on the construction levels, they should also be realised in Construction Supply Chain. These will result in a greater and true combined benefits if, all the members of the Construction Supply Chain are integrated and hence collaborated, adopting the integration of GLASS management strategies. There are no studies to date that combined the benefits of GLASS and integrate GLASS into CSC. Hence, this paper proposes a model of the integration of Green, Lean, Agile and Six Sigma management strategies with Construction Supply Chain.

The lack of integration of GLASS and CSC could be illustrated in Figure 2. If gears collection on the left represents Green Management, Lean Management, Agile Management, Six Sigma Management and Construction Supply Chain (CSC) respectively, the misalignment interrupts efficient functioning of CSC.

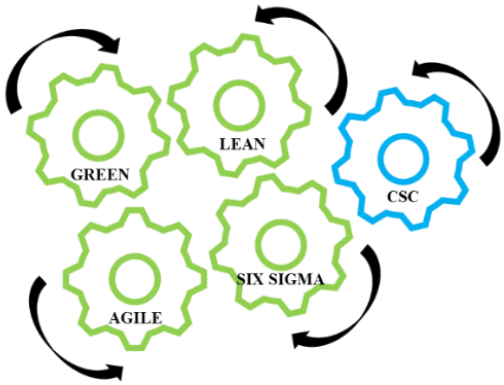

FIGURE 2: LACK OF INTEGRATION OF GLASS AND CSC (GEARS NOT ALIGNED)

3 PROPOSED FRAMEWORK

Construction industry is faced with the problem of continuous improvement**.** This paper provides a solution, based on the discussions above, by proposing a model of Construction Supply Chain Management (CSCM). It proposes the development of a novel, integrated framework that combines the advantages of Green, Lean, Agile and Six Sigma Management strategies (GLASS) incorporated into Construction Supply Chain Management (CSCM) to manage the whole Construction Supply Chain (CSC).

The construction process is improved by implementing Green, Lean, Six Sigma management strategies (GLSS) (Banawi & Bilec 2014). The combined benefits of GLSS can be achieved by the integration of GLSS and this will overcome the limitations of individual application of Green, Lean and Six Sigma (Hussain et al. 2023; Kaswan & Rathi 2020a).

The integration model will promote collaboration among the Construction Supply Chain Stakeholders. This proposed research's outcome promotes harmony and ensure longevity on the Construction Supply Chain relationship. The Lean Construction Supply Chain Management approach will increase construction productivity by reducing wasteful activities and hence add value to the construction projects.

Green, Lean, Agile, and Six Sigma (GLASS) are complementary in the integration. Figure 3 below depicts the concept of the integration of GLASS. Integration is the process of combining two or more things, so that they work together. The integration of Green, Lean, Agile and Six Sigma management strategies, are thus, amalgamated into one new management strategy, namely, the GLASS (a term, which is coined by the author) management strategy. Therefore, each method has the potential to minimise the disadvantages of the others (Banawi & Bilec 2014). Lean is valued for its ability to identify waste (Lapinski, Horman & Riley 2006) (Klotz, Horman & Bodenschatz 2007), however, it does not quantify environmental consequences. Green can fill the gap and evaluate the impact of the generated waste (Li, Zhu & Zhang 2010). Together, Lean and Green have the ability to identify waste and evaluate the environmental impact, but they often do not provide an actual method to reduce waste. Six Sigma has the potential to fill this gap (Han et al. 2008). Nevertheless, to date, there have been limited researches on how to combine Green, Lean and Six Sigma into managing construction projects (Banawi & Bilec 2014) and there have not been any researches conducted on how to combine or integrate GLASS management techniques into managing the Construction Supply Chain (CSC) or into Construction Supply Chain Management (CSCM).

