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Research Article

A framework for evaluation of improvement opportunities for environmental impacts on construction works using life cycle assessment and value stream mapping concepts: offsite and onsite building construction

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Abstract: There have been various concerns about the environmental impact of construction works. This generates a need to take a more proactive approach in evaluating the environmental impacts of construction operations and further explore ways to reduce the environmental impacts. Enormous opportunities exist within the building industry to achieve a reduction in greenhouse gas emissions. The aim of the study is to develop a framework for the evaluation of improvement opportunities for environmental impact for onsite and offsite building construction works using life cycle assessment (LCA) and value-stream-mapping concepts. Various tools for LCA exist; however, there is a need for the development of an LCA framework and improvement opportunities that can be localized to various communities to evaluate improvement opportunities for building construction. This study conducts a review of methods to evaluate the LCA of buildings on local construction sites. A procedure for establishing improvement opportunities is also developed. Based on the author's knowledge and experience, including site visits, using value stream mapping (VSM) techniques, a conceptual framework of the present state map and future state map of residential construction works was developed. The study presents a procedure for the evaluation of improvement opportunities for the environmental impacts of construction operations.

Keywords: Building Construction; Continuous Improvement; Environmental Impacts; Framework; Life Cycle Assessment; Offsite Construction; Onsite Construction; Value Stream Mapping

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1. Introduction

The construction industry plays a crucial role in the economy, as the activities are important to the achievement of national socioeconomic development goals of providing employment, shelter, and infrastructure [1]. Although the construction industry is one of the pillars of modern civilization, there have been various concerns about the environmental impact of construction works. The construction industry and the implementation of civil projects are considered one of the causes of environmental pollution [2]. Environmental pollution is considered a major problem in construction projects [3]. All over the world, the construction industry generates a large amount of waste [4]. In many countries, the economic growth and the development of the construction industry have had a negative impact on the environment and the natural ecosystem [5]. A large share of greenhouse gas (GHG) emissions comes from buildings [6]. In addition to its contribution to the environmental impacts, the building sector contributes to a great portion of energy consumption in different countries [7]. The global status report for building and construction indicated that in 2020, the sector is responsible for 36% of global final energy consumption and 37% of energy-related CO_2 emissions (when compared to other end-use sectors) [8]. At roughly 80% of the energy consumption, the building sector has the largest energy consumption in Saudi Arabia [7]. Approximately 36% of energy-related GHG emissions and 40% of EU energy consumption are from buildings [9-11]. In Europe, domestic hot water, heating, and cooling account for 80% of the energy that the citizens consume [9]. The building sector is important to achieving the energy conservation and emission reduction targets in China, as the building sector contributes to more than 30% of the national energy consumption in the past decades [12]. The building sector is important for the European Union's EU environment and energy goals [9]. Hence, there is a great interest in the reduction of the environmental impacts of construction activities.

The ultimate goal of managers and decision-makers in the construction industry is to implement projects with acceptable quality and at minimum cost and time. However, the reduction of the environmentally destructive effects that are developed during the implementation of projects is of uttermost importance [13]. In Architecture, Engineering, and Construction, the concept of sustainable production has become significantly important [14]. Globally, significant effort has been devoted to the reduction of environmental impacts and waste management from building construction [15]. Some researchers [13] considered environmental pollution with the project's golden triangle of cost, time, and quality. The environmental effects of construction projects and the conflicting goals of quality, budget (cost), and duration (time) were considered. A fuzzy goal programming method was used for the analysis of the proposed model that was implemented on a rural water project [13]. With the aim to identify and evaluate the environmental impacts of construction projects and eventually determine the most favorable means of executing projects to achieve the least cost, environmental impact, and duration some scholars [5] grouped the environmental consequences of projects into three categories, physiochemical, biological and socioeconomic environments. Citing a previous study, the researchers described the Leopold matrix, LP method as one that can be used for the evaluation of environmental effects to summarize the positive and negative impacts of the project phases. In the LP method, a matrix with all activities is structured. Numbers denoting the significance of the impacts can be assigned to range from +5 to -5. The columns represent the environmental factors. The positive and negative signs show the kind of consequences. The mean of positive and negative effects for each activity and environmental factor is calculated. Citing other previous works, the study noted that the Best Worst Method (BWM) is based on criteria measurement by pairwise comparison. However, the BMW method is limited by the ambiguity and uncertainty of human qualitative judgment. The fuzzy BMW method was developed to model ambiguity and uncertainty in human judgments. The researchers used the Leopold matrix method to assess the positive and negative environmental impacts. The fuzzy BWM method was used to calculate the time, cost, and negative and positive environmental impacts. Meanwhile, more opportunities for the identification and evaluation of improvement opportunities still exist.

This study proposed a framework that extends the LCA process to include target setting for improvement, implementation of the improvement goals, and periodic checks of the status of the improvement targets. The proposed framework is meant to encourage a continuous improvement culture, reviewing the environmental impacts of each project, and using the lessons learned from previous projects to improve the environmental performance of future projects. Various researchers have looked into how to improve the environmental impacts of construction. Some scholars [16] noted that recent research on the benefits of modular construction indicated that when compared with conventional construction methods, implementation of modular construction yields benefits such as reduced defects, costs, risks, and environmental impacts. The benefits of integrating building information modeling with life cycle assessment for different design scenarios have been shown in previous work [17]. Among other things, the authors noted that LCA-BIM integration could help to streamline environmental stewardship and also prioritize action. Knowledge of the environmental impacts and the sources of the impacts is necessary to know the best approach to minimizing the environmental impacts while we continue to reap the benefit of modern construction (to support the growth of humanity). Considering the pollution and impacts that are produced by various projects, it is important to identify the environmental impacts to be able to reduce their effects [2].

