Exploring the Implementation of Green Lean Six Sigma for Indoor Air Quality Improvement

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Abstract

Attention to the importance of indoor air quality (IAQ) has increased in recent years. It is a topic that has grabbed the interest of scholars, researchers, and the public. Unfortunately, research shows that many indoor locations such as houses, nurseries, schools and offices have been suffering from unhealthy indoor air. Current literature shows that the most significant indoor air contaminants are CO_2, CO, NO_2, O_3, TVOCs, and particular matter along with thermal conditions such as temperature and humidity. The presence of those contaminants affects human health negatively. While different methods to improve indoor air do exist today, yet there is no one best solution. Green Lean Six Sigma (GLSS) frameworks has been used successfully to tackle the problems related to environmental issues in different fields. Accordingly, this paper tries to address a core question of the possibility of applying GLSS approach to improve indoor air quality within various facilities. The definition of GLSS and an overview of the developed GLSS frameworks and their applications will be presented through a review of the relevant articles available in the literature. The findings will highlight possible challenges and featured strong promising research opportunities regarding the use of GLSS approach to improve indoor air quality. The major finding is that there is a lack of implementation of GLSS in different fields and exploring new fields will most probably show positive feedback.

Keywords
Green Lean Six Sigma, Indoor air quality, air quality frameworks, sustainability and systematic review.

1. Introduction
Clean air is an essential requirement to life and vital for people's well-being. For that reason, the quality of the air is a major concern to many researchers. Research indicate that 91% of the world's population live in places where air quality levels exceed World Health Organization limits, although it has been proven that individuals in developed countries spend almost 90% of their time indoor (World Health Organization (WHO) 2014) (Beig et al. 2019). Air quality is one of the pillars of indoor environment, which is one of the top five environmental risks to public health (Asere and Blumberga 2020). Thus, it is said that ensuring a good quality indoor air works on reducing the health problems that children and adults may face throughout the years.

In general, clean air is measured by how far the air is free from harmful pollutants. The balance between indoor air pollutants and outdoor air pollutants is a matter of building tightness, construction materials, road traffic, cooking appliance, lifestyle habits, and personal activities of the occupants (Funk et al. 2014). Indoor air includes particles that penetrates from outdoor air, along with particles that results from occupants' behaviors such as indoor activities including cleaning, cooling etc. (Khaki et al. 2020). Indoor air can be categorized into physical properties, chemical properties and adverse health effects (Khaki et al. 2020). Chemical properties include pollutants such as Carbon Dioxide (CO_2), Carbon Monoxide (CO), Formaldehyde, Nitrogen Dioxide (NO_2), Ozone (O_3), Total Volatile Organic Compounds (TVOC), Airborne Particulate Matters Smaller than 2.5 μm in Diameter Suspended in the Air (PM2.5), Airborne Particulate Matters with a diameter less than 10 μm (PM10), dust and some other industrial or agriculture pollutants (Schütze et al. 2020) (Khaki et al. 2020). Those pollutants are considered frequent pollutants that are contributing to weakening the indoor air quality (Jones 2017). Moreover, physical properties include particle and fibers such as asbestos (Khaki et al., 2020). In addition to, humidity and temperature (Van Tran et al. 2020). Finally, examples of adverse health effects include eye irritation.

Different frameworks, methods and strategies has been used to improve IAQ. Solutions varied from applying interventions such as the one discussed by Ballard- Tremeer and Mathee (2000) to move from using wood or charcoal as energy sources to Kerosene, LPG, biogas, or Grid electricity. Furthermore, three main approaches to improve IAQ are control of emission sources, development of air purification technologies, and improvement of ventilation systems (Van Tran et al. 2020). In addition, adopting Heating, ventilation, and air conditioning filters is considered one of the solutions. Nevertheless, intelligent homes is considered as a promising solution for the improvement of IAQ (Patil et al. 2019; Van Tran et al. 2020). However, there is still a shortage on an overall solution that fits all cases. In addition, many solutions does not provide long term advantage such as the air filters which falls in long term (Van Tran et al. 2020). Mostly the drawbacks in the solutions are related to the fact that the solutions are mainly to certain households or indoor situation. For example related to the type of heating used indoors (Ballard-Tremeer and Mathee 2000). In addition, some solutions increase the emissions of certain pollutants for example CO_2. Exploring new methods such as GLSS in improving IAQ will be discussed in this paper. In the current paper, GLSS methods has been highlighted based on systematic literature review. This Paper will be following this structure: first, research objectives; second, a high-level explanation of the research methodology; third, literature review; fourth, research gaps has been highlighted and finally, discussion and conclusion.