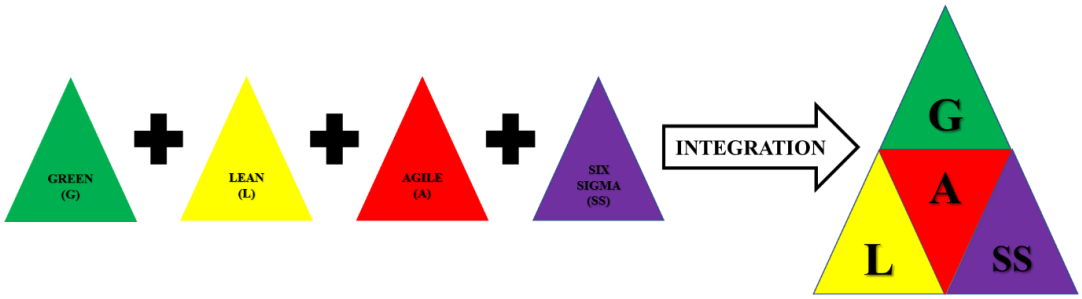

FIGURE 3: INTEGRATION OF GLASS

This paper suggests that the integrated CSC that adopts the integration management strategies of Green, aims at minimising environmental impact; Lean, aims at reducing or eliminating waste and promoting continuous improvement; Agile, being responsive and flexible; and Six Sigma, aims at minimising the defective outcomes and promoting quality improvement, would increase the value of the overall construction project. This is demonstrated by the integration of GLSS is beneficial to overcome the limitations of individual application of GLSS (Kaswan & Rathi 2020a, 2020b). It combines the benefits of Green, Lean and Six Sigma to mitigate the environmental impacts by reducing carbon footprint, rejection rates and producing high quality products and profits (Kaswan & Rathi 2020a). This proposes the compatibility of the combined approaches of Green, Lean and Six Sigma (GLSS) (Gholami et al.

2021)**.** There are no studies to date, that combined the benefits of the integration of GLASS into CSCM. Hence, this paper proposes a CSCM model of an integrated GLASS management strategies into an integrated CSC to fill this research gap. The analyses of the benefits of the integration of GLASS management strategies are illustrated in table 1 below. The attributes and characteristics of Green, Lean, Agile and Six Sigma are listed. When Green, Lean, Agile and Six Sigma management strategies are used but not integrated, only the common benefits are realised, as illustrated in figure 9 below. When Green, Lean, Agile and Six Sigma management strategies are integrated, all the combined benefits of GLASS are realised, as illustrated in figure 10 below.

TABLE 1: ANALYSING THE BENEFITS OF GLASS

ATTRIBUTES	Green	Lean	Agile	Six Sigma	Combining GLASS but applying Individually	Integrating GLASS
Eco-friendly methods	✓					✓
Decrease environmental impact	✓					✓
Reduce / eliminate waste generation	✓	✓				✓
Reduce non-value-added activities		✓				✓
Enhance performance	✓	✓				✓
Enhance quality	✓	✓	✓	✓	✓	✓
Fast, effective response to non-expected changes			✓			✓
Continuous improvement	✓	✓	✓	✓	✓	✓
Identify waste	✓	✓				✓
Evaluate the impact of the generated waste	✓	✓				✓
Reduction or elimination of defects/wastes				✓		✓
Improves productivity		✓	✓			✓

Therefore, the integration of GLASS into CSCM optimises the advantages of Green, Lean, Agile and Six Sigma management strategies in CSCM, is confirmed through the above literature review and analyses.

3.1 Integration of Construction Supply Chain (CSC)

The problem of lack of integration of Construction Supply Chain (CSC) is identified through literature review. A solution is proposed by developing a model. The proposed model of the integrated CSC could be illustrated or modelled as in Figure 4 below. Each of the gear represents a member of the CSC. The arrows represent the direction of turning of the gears. The gears are all well aligned and synchronised. This signifies that, all the gears are working harmoniously as a whole. This represents all the stakeholders are brought together to working as one whole unit. This synergy is better than the sum of all the stakeholders' efforts working individually. This will result in a high efficiency output.