LCA is one of the management tools that is used to evaluate environmental concerns [18]. It is a standardized method that is used to quantify the environmental impacts in the lifecycle of a product from resource extraction to the production of material (manufacturing stage), use and end of life, disposal, and recycling [19]. Moreover, it has been used in various studies to evaluate the environmental impacts of construction operations. The life cycle performance approach has been used to perform a cross-comparison between the refurbishment and replacement of two housing archetypes in London (for a mid-terrace house and a bungalow). Optimal refurbishment archetypes were found to perform better than replacement scenarios [20]. Some scholars [21] used an attributional LCA to quantify the contributions of each stage of the end-of-life phase of a residential building, especially regarding the management of demolition waste. The estimated contributions of the overall impact of each stage of the construction and demolition waste that was investigated showed the important role of recycling different waste streams, especially that of reinforcing steel. Other scholars [22] used the LCA approach to compare the performance of three high-rise buildings made with conventional reinforced concrete, cross-laminated timber, CLT, and hybrid CLT buildings. The study focused on life cycle primary energy and life cycle greenhouse gas emissions.

Several studies have looked into performance improvement of the prefabrication process but the use of lean techniques in the integration of the production and erection process (and consideration of their effects on each other) have not been comprehensively studied [23]. In terms of energy consumption and CO_2 emissions, some scholars [23] tried to improve the production, transportation, and erection process of prefabricated steel frame components. Elimination of process waste and improvement in resource efficiency was achieved through four lean techniques (value stream mapping, continuous flow, total productive maintenance, and just in time). The result showed that CO_2 emissions and energy consumption are reduced by 4.4% and 9.2% respectively. Although the authors recognize some other environmental impact indicators, it was noted that only GWP was calculated for eco-efficiency for the application of the 'lean and green' approach [14]. The achievement of sustainable development goals will not be possible without consideration for environmental issues [5].

Environmental performance can be improved through the use of LCA during the design phase of buildings [6]. Various studies have mentioned about environmental impacts of construction operations. A previous work [24] reported the following parameters in the updated German average LCA results for cross-laminated timber (CLT) in accordance with EN 15804 (2014) for OKOBAUDAT 2017 (shown in Table 1).

Table 1. Parameters for an LCA evaluation (Adapted from Hafner and Ruter, 2018).

Environmental impacts	Resource use	Output flows and waste categories
Global warming potential (GWP)	The use of renewable primary energy excluding renewable primary energy resources used as raw materials, PERE	Hazardous waste disposed, HWD
Acidification potential (AP)	The use of renewable primary energy resources used as raw materials, PERM	Nonhazardous waste disposed, NHWD
Ozone depletion potential (ODP)	Total use of renewable primary energy resources, PERT.	Radioactive waste disposed, RWD
Eutrophication potential (EP)	The use of non-renewable primary energy resources used as raw materials, PENRM	Components for reuse, CRU
Tropospheric ozone concentration increase (POCP)	Total use of non-renewable primary energy resources, PENRT	Materials for recycling (MFR)
Abiotic resource depletion for fossil resources (ADPF)	The use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials, PENRE;	Materials for energy recovery, MER
Abiotic resource depletion for non-fossil resources (ADPE)	The use of secondary material, SM;	Exported energy, EE [24]
	Use of renewable secondary fuels, RSF;	
	Use of non-renewable secondary fuels, NRSF;	
	Net use of fresh water, FW.	

Although LCA provides an opportunity to know and also quantify the environmental impacts of construction works, there is a need for a reasonable degree of accuracy in the quantification of the inputs and outputs to be able to have a good representation of the quantity of hazardous materials that are being released into the environment. Most LCA studies for buildings present a rough estimate of the materials and fuels that are used in construction; these exclude choices on a variety of construction methods, materials, machines, and specialties [25]. Meanwhile, there is a need for the incorporation of a reasonable level of detail to reflect the effect of construction methods on environmental impacts. There are tools for the evaluation of LCA for certain locations (e.g., ATHENA Materials Institute provides software for the evaluation of LCA for specific locations in North America). When available, the use of local or national data is always preferable. Many countries face the challenge of local or nationally derived data that are not readily available, resulting in a burden on building professionals to use, or misuse complex tools that are not relevant to the local or national context. Hence, it is better to simplify the process for an early decision-making process in new construction and building renovation [26].

Results from life cycle assessment are not very useful if nothing is done about the LCA results. On this note, this project hypothesized that the LCA procedure [27] can be improved to incorporate actionable goals for continuous improvement of the environmental impacts of construction operations (towards the goal of zero environmental impacts for construction operations). In addition, the value stream mapping in lean manufacturing can be applied to identify and develop strategies for the improvement of the environmental impacts of construction works. These generate the following research questions:

How can we improve the LCA system to ensure that actionable goals are identified and developed for the project?

How can we apply the value stream mapping as an improvement tool for the environmental impacts of building construction operations?

This study provides a framework to have a detailed evaluation of the impact of localized construction methods on the life cycle analysis of building construction. A conceptual present state map of environmental impact from construction operations is developed through value stream mapping techniques. The study also provides a framework and recommendations on how to achieve the future state of environmental impacts from construction works.

2. Literature review

2.1. Application of lean concepts to the improvement of environmental impacts of construction operation

Lean philosophy aims at achieving more with less while minimizing waste. The ultimate goal of lean philosophy is to decrease or eliminate waste and deliver value to the customer [28]. By formulating recommendations to reduce or eliminate waste, lean construction is one of the approaches that can be used to improve common problems in construction or project-based industry such as deadline delays, inadequate quality, and budget overruns [29]. The lean concept focuses on value for the customer, based on user perspective. The concept believes that customers' expectations can be fulfilled through waste identification and elimination [29]. Recently, lean construction has attracted attention in the home building industry [30].

Some scholars [31] aimed at contributing to the construction transport time efficiency by the identification of non-value-adding activities and their causes from a freight forwarder perspective. The non-value-adding activities that were mentioned include waiting, empty traveling, searching for the right address to unload material, etc. The authors noted that there is a need for better planning, coordination, and communication within construction transport. The scholars noted that the limitation of the study is that it is based on a single case of a freight forwarder. It does not provide a full picture of the construction transport efficiency. This present study seeks to illustrate how the value stream mapping concept can be incorporated with LCA for a more holistic and continuous evaluation of improvement opportunities for building construction operations. In recent days, the European Union is encouraging member states to achieve a net zero emission status in buildings by 2050 [32]. Net zero emissions cannot be achieved without adequate strategies and actionable goals to achieve the strategy. Wastes in construction often refer to things like material waste, time waste, and economic waste through inefficient use of resources. It could also include waste of energy. At this time, it is not very common to classify GHG emissions as wastes that can be improved through project efficiency tools such as value stream mapping, and five why's for root cause analysis. Meanwhile, these tools can also be used to identify GHG emission 'wastes', identify the root cause and propose actionable solutions for future improvements.