2. Core question of this review

The purpose of this paper is to present and appraise the previous efforts done in developing GLSS frameworks to address various environment and sustainability issues. The focus then is tailored to explore relevant literature gaps and the possibility of applying GLSS to solve the IAQ improvement problem.

3. Review Methodology

Having the above core question formulated, a systematic review methodology is used in this research that involved the following steps:

   A. A search of the literature using the following search keywords, Green Lean Six Sigma, Indoor air quality, air quality frameworks, Sustainability, Systematic Review was undertaken in search engines and databases such as google scholar, science direct, Scopus, and Emerald.
   B. Included articles are the ones that resulted from the keywords, published in English mainly from the years 2010-2022, and directly related to the research objectives.
   C. The research gaps, discussion, and conclusions will be presented based on the results of the literature review. Figure 1 represent the summary of the methodology followed in the review process.
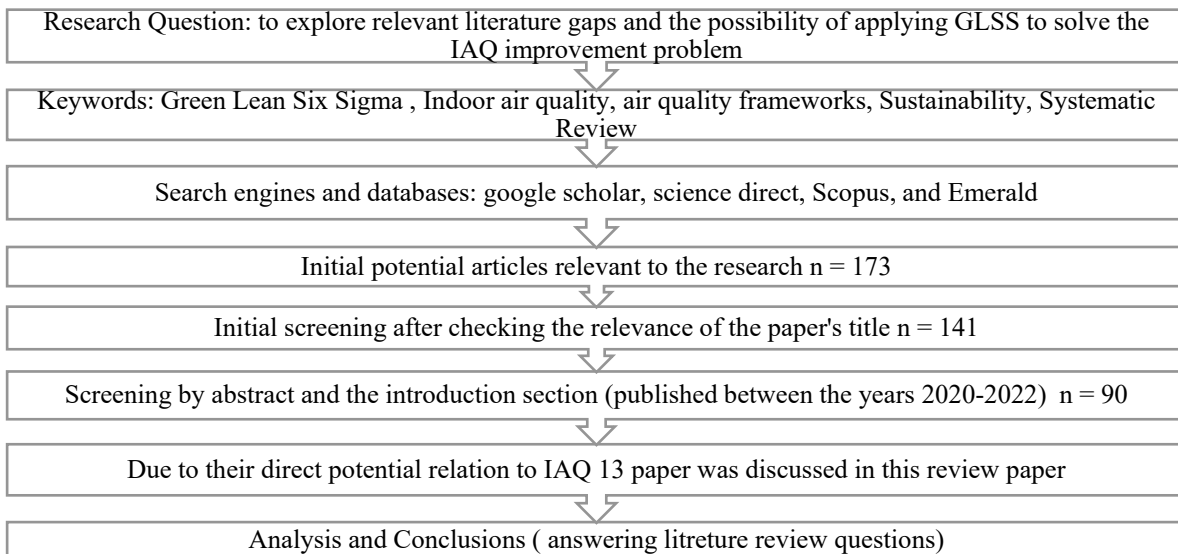
| Research Question: to explore relevant literature gaps and the possibility of applying GLSS to solve the IAQ improvement problem |
| Keywords: Green Lean Six Sigma , Indoor air quality, air quality frameworks, Sustainability, Systematic Review |
| Search engines and databases: google scholar, science direct, Scopus, and Emerald |
| Initial potential articles relevant to the research n = 173 |
| Initial screening after checking the relevance of the paper's title n = 141 |
| Screening by abstract and the introduction section (published between the years 2020-2022) n = 90 |
| Due to their direct potential relation to IAQ 13 paper was discussed in this review paper |
| Analysis and Conclusions (answering litreture review questions) |

Figure 1. Review of Methodology

4. Review of selected literature

This section will cover the previous work in defining indoor air and indoor air quality, its pollutants, the definition of GLSS and frameworks that has applied previously utilizing GLSS and finally the gaps in literature review.