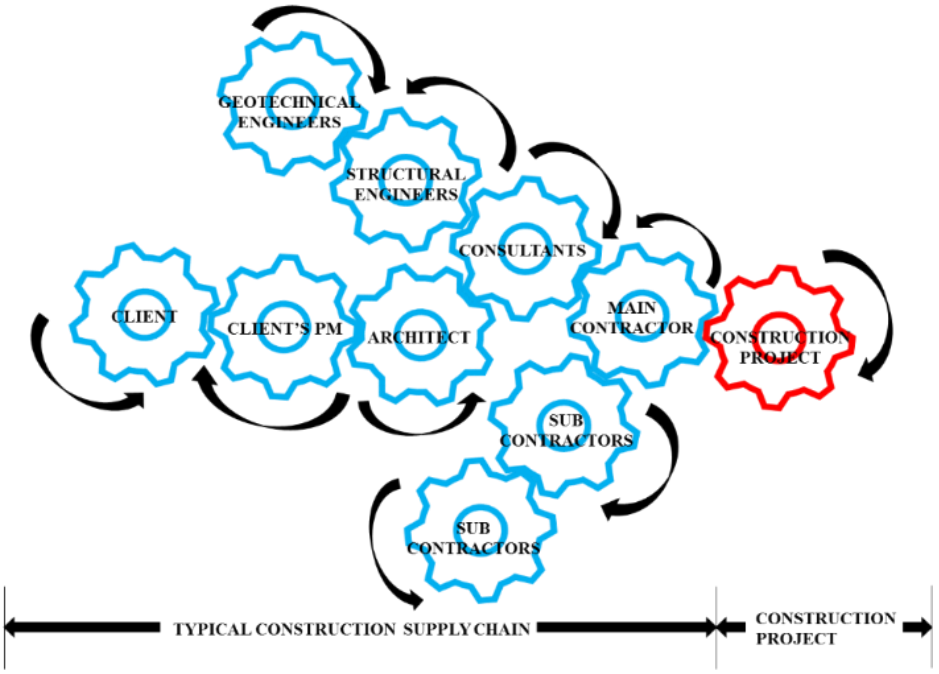

FIGURE 4: AN INTEGRATED CSC (ALL GEARS ARE ALIGNED AND SYNCHRONISED)

3.2 Integration of GLASS and CSC

The proposed model of the integration of GLASS and CSC could be modelled as in Figure 5. Each of the gear represents Green Management, Lean Management, Agile Management, Six Sigma Management and CSC, respectively. The gears are all well aligned and synchronised. This will result in a highly efficient output.

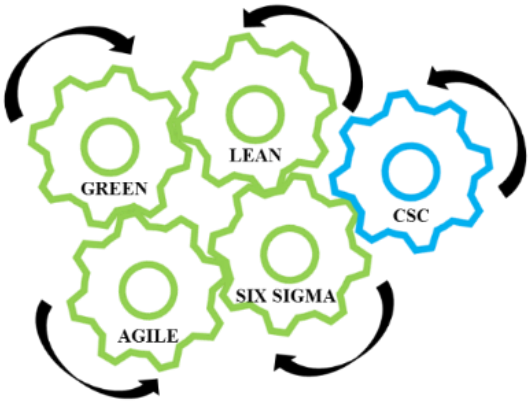

FIGURE 5: INTEGRATION OF GLASS AND CSC (ALL GEARS ARE ALIGNED AND SYNCHRONISED)

3.3 Integrated CSCM Model

The proposed conceptual model is,
'The integrated management approach of CSC, integrated with the GLASS supply chain management strategies, would reduce waste, add value and improve the productivity of the construction project'.

The following figures illustrate the integration of GLASS and CSCM. Figure 6 illustrates the proposed model of the integrated and collaborating CSC entities that work harmoniously as a united entity. All the gears are aligned and synchronised which is represented by one single gear.

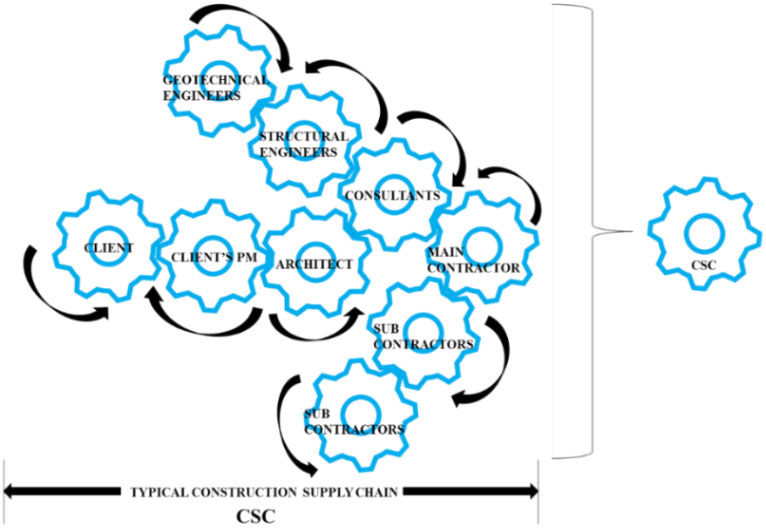

FIGURE 6: REPRESENTING THE INTEGRATION OF CSC WITH ONE GEAR

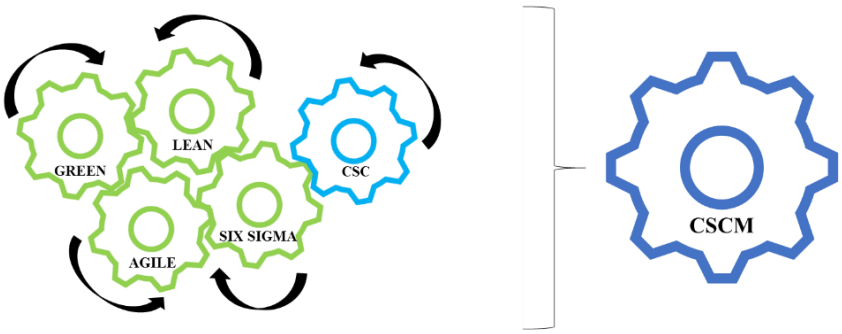

FIGURE 7: REPRESENTING THE CSCM WITH ONE GEAR

Figure 7 illustrates the proposed model of Construction Supply Chain Management (CSCM). It is the integrated Construction Supply Chain (CSC), integrated with GLASS concepts. The figure illustrates that all the gears are well aligned and synchronised that will spin as a united one.