2.1.1. The use of value stream mapping (VSM) in the evaluation of improvement opportunities for environmental impacts in construction operations

Value stream mapping (VSM) is a tool that is used in lean manufacturing or lean construction for process improvement. Among other things, a previous work [33] highlighted the following as reasons that make VSM an essential tool:

1. With VSM, you can see the flow, (i.e., you can visualize more than just a single-process level).

2. In addition to waste identification, VSM can help with the identification of the sources of waste in the value stream.
3. A common language to discuss manufacturing processes is presented by VSM. In addition, VSM gives a clear view of decisions about the flow.
4. A blueprint for lean implementation is achievable with VSM. (It helps to design how the entire door-to-door flow should operate).
5. In addition to showing a linkage between material and information flow, VSM is a tool that can be used to describe how your facility should operate to create flow.

Value stream mapping has been used as a lean technique in manufacturing such as in the production phase of prefabricated steel frames [28]. After the identification and reduction of some of the waste in the current state, a future state was modeled. The result showed a 34% reduction in production lead time and a 16% reduction in costs. To identify waste, value stream mapping can be used to understand the flow of information and material. Five why's analysis can be used to know the root cause of the waste, the root causes can be ranked according to priority, and suggestions for eliminating the root causes of waste can be achieved [29]. The use of value stream mapping in the evaluation of environmental impacts of construction operations can help to evaluate opportunities for emission reduction while minimizing environmental impacts. VSM has been used as a sustainable construction tool for the installation of the underground pipeline [32]. VSM was adapted to reduce a great percentage of time wastage and non-value-added activities during the construction stage. The study adopted the cost implementation of VSM to improve productivity in underground pipeline projects. The result helped to achieve a 20.8% cost reduction between the current and the future state. VSM has been used simultaneously to assess environmental and production waste over the execution stage of the construction project [35]. The scholars [35] showed that a detailed diagnosis of the main construction element of the current state of production of the structural concrete work of a project can be elaborated using VSM methods, making it possible to see the production and the environmental waste that systematically, occurred and revealing improvement opportunities that typically remain hidden to the production control personnel.

VSM method has been applied for the improvement of lift-up and procurement workflow [34]. Root cause analysis is a structured evaluation method that can be used to evaluate the reason behind undesired outcomes, and also identify steps that can be used to prevent the recurrence of undesired outcomes [29]. The process of delivery of a constructed facility in the construction sector is similar to the making of products in the manufacturing industry [28]. When using VSM during the evaluation of environmental impacts of construction, the process will attract questions such as, 'what can we do differently to reduce the environmental impact of construction, what alternative way exists, etc.' VSM tackles the root cause, while traditional tools deal with symptoms [35].

A previous work [30] mentioned that prior to the commencement of value stream mapping, two management decisions to be made include, the selection of a value stream, and deciding on the level of mapping. Building construction has lots of processes that can be improved. The selection of specific phases of the construction works for the improvement of the environmental impacts is good. At the same time, it is good to not only have the plan to evaluate and create present state maps for all the construction phases, but it is also good to create a future state map for the reduction of environmental impacts of all the phases in the building construction industry. A previous work [14] proposed a lean and green approach that was based on an eco-efficiency assessment. The scholars used a combination of LCA (as a green tool) and VSM (as a lean tool) to compare the same house built with different construction systems (steel framing and concrete structure). The indicators that were considered include global warming potential and value added to production (VAP). The VAP indicator is the sum of the total costs with embedded materials and labor (calculated in monetary terms). For economic analysis, the VSM indicators that were chosen include lead time, cycle time, value-added time, wasted material, embedded material, value-added, and non-value-added. The cycle time is the total time that is required for a material to move through a production flow. Cycle time includes the processing time, inspection time, wait time, and move time [16]. Reduction of the cycle time results in a reduction in time to complete the project. In terms of environmental impact, this has to be viewed from a holistic point of view. Except when absolutely necessary to achieve a specific and important project goal, a reduction of cycle time that comes with the utilization of equipment that results in more GHG emissions may not be the preferable choice. The need to apply techniques such as lean techniques (aimed at reducing environmental impacts by reducing wastes) is demonstrated by the growing development of the building industry and the significant contribution of the construction industry to CO_2 emissions and global energy consumption [23].

The use of value stream mapping in emission reduction and evaluation of improvement opportunities for environmental impact on building construction holds great potential as VSM will help to see the current state of various environmental impact categories in various construction stages on one map. VSM techniques will also help develop a targeted future state for continuous improvement. The future state shows where you want to go. A yearly value stream plan for the improvement of environmental impacts on construction projects will be a good endeavor for projects that extends beyond one year. The yearly value stream plan shows: (1) A step-by-step plan of what you plan to do, and when you want to do them. (2) Measurable goals, and (3) Clear checkpoints with real deadlines and named reviewers [33].

2.1.2. Expected benefits from the improvement of environmental impacts of construction operations

In addition to environmental benefits, considerable socio-economic benefits are also expected from the improvement of the environmental impacts of construction. Air pollution has been associated with various socio-economic impacts. Various researchers have linked air pollution with health issues [37-42], mortality rate [43-45, 39], labor loss [38], social factors [46], economic burden [38], or financial/economic losses [47-49].

A huge body of evidence shows that air pollution is detrimental to health, often measured by hospitalization and death [40]. In addition to significant burdens on healthcare providers, huge economic losses result from health-related implications of air pollution [47]. Some scholars [48] have reported that financial losses are associated with the treatment of diseases that are caused by air pollution. Some researchers [38] related air pollution to public health issues, loss of labor, and economic burden in the long run. Some other scholars, [39] associated air pollution with various health issues and death. By promoting the onset of some non-communicable diseases, air pollution puts additional strain on social care and the National health service [39]. Some scholars noted that in addition to increased impact in terms of increased hospitalizations and premature mortality, air pollution comes with a significant economic cost [50]. Meanwhile, Economic gains have been associated with better air quality [51].