4.1 Importance of Indoor Air Quality

Indoor air quality (IAQ) is defined as the quality of air within or around the buildings (United States Environmental Protection Agency (US EPA) 2019). Human exposure to air pollutants may have negative effects on the well-being of the occupants (Ahmed et al. 2015). Pollutants generated indoors can lead to a variety of symptoms and health conditions, especially that people spend almost 90% of their time indoors. Indoor air pollutants can affect occupant in three different ways: inhalation, through the skin and ingestion. Thus, it is significantly important to understand, analyze and reduce the indoor air pollutants.

IAQ is affected by three groups of pollutants: outdoor air pollutants, occupant related pollutants, and building pollutants (Schieweck et al. 2018). It is said that to maintain an IAQ the outdoor air should be fairly free of contaminations (Persily 2015). Most studies related to indoor pollutants considers volatile organic compounds (VOCs), formaldehyde, and carbon dioxide (CO_2) when studying IAQ (Wenjuan Wei and Ramalho 2015). Moreover, CO_2 is observed in 65% of the green buildings certificates as an indoor air pollutant (Wenjuan Wei and Olivier Ramalho 2015). Furthermore, Khaki et al. mentions that IAQ is mainly affected by NO_2, formaldehyde (HCHO), CO, SO_2, total volatile organic compounds (TVOCs) and airborne particulate matters (PM) (i.e. PM 2.5 and PM 10) (Khaki et al. 2020).

4.2 Environmental Aspects and Environmental Performance

Environmental aspects are defined as the way an activity, service or product affects the environment. Environmental aspect is one of the pillars of ISO 14001 and it is defined as "an element of an organization's activities, products, or services that has or may have an impact on the environment" (*ISO 14001 environmental aspects:* 4 steps in identification and evaluation of environmental aspects, n.d). While Environmental performance is defined as the method, in which green initiatives can be measured. Figure 2. Represents the measures used for environmental performance.
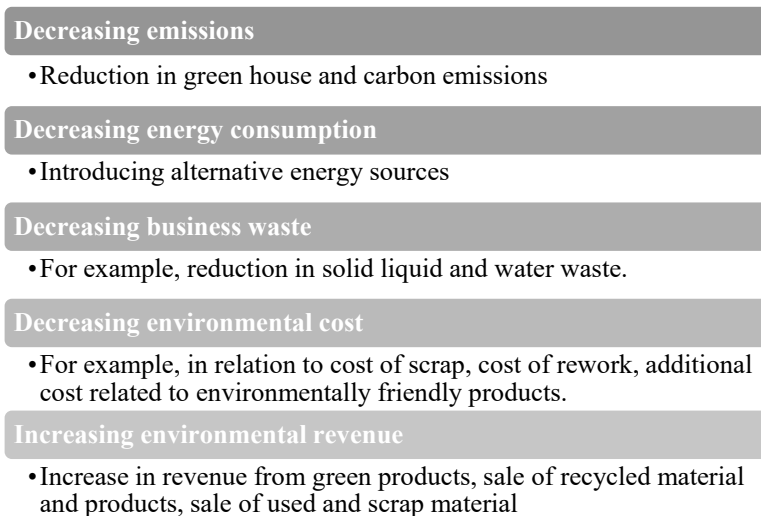
Decreasing emissions

- Reduction in green house and carbon emissions

Decreasing energy consumption

- Introducing alternative energy sources

Decreasing business waste

- For example, reduction in solid liquid and water waste.

Decreasing environmental cost

- For example, in relation to cost of scrap, cost of rework, additional cost related to environmentally friendly products.

Increasing environmental revenue

- Increase in revenue from green products, sale of recycled material and products, sale of used and scrap material

Figure 2. Measures for environmental performance adapted from (Sagnak and Kazancoglu 2016) .