Figure 8 illustrates the proposed final model of the harmonious CSCM strategy that will manage and handle the construction project more efficiently, effectively, and productively. It illustrates with all the gears representing CSC, and GLASS are well aligned and synchronised within the bigger gear, which represent CSCM. It signifies that CSCM should be powered by the integrated CSC, and GLASS, a CSCM strategy. This will definitely be more efficient, effective and productive.

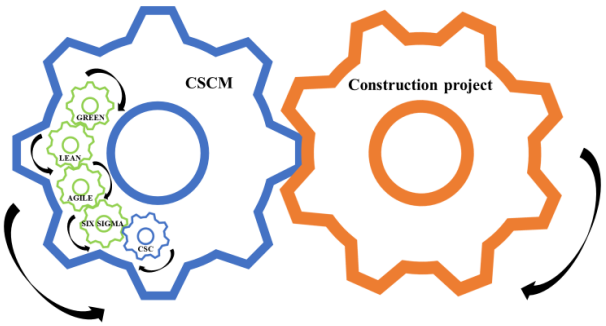

FIGURE 8: THE INTEGRATION OF GLASS, AND CSC INTO CSCM WILL POWER CONSTRUCTION MORE EFFICIENTLY (ALL GEARS ARE ALIGNED AND SYNCHRONISED)

4 CONCLUSION

The planning, design and construction of buildings and other physical infrastructure projects generally involve complex and fragmented activities requiring the inputs of several professionals and non-professionals resulting in cumbersome coordination requirements (Babalola, Ibem & Ezema 2019). Consequently, the construction industry is confronted with challenges associated with the inclusion of non-value adding activities and processes in its supply chain resulting in inefficiency and low productivity.

There have not been any structured and complete methods and models for the integration of Green, Lean, Agile and Six Sigma found in the literature (Kaswan & Rathi 2020a). The benefits in terms of waste reduction, improved productivity and performance have been achieved through Green, Lean and Six Sigma (GLSS) individually (Thomas & Khanduja 2022). The present paper proposes a theoretical integration model of Green, Lean, Agile and Six Sigma (GLASS) management strategies, integrated with the Construction Supply Chain (CSC). Figure 9 below depicts the use of Green, Lean, Agile and Six Sigma (GLASS) management strategies but there is no integration. Whereas, Figure 10 depicts the model of the integration of Green, Lean, Agile and Six Sigma (GLASS) management strategies, the combined benefits of GLASS is realised.

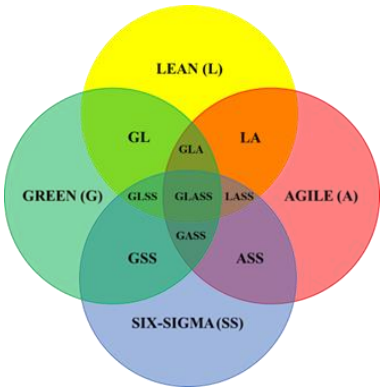

FIGURE 9: THE MODEL OF GREEN, LEAN, AGILE AND SIX SIGMA MANAGEMENT STRATEGIES ARE USED BUT ARE NOT INTEGRATED

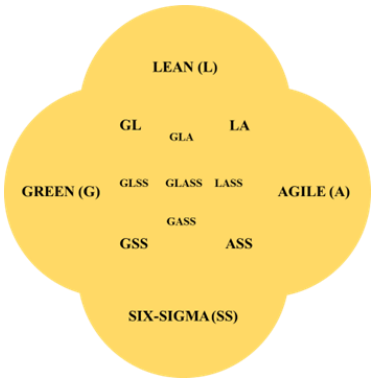

FIGURE 10: THE INTEGRATION MODEL OF GREEN, LEAN, AGILE AND SIX SIGMA MANAGEMENT STRATEGIES (GLASS), ILLUSTRATING THE COMBINED BENEFITS OF GLASS

The integration model will promote collaboration among the Construction Supply Chain Stakeholders. This outcome promotes harmony and ensure longevity on the Construction Supply Chain relationship. The Lean Construction Supply Chain Management approach will increase construction productivity by reducing wasteful activities and hence add value to the construction projects.

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