Some scholars [52] presented lessons learned from the design and construction strategies of two low-emission construction sites in a country. It was noted that in addition to zero GHG emissions, the advantage of the implementation of emission-free construction solutions includes reduced harmful environmental emissions like Sulphur oxides (SOx), particulate matter (PM10, PM5,), noise and Nitrogen oxides (NOx). Reduction in air pollution through strategies for GHG emission reduction is expected to help ensure that the funds that would have been used to attend to diseases that result from (or are aggravated by) an increase in air pollution can be diverted to other beneficial uses such as infrastructure construction and maintenance, social welfare programs, etc.

Reduction in material waste is expected to translate into good management of natural resources, and the associated benefits which include the reduction in the environmental impacts that arise as a result of the production of those materials.

A scholar [53] recommended a coordinated effort in sharing best practices for emission management and control from all jurisdictions globally. Sharing information on advancements in emission management techniques is expected to help ensure that no country is left behind in advanced emission management systems.

3. Materials and Methods

In the effort to develop a framework for the evaluation of life cycle assessment for residential building construction, this study embarked on a literature review to examine some of the works that have been done on the subject. An offsite construction facility was visited to have first-hand knowledge of the work process. An onsite construction site was also visited during some of the work operations for some inventory evaluation (to have a record of some of the equipment that is used in the construction works, and note some of the paths for environmental impacts from the work). The study presents a framework that can be easily followed to evaluate the lifecycle impacts of buildings using wood as the major construction material. The goal of this study is to develop a procedure that can be easily adapted to evaluate the environmental impacts of building construction. Figure 1 shows an illustration of the project approach.

- Literature review
- Site visits, some inventory evaluation of some of the work processes
- Development of conceptual present state map of environmental impacts (using VSM techniques)
- Development of a conceptual model for a continuous improvement of the environmental impacts of building construction.
- Development of conceptual future state map for environmental impacts.
- Discussion of the conceptual model and some improvement opportunities for the environmental impact of building construction.

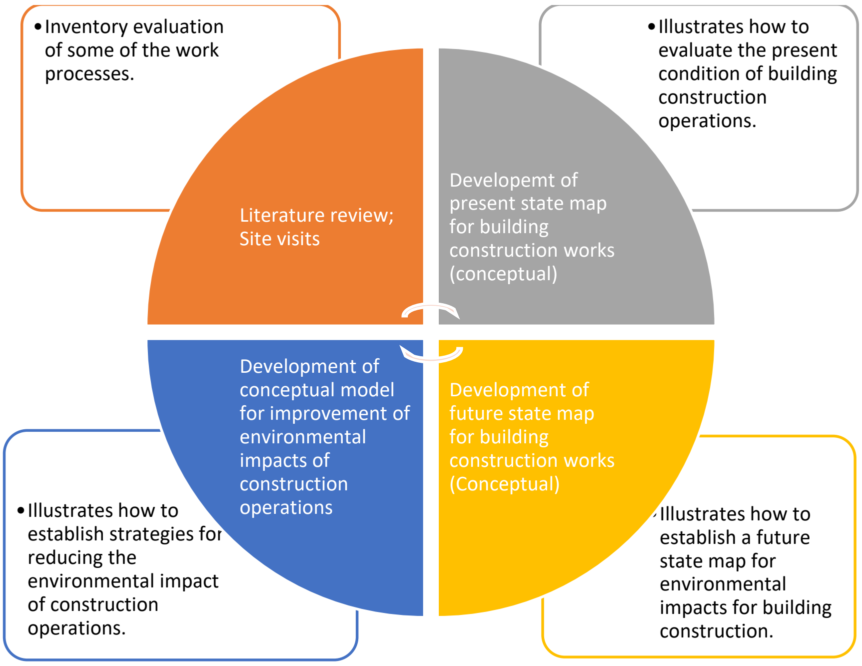

Figure 1. Project methodology.

The present state map is expected to show the present condition of building construction operations. This could be from data from a previous project (i.e., showing how the organization will normally perform the work). Given that there are multiple items on the work breakdown structure for building construction, a generic present state map can be drawn on the whole building level, grouping a number of subcomponents of the work items into specific groups. The future state map is expected to establish a future state for the environmental impacts of building construction. To dig deeper on the unit level (for the work breakdown structure, (WBS), separate present state and future state maps can be developed for subunits of the building. This study further provided a framework for the identification of improvement opportunities for environmental impacts from building construction projects. The developed framework follows the traditional steps in life cycle assessment by ISO 14040 [54]. However, in the goal toward 'vision-zero' for environmental impacts, the traditional steps for LCA were modified to include additional steps as presented in Figure 2 and Figure 7. Five additional steps that were included in Figure 2 are (1) the development of the present state map for environmental impact (2) the development of mitigation strategies for the environmental impacts, (3) the development of a future state map for the environmental impact of construction works (4) implementation of the mitigation strategies, and (5) periodic monitoring of progress to ensure adequate correction if there is a negative diversion from the plan. This is expected to be a continuous activity towards "vision zero" for the environmental impacts of construction works as illustrated in Figure 8 of the appendix section

Figure 2. Steps in a life cycle assessment (LCA). Adapted from [27, 54 - 56].

A combination of a modified LCA concepts in Figure 1 and Figure 2 should arrive at the improved framework for continuous improvement of the environmental impact of building construction operation as discussed in later section of this project.

3.1. System boundary

In LCA, the system boundary specifies which unit processes are included in a product system [27, 54]. The targeted system boundary for the present phase of the project is the construction stage of the building. To achieve the goals that have been earlier stated, the lifecycle inventory for the construction process will include documentation of the inputs and output for the construction process (to a reasonable level of detail). For example, in offsite construction, input and output for the work processes specified in Figure 3 will be recorded for further evaluation.