4.3 Green Lean Six Sigma

Six Sigma works on identifying and reducing variation (Sony and Naik 2020). Generally, DMIAC (Define-Measure-Improve-Analyze-Control) methodology is used in Six Sigma. Manufacturing is considered as the major sector in which Six Sigma has been implemented. Although Six Sigma is considered beneficial in reducing variation, it lacks

in reducing waste. Waste such as such overproduction, waste of rework, transportation waste, waiting time, inventory, processing waste, defects waste, and waste of motion was first identified by Haiiachi Ohno (Lander and Liker 2007). The target of reducing waste let to the introduction of Lean. Lean as a concept focuses on increasing efficiency in the procedures and reducing waste (Pierce and Dalal 2019). Lean does not consider environmental impact, and does not quantify environmental consequences, and this is considered as drawback in Lean (Fatemi and Franchetti 2016); (Banawi and Bilec 2014). Both Six Sigma and Lean have common practices on identifying errors and resolving them (Pierce and Dalal 2019). As mentioned by Albliwi et al. (2014), the implementation of the integrated Lean Six Sigma methodology will most probably reduce the waste and variation in a process. Research indicates that the first integration between Lean and Six Sigma occurred in 1986 although the term itself was known in later stages (Albliwi et al. 2014).

Green was introduced to Lean Six Sigma to solve the drawbacks in it related to environmental issues. The main target of Lean is to reduce waste, while the main target of Green is to reduce the environmental impact. To solve the limitations in Lean and Green, Six Sigma was introduced to them. This resulted in the development of Green Lean Six Sigma (GLSS). GLSS is defined as an "approach of sustainable development that enhances the profitability dynamics of the industry through the reduction of wastes, emission and variations in the process" (Kaswan and Rathi 2020). As mentioned in literature, Lean Six Sigma are one of the most known business strategies to improve manufacturing, services, and public sectors. Thus, applying GLSS enables organizations, decision makers and entities to add an environmental prospective to their targets or goal.

Due to the development of GLSS researchers started to use it in the development of the GLSS Framework. GLSS considered as a relatively new strategy. It has been utilized in different sectors. Pandey et al. (2018) mentions that frameworks are not enough for implementing GLSS; However, understanding and analyzing the enablers is considered as important (Kaswan and Rathi 2020). Literature mentions different enablers to GLSS. For instance, Kaswan and Rathi (2020) mentioned that in manufacturing field major GLSS enablers are "organizational readiness for GLSS measures together with competence for Green product and process, top management commitment toward sustainable performance improvement, effective performance and feedback measure both at upstream and downstream, organizational ambience, expertise training in GLSS, linking of GLSS to business objectives, and availability of funds with organization". In addition, organizational readiness for in GLSS along with top management commitment toward sustainable performance improvement is some of the enablers of GLSS (Kaswan and Rathi 2020).

4.4 Green Lean Six Sigma frameworks

GLSS is a quality improvement philosophy used to improve process and reduce waste or issues in the process. Frameworks are often implemented to overcome waste and improve processes. Since IAQ can be improved by taking actions to reduce the indoor air pollutants, the process in doing this can be improved so that the quality of indoor air is better. The targeted pollutants are the most common pollutants in indoor air, which are CO_2, CO, NO_2, O_3, TVOCs, and particular matter.

Based on the literature review different frameworks for GLSS were developed by researchers. Although there have been many papers that discussed this topic; the main ones have been summarized in Table 1. The papers mentioned in Table 1 are chosen based on their relative affinity to IAQ. IAQ has not been studied profoundly in a GLSS, and the frameworks working on improving it have not been fully developed. With the target of improving indoor air, the most relevant papers are probably the ones developed by Hussain et al. (2019), Sony and Naik (2020). Although the paper developed by Hussain et al. (2019) is related to the construction industry, however, the barriers identified can be available in indoor air. Hussain et al. (2019) identified 24 barriers such as: lack of training and workshops, inefficient utilization of infrastructure, lack of advanced facilities and technology, lack of customers involvement and awareness, lack of top leadership support, inefficient logistics, lack of communication, inefficient time management, inefficient human resources, and so on. Some of those barriers can be identified as IAQ improvement barriers. Hussain et. al (2019) used a survey to prioritize those barriers based on importance to the construction industry. In addition, the authors suggested using AHP in future studies to prioritize the barriers to the implantation of GLSS in other fields. Furthermore, Sony and Naik (2020) studied GLSS through a case study in a mine in India. This study is more related to IAQ since it aims to reduce indoor pollutants such as dust. Especially that one of the most used solutions to improve IAQ is using air purifiers; however it is proved that in long run this solution can induce the availability of dust and molds (Van Tran et al. 2020).The framework developed by Sony and Naik (2020) depends on five phases which are: phase 1 (specify value): to set the target of the improvement, phase 2 (align the internal value stream): development of an environmental value stream mapping. Phase 3: Create the flow: in which the improvement begins. Phase 4 (pull