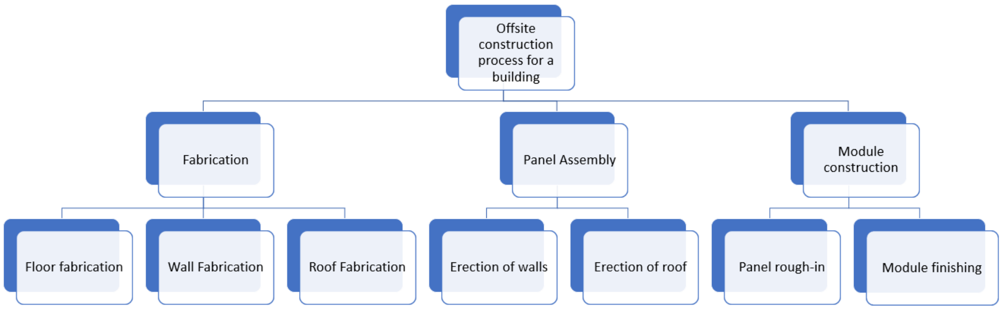

Figure 3. Offsite construction process for a building (*Adapted from Zhang Y., 2017 [57]).

Figure 4 shows an example of the data that will be collected for input analysis during the data collection process for the study. The above example is for offsite construction. Relevant information on the output from the construction processes will also be collected for further analysis.

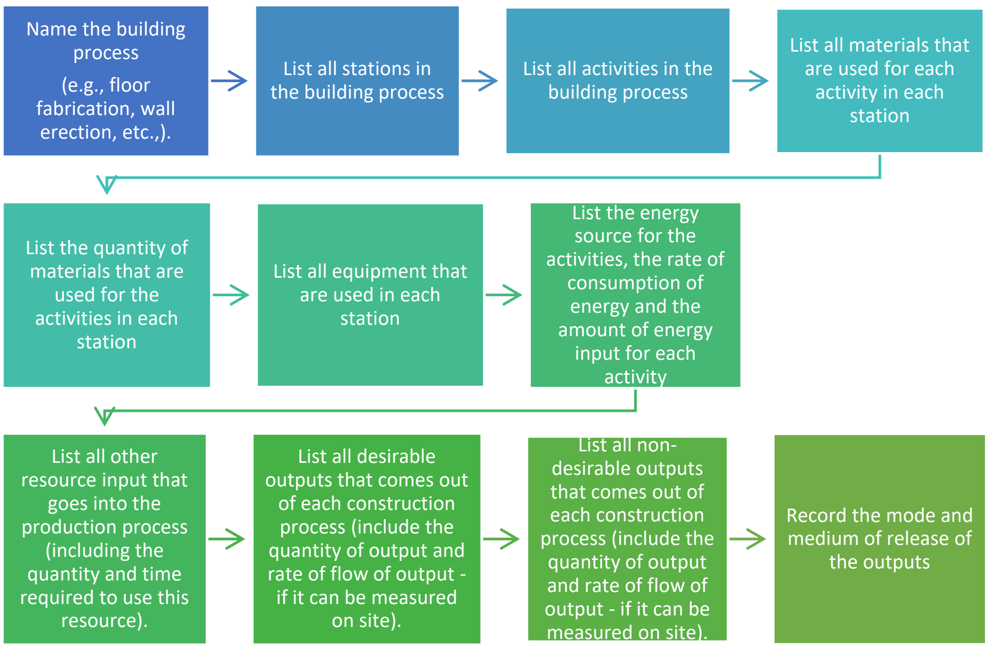

Figure 4. Data requirement for life cycle analysis of offsite building construction process (inputs and outputs).

Previous works described emissions as a factor of activity volume and emission coefficient [58]. i.e.,

$$Emissions \ = \ Activity\ volume\ x\ emission\ coefficient \tag{1}$$

In addition to recording the outputs from construction works, a record of the mode of release of outputs from the construction operations will also be helpful in the development of strategies to minimize the environmental impacts. A similar experimental procedure as above should be done for both offsite and onsite construction for a comparative analysis of the environmental impacts of the construction processes. During site visits to an onsite construction location, some of the equipment that was seen on the site included a diesel-powered Komatsu backhoe excavator for the demolition of the existing wood structure, and for excavation works. The equipment has an exhaust section where gases are released into the atmosphere. A battery-powered nail driver was used for some works that require the fastening of some wood products together during shoring operations. In offsite construction, the gantry crane is available to facilitate the lifting of heavy items such as walls, and roof sections into place before panel connections, finishing, and transportation of modules to the site. Although for the electric-powered equipment, no emission channel was recorded on site, various emissions are associated with electricity production. Hence, electric-powered equipment can also be billed for emissions that are associated with the production of the amount of kWh that they use from the grid.

4. Results

4.1. A case study of environmental impact from an operation on site

Some of the works that were done at the site during the site visit include the demolition of existing buildings, excavation, hauling of excavated materials away from the site, connections to utilities, and shoring operation. The demolished concrete was hauled out of the site to a location where it will be further processed using tandem trucks. Tandem trucks were used during excavation works for the basement to haul some excavated material out of the site. An online map was used to estimate the round-trip distance that is associated with this as 38.2 km (round trip) for hauling demolished concrete by one truck (The distance indicated is the distance from the office of the trucking company to the site, then to the dump yard and back to the office of the trucking company). 'The average fuel efficiency for trucks is 39.5liters / 100 km' = 0.395 liters /km. This is about 7 miles/gallon (in 1999). It excludes fleets operating B trains (having a substantially lower average fuel efficiency) [59].