on demand): This means taking further action based on the demand. Finally, phase 5 (create perfection) which is the improvements done after analyzing phase 3 (Figure 3).

Table 1 Different frameworks on GLSS

| Author	Major Findings	Sector of Implementation
(Cluzel et al. 2010)	Developed a LSS methodology called eco-design.	Manufacturing
(Besseris 2011)	A model to present how process efficiency and environmental waste are dealt in a lean and green project driven by hardcore LSS tools.	Manufacturing (validated through a case study)
Habidin and Yusof 2012	Investigated the relationship between LSS, organization performance and environmental management systems.	Automotive Industry
Banawi and Bilec 2014	Developed a framework for construction industry. The framework depended on DMIAC model with a number of modifications.	Construction
Garza-Reyes 2015	The author establishes a detailed review on the attributes of Green, Lean and Six Sigma.	General information
Kumar et al. 2016	A conceptual framework has been established on GLSS, barriers on implementing GLSS has been identified. Seven barriers are identified as driver barriers, nine as dependent, and five barriers as linkage.	General information
Sagnak and Kazancoglu 2016	The authors mention the limitation of Green Lean and proposed the introduction of Six Sigma to overcome it. The methodology of this study depended on measurement System Analysis and Gage Control to measure the variations of the process.	Manufacturing
Cherrafi et al. 2017	A framework to implement GLSS in construction industries through a 5- step and 16 stages procedure.	Construction
Sreedharan V, Sandhya and Raju 2018	The barriers in implementing GLSS in public services were explored. The authors developed a framework that depends on three stages that are procurement, production, and distribution.	Public services
Mahender Singh Kaswan 2019	The authors present GLSS enablers identification related to construction industry and modeling using Interpretive Structural Modeling (ISM).	Construction
Hussain et al. 2019	24 barriers related to GLSS were identified in the study.	Construction
Sony and Naik 2020	Created a GLSS framework that relies on organizational culture and depends on 5 major steps: 1. Understands the current organizational culture in relation to green initiatives. 2. Advertise the greening initiatives to each employee in the organization. 3.Implement Lean Six Sigma to every project in the organization 4. Utilize DMAIC. 5. Utilize value stream mapping (VSM).	General information
Kaswan and Rathi 2020	Investigated GLSS based on best - worst method. Suggested that the most critical enablers for implementing GLSS are organizational reediness, top management commitment, and integration of GLSS with organizational objectives	manufacturing field
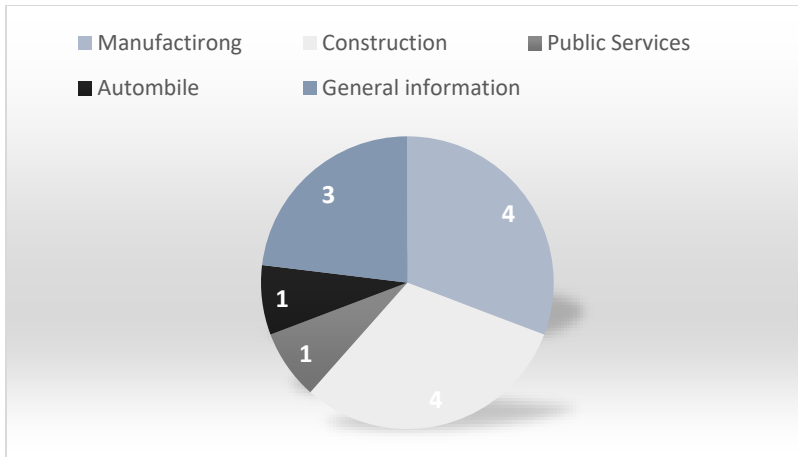
Figure 3. The distribution of papers based on field of study

4.5 Future Orientations for the GLSS related research (Research gaps Harvest)

Most of the papers were justified based on a case study. Research gap was identified based on the papers that has been explored in the literature review. Table 2 presents those gaps.

Table 2. Identified Research gap in Literature review

Author and Year	Context	Tools	Findings	Future work / Gap
Cluzel et al. 2010	Aluminum electrolysis- Manufacturing	-LSS -DMAIC -Life cycle invention analysis -Life cycle impact assessment -Life cycle interpretation	LSS methodology called eco-design	Implementing Analytical Target Cascade- ing
Besseris 2011	Operations	- DMAIC cycle - Design of Experiments	Shows how can Lean and green work together utilizing Six Sigma tools	-
Habidin and Yusof 2012	Automotive industry	- Exploratory Factor Analyses (EFA) - Confirmatory Factor Analysis (CFA) - Reliability analysis	Results shows that ISO 14001 certification does not significantly moderate the relationship between LSS and OP	To find a structural relationship between LSS and other quality management systems
Banawi and Bilec 2014	Construction industry	• DMAIC cycle • VSM was used to represent Lean, while life cycle assessment was used to represent green methodologies.	GLSS offers a comprehensive, multistage approach related to process improvements and minimization of life cycle environmental impacts	To develop a model based on GLSS tools to eliminate waste. by highlighting the process that have a higher potential to produce waste in advance
Kumar et al. 2016	Manufacturing (automobile industry)	- Brainstorming sessions -Experts view and literature review -Interruptive structural modeling	Identified: - Seven barriers are as driver barriers Nine as dependent	Check the usage of the developed model in different sectors

			- Five barriers as linkage barriers	

Sagnak and Kazancoglu 2016	To study the gases emitted	- Measurement System analysis
		- Gage control
			Emphasizes the need to implement Six Sigma when implementing Lean and green	Recommend the use of:
				- DOE
				  - DMIAC cycle,
				  - Process control charts
				  - process capability index
				In future work.

Cherrafi et al. 2017	Four different types of industries	Action Learning cycles: (a) identify general idea; (b) action steps; (c) monitoring implementation and effects; and (d) reconnaissance and summary of learning.	After applying GLSS, results shows that organization where able to reduce consumption by 20-40%	To take the proposed framework to multi-factory and supply chain level
Sony and Naik 2020	Mine in India	Created a framework based on DMIAC cycle and Lean cycle	GLSS framework to Accomplish the green objectives on the five dimensions of environment-al performance	Implement the framework in different field or different context
Tiwari et al. 2020	Manufacturing	- Delphi method for validation - Case study implementation of the framework	The GLSS formwork can improve suitability pillars	-

5. Results

Throughout the years 2010 to 2020 many studies and research were done to implement GLSS in different sectors. Tools used in Six Sigma and the tools used in Lean are mainly the tools used in the implementation of GLSS. The utilization of DMAIC has been highlighted several times in the selected literature review. Some researchers did not concentrate on the implementation of GLSS itself, rather they concentrated on the barriers and enablers related to GLSS. For example, Hussain et al. (2019) mentioned 24 barriers related to construction industry such as lack of training and lack of kaizen environment. GLSS has shown some positive outcomes in the different fields; however, based on the selected literature review more studies need to be done, for example to explore GLSS implementation in quality management systems. In addition, one of the major research gaps is implementing GLSS to different fields and examining an actual implementation of it in the field and not only relying on theoretical results. GLSS has been used in certain fields, however based on the selected review papers it has not been used in IAQ. IAQ is an important issue that is grappling the world's attention since more that 90% of people are living indoors. Having bad indoor conditions affects people productivity and health. The methods used in construction can be retrieved and modified to improve IAQ.