Note that the possible impact of traffic hold-up and load effect may affect the rate of energy consumption. For simplicity, this illustration may be used. The fuel consumption in hauling a load of concrete out of the site to the 'concrete yard' F_c can be estimated as 'the rate of fuel usage R_f' multiplied by the distance traveled d_t

$$\text{Fuel consumption,}\quad F_c = R_f * d_t \tag{2}$$

The average fuel efficiency for trucks mentioned above was used for this estimate (with an assumption that the average fuel usage of the truck is 39.5liters/100km). If a company assigns an environmental impact monitoring engineer to the construction operations, a more accurate estimate of the fuel consumption may be obtained through the actual amount of fuel that is used during the hauling operation. This can be known from the fuel receipt if the fuel tank is filled before and after the hauling operation. Previous work [60] has reported that diesel engines give 2.7KgCO_2 per liter of diesel

Carbon dioxide emission E_c from the hauling operation can be estimated by a product of the rate of fuel usage, R_f (Liters/km), the CO_2 emissions per liter, E_l of diesel (KgCO_2/liter), and the distance traveled (km), d_t.

$$E_c = R_f * E_l * d_t \tag{3}$$

For the above illustration, the carbon dioxide emission can be estimated as

$$E_c = 0.395\frac{liters}{km} * 2.7\frac{KgCO_2}{liter} * 38.2km = 40.74\ KgCO_2$$

The above result can be further improved with applicable carbon dioxide equivalent coefficients to account for other GHG emissions that can be associated with the hauling operation. Equation 1, indicates that the quantity of emissions is a product of activity volume and emission coefficient. The activity volume in equation 3 is the product of the distance traveled and the rate of fuel usage for the vehicle. The emission coefficient is the amount of carbon dioxide emission per liter of diesel. The aggregate of information like this (including employee transport, equipment transport, all material transport, and the use of equipment on site) will be included in the present state condition for the project. Future state targets can explore opportunities for reduction of hauling distance for example if there are other concrete processing yards that are closer to the construction site. The use of an alternative transportation option with better fuel economy or lower emission coefficient will also help reduce the impact of that operation.

Another scenario that was known from the site is worker commute distance. An operator on the site has a daily commute of 90 kilometers. A scholar [61] used this to evaluate potential impacts with different sources of energy if the operator comes to the site for 10 days. An example of a mitigation opportunity for significant worker travel is to explore temporary accommodation that is close to the site instead of long-distance travel every day. Alternative analysis can be used in the development of mitigation strategies and actionable goals (that can be included in the future state map) toward the reduction and eventual elimination of the environmental impact of construction operations.

Tables 2, 3, and 4 of the appendix section have some of the work breakdown structures for building construction. This can be used as a guide to starting inventory analysis for the environmental impact of construction operations. Note that this will have to be further expanded with all the additional work that is done on the site. The tables do not show a complete list of all the work that can be seen on the building construction site.

5. Discussion

5.1. Value stream mapping (VSM) evaluation of environmental impacts of construction operations

Value stream mapping (VSM) is a process improvement tool. Some scholars [62] mentioned that value stream mapping is a tool that is offered by the lean production movement for redesigning productive systems. VSM has been applied in a variety of industries [63]. This study proposes the application of the value stream technique to review how the environmental impacts of construction operations can be improved.

5.1.1. Present state map for environmental impacts of construction operations

A present state map shows the present condition of the processes in an operation. This may include the amount of time spent on the operation, the amount of resources that are used, etc. In the process of site evaluation of construction works, using value stream mapping techniques, a present state map for the environmental impacts of construction works for each site will include a list of environmental impacts (to be obtained from the outputs) from each construction process. More items could be added to the list in the site preparation box of Figure 5 below. Previous works have given various lists of environmental impacts from construction works. Some scholars [3] noted that environmental impact indicators include eutrophication potential, greenhouse gas (GHG) footprint, human health particulate, acidification potential (AP), smog, and ozone depletion.

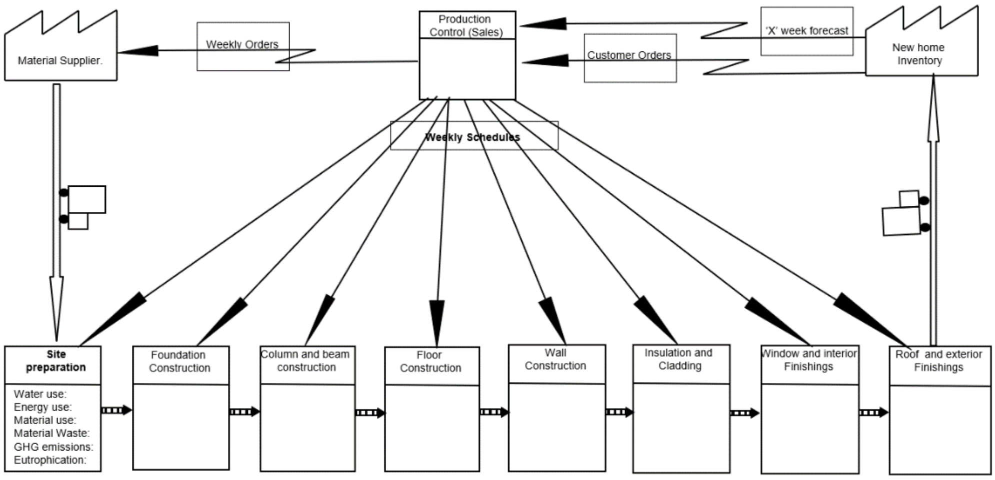

Figure 5. Present state map for building construction- for evaluation of environmental impacts of construction. (Adapted from Rother and Shook, 1999 [33]).

Various software exists that can be used for LCA analysis. These include ATHENA, Simapro, Gabi, etc. Output from analysis of any of these software can also be used to determine the environmental impacts at each subsection of the construction processes. However, wherever the databases used for the software do not have the applicable information on local conditions, the use of local information is preferable. This will also help to identify the critical zones in the construction operations (i.e., the areas in which when improved, there will be a significant reduction in the environmental impacts of the construction works). Outputs from the software and other notes that will be taken onsite will be helpful in completing the present state map of environmental impacts of various subsections of the offsite and onsite construction works.

5.1.2. Development of a list of environmental impacts from the outputs on construction sites

As earlier mentioned, previous works have identified various lists of environmental impacts in construction operations. These include acidification potential, ozone layer depletion, global warming, etc. In addition to using available software for evaluation, and noting the environmental impacts that were provided, any other activities from the construction site that can impact the environment (that is missing from the software - if any is noted during the site visits) can be recorded and evaluated for potential improvements. For example, dust from construction works, and dirt on the streets can be added. Recommendations may include spraying water where applicable to reduce dust during construction. Sweeping of streets to minimize the possibility of silt washing into the nearby streams and lakes, etc.

5.1.3. Future state map for environmental impacts of construction operations

A future state map is a forecast of a desirable state for a process. In production systems, the future state may be targeted towards the reduction of the amount of time that is spent in the production process or an increase in the number of outputs. A previous work [30] noted that the goal of the current state map is to create a clear picture of the existing production process and also show where the wastes are. The future state map is focused on the elimination of the root causes of wastes, whilst linking the value stream in smooth flow [30]. The future state for the application of lean tools such as VSM in the improvement of the environmental impact of construction will strive to greatly reduce or eliminate the root causes of the environmental impacts in construction.

For the environmental impacts of construction operations, the goal will be to reduce the environmental impacts without hindering the growth of humanity at large. After the development of the present state map, the next stage is the development of the future state map for construction operations. This should be based on good engineering judgment and comparative analysis with results from benchmark studies such as the study on "Benchmarking the Embodied Carbon of Buildings" [64] and other feasible targets that may be set in the future. The future state map for the environmental impact of construction works is one that is expected to evolve as the world experience more technological growth to reduce the environmental impacts of construction operations. Global emission targets can also be used to set benchmarks for various environmental impacts from construction operations. Figure 6 shows a conceptual future state map with an example of some of the parameters that can be targeted during the improvement process

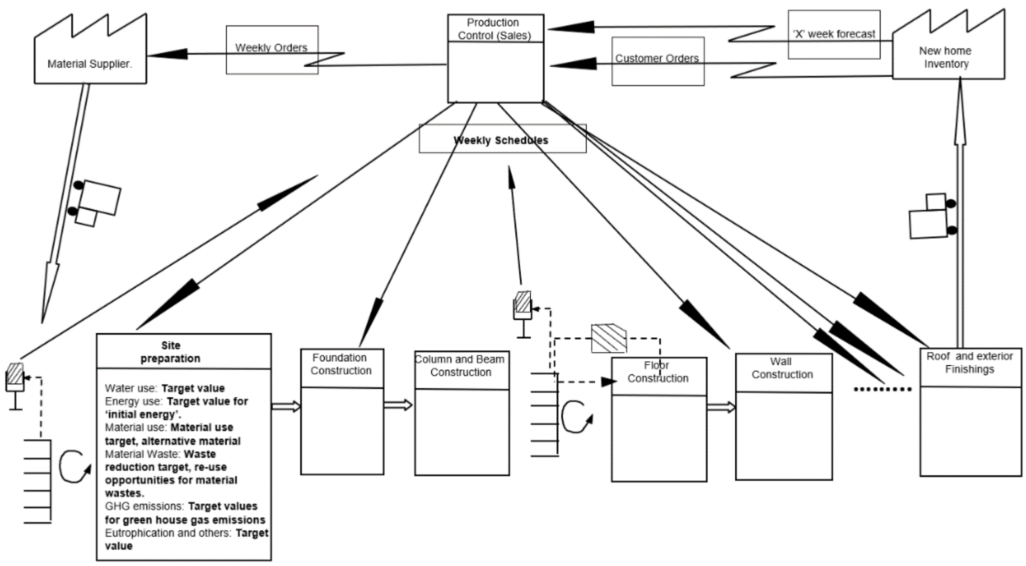

Figure 6. Sample future state map for evaluation of environmental impacts of building construction. (Adapted from Rother and Shook, 1999).

5.1.4. Identification of potential opportunities for improvement of environmental impacts of construction operations

Adequate documentation during a site visit is expected to give more understanding of potential areas of improvement, to reduce environmental impacts and emissions from construction works. Some of these may involve the need for further research to achieve the expected goal. For example, the use of a diesel-powered excavator as mentioned earlier generates a release of gaseous substances into the atmosphere. Reduction of these gaseous substances will include the development of technologies (such as carbon capture technologies) to capture the gaseous substances, and reconvert them to usable materials through adequate systems that are designed for a reversal of states of matter (from gaseous materials to liquid, and to solid) or other techniques. This will require further studies such as the exploration of adequate solutions that can dissolve the gaseous materials, allow the materials to form crystals with other elements, and reconvert them into beneficial products for the environment and for human use. Another interdisciplinary research that can follow this includes an effort to answer the question, "what happens when we pass the emissions through a cold mist, and subsequently over some other compounds? Do we form a new material that is beneficial for humanity in this process?" This study also recommends research on the question, "How can we apply the present carbon capture technologies to achieve zero emissions in fossil-powered equipment and automobiles?" These questions may be addressed in multiple countries around the world. Questions like this can be approached through a collaborative effort of different disciplines such as mechanical engineers to design a cooling compartment, chemical engineers to evaluate various chemical combinations that can react with GHG gasses to form useful substances, etc. Governmental support for projects that are geared toward achieving good progress in capturing and reprocessing GHG materials into beneficial products will be commendable.

An alternative improvement opportunity will be to replace the equipment with electric-powered equipment. Electric-powered equipment will also have environmental impacts that are generated during the production of electricity upstream. Hence, the improvement opportunities for electric-powered equipment will include efforts to reduce emissions and other environmental impacts during the production of electricity. This may also require research and implementation of technologies to capture emissions and convert them to beneficial products for humanity. According to the new decarbonization target that was set by the European Union, the supply of electricity from renewable energy is one of the key measures to reduce environmental impacts [65]. It was reported that an employment increase is one of the most important benefits that is expected from the move [65]. Meanwhile, transitioning to renewable energy takes time. Photovoltaic (PV) energy is one of the energy sources that is recognized as renewable because it takes energy from sunlight. PV is a clean source of energy during the operation phase, but the impact on climate change and air quality can be seen during the manufacturing phase. Life cycle analysis indicates that PV systems cannot be considered a zero-emission technology because of probable environmental effects that are imposed by land use, water use, air quality, possible noise/visual pollution, and the inclusion of hazardous materials. However, with an optimized design, the negative environmental impacts of PV systems could be substantially mitigated. The recycling of solar cell materials can yield up to a 42% reduction in GHG emissions [66]. The impact of PV energy on air and climate change is significantly lower than any other traditional power generation system [66]. If adequately managed, the PV system can be a good supplement to the energy supply for construction operations and the community.