6. Discussion and Conclusion

It has been shown in selected literature review that GLSS framework is useful for fields such as construction and automotive industry; however, there is a lack of research in investigating the advantages of the integrated Green Lean Six Sigma framework in IAQ improvements. As seen in literature, a limited number of studies aims on finding the critical success and failure factors of GLSS. Furthermore, in case those studies where available their objective was towards finding theoretical models, without empirical validation and experimental verification (Tiwari et al. 2020). Finally, there is a lack of generic framework that governs the implementation of GLSS (Sony and Naik 2020).

Based on literature review certain areas showed more connection to GLSS. The most highlighted areas are highlighted in the Figure 4 below.

Enviromental performance	Life cycle environmental impacts	Five dimensions of environmental performance

Figure 4. Some related areas to GLSS

In this paper, articles were selected based on their relevance to IAQ. The articles discussed in this paper are directly related to GLSS and published between the years 2010-2020. Most of the articles considered either manufacturing field or construction field, while some articles provided general information without suggesting any field of implementation. While comparing construction field and manufacturing field to the other fields, it can be said that implementation of GLSS in construction and in manufacturing takes 80% of the field of implementation. This consists of 40% for construction and 40% for manufacturing. Based on the selected literature review it seems that GLSS is successful in construction and manufacturing field. Some researchers have suggested some methodologies such as eco-design. The selected literature shows that tools such as life cycle invention analysis, cause and effect diagram, Pareto chart and value stream mapping are useful tools for GLSS implementation. Based on literature review, some researchers highlighted the importance to understand the barriers to implementation of a GLSS framework before considering it as a solution to any situation.

This study presents a literature review related to development and application of Green Lean Six Sigma framework. Although GLSS framework has been used in different fields, it is shown that it has not been utilized to solve the problem of IAQ. In general, the field of IAQ is considered as an engaging research field and more research is required to mitigate this issue. Improving indoor air does not only require frameworks and methods to be implemented but also peoples, organizations, governments belief that it is a major risk which is affecting humans' health especially in long term. The study done by Sony and Naik (2020) showed that GLSS can solve the problem of the increasing dust in mines. This is an indication that it can also be used to improve IAQ in houses, offices etc. As per literature review, there exist many processes and methods that can improve IAQ; however, most of those methods are useful for short run. In long run, those methods result in negative impacts such as producing dust and pollutants. GLSS frameworks targets reducing waste and applying green solutions that reduces the negative effects on the environment. We can conclude that exploring this field is very significant for future researchers to ensure that there will be solution that improves indoor air in short term and long term.

Based on the selected literature review, and although there has been no direct prove that GLSS framework has been utilized previously for IAQ improvement. However, by comparing IAQ as a field to manufacturing since they have some similarities in pollutants, and harmful emissions it seems clear the GLSS framework can by used to improve IAQ. Based on the selected literature review from the years 2020 to 2022 many gaps have been identified. Those gaps are the base for future research. Some researcher targeted suggesting tools for the implementation of GLSS such as Analytical Target Cascade-ing. While other researchers suggested exploring the suggested frameworks in different field or different contexts. The challenge related to IAQ improvement using GLSS framework is not only related to the implementation of the framework but also exploring the barriers and success factors related to it in order to reduce the indoor air pollutants. Certain gaps related to GLSS has been identified from literature review. However, it has been identified that most of the researchers examined GLSS to solve a current situation without focusing on long term. In addition, some of the researcher studied GLSS theoretically only and suggested that it is a new target for other researchers to prove that their results is feasible.

7. Future Research
People are exposed to conditions indoors more than outdoors (Idemudia and Michael 2022). Due to the serious subject of IAQ, governments and organizations started improving prevention practices and control of pollutions in order to find sustainable solutions. Until today, there is no substantially leading solution to improve indoor air and reduce indoor pollutants.

Some research gaps have been highlighted in this paper. There is a challenge in figuring out how to connect LSS to environmental considerations and sustainability concepts (United Stated Environmental Protection Agency 2009). This challenge is also related to connecting GLSS to IAQ. However considering that improving indoor air requires improvements in the process such as improving ventilation systems then GLSS frameworks can be tested in this field.

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