Some companies provide buses for employees from various parts of the city to the office or construction site. This will not only help reduce congestion on the roads, it is also expected to help with the conservation of natural resources. Among other things, one of the mitigation strategies that were reported by some scholars [38] includes the selection of building materials that were produced locally to reduce the embodied emissions associated with long distant travel.

5.1.5. Emission-free alternatives

Among other emission mitigation opportunities reported, 'emission-free alternatives' mentioned by some scholars [38] include battery or hydrogen-powered construction equipment, and the use of zero-emission vehicles for roundtrip transportation of equipment, manpower, materials, and wastes from the construction site. Another scholar reported that although no tailpipe emission is seen from electric vehicles, apart from non-exhaust emission sources, (such as tire and road wear, brake wear, road dust resuspension, and clutch wear [67]), there are associated indirect GHG emissions that need to be considered when the electricity that is used to power a vehicle is from a GHG-emitting electricity grid [61]. Rather than releasing gaseous emissions from industrial plants into the atmosphere, the study [61] also presented a figurative illustration of a framework to capture and ensure local treatment of emissions from industrial plants.

5.1.6. Opportunities for improvement of environmental impacts from the perspective of methods of construction and type of materials

Opportunities for the reduction of environmental impacts exist with the choice of the right type of materials and the right type of methods of construction for various geographical locations. Various studies have presented LCA results on the comparison of various types of construction materials. A previous work [68] compared the environmental impact of concrete and mass timber in building construction. As regards the method of construction. Some scholars [69] have mentioned that there is no clear agreement on whether prefabrication is better than onsite construction. Some other researchers [70] mentioned that although prefabrication can be advantageous in terms of material and time efficiency, the overall environmental and cost trade-offs between prefabricated and conventional construction are not clear, and they are influenced by the choice of the structural material. Given this lack of clarity, a scholar [71] presented a multi-variable system dynamic model to evaluate the environmental impacts of building construction (in terms of GHG emissions) for both onsite and offsite construction from a holistic viewpoint. In the effort to reduce the environmental impact of construction, during the planning stage for construction operations, this study recommends a review of the environmental impact for both offsite and onsite construction from a more holistic (systems) perspective as described in the work by a scholar [71]. In addition to this, other social, economic, and technical factors should be considered for multi-criteria decision-making for construction operations.

5.1.7. Analysis of future state map

Water use target: During site visits, each organization will document the amount of water used on site. Wastage of water will also be quantified. This wastage can be included as a target for reduction. Mitigation strategies to reduce wastage will be prepared. Some strategies that are already in use during building operation include having various automatic control (sensors) for water faucets. Each scenario on the site may have unique strategies that may have to be customized to it.

Energy use target: This will also include a review of the work process to eliminate the wastage of energy. For example, during one of the site visits, some idle times were noted for the backhoe excavator. At these times, the machine may be put off to minimize energy use.

Material use targets: This may include targets for the inclusion of innovative and alternative materials to supplement existing construction materials.

Material waste targets: This may include waste reduction and recycling targets for construction sites. This may also include targets for the reuse of construction materials from old projects.

GHG emission targets: This may include the implementation of targets to reduce the amount of GHG emissions on the project.

Eutrophication and others: This may include measures to reduce the amount of materials that can be washed into the lakes and other water bodies nearby. All other environmental impact categories can also be included in this list. This should be followed with appropriate mitigation strategies, implementation of the strategies, and periodic review to ensure that the project is on track to achieving the targeted improvements for the work.

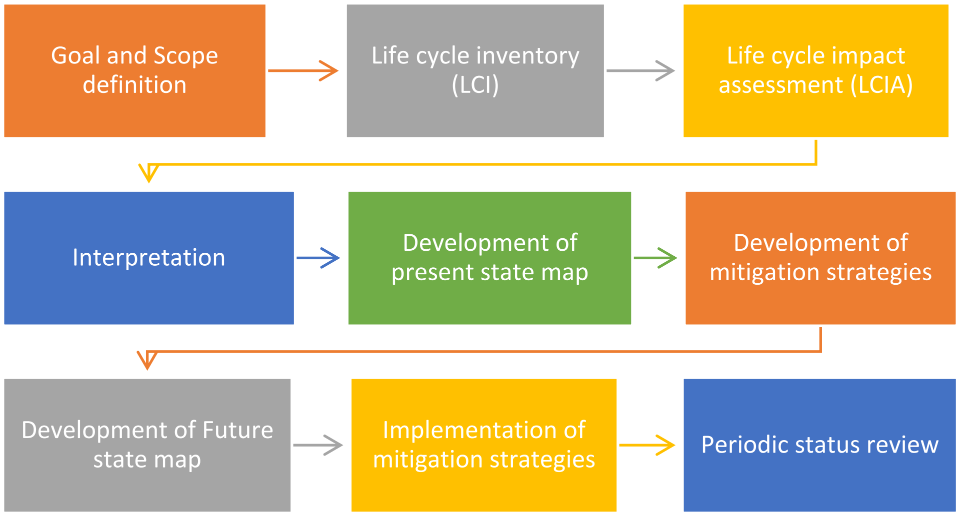

Figure 7. LCA steps: modified with the inclusion of present state, future state map, development and implementation of mitigation strategies, and periodic status review for continuous improvement. Adapted from ISO 14040 [27]; Hollberg, Genova, and Habert, (2020) [33]; Wolodko, (2019) [34].

Value stream mapping for improvement of environmental impacts of building construction processes will include a step-by-step plan of how we intend to achieve the goal of zero embodied energy and zero GHG emissions in construction operations. This will include yearly measurable goals. The modified steps for life cycle assessment (as illustrated in Figure 7) do not stop at the interpretation of results. After the identification of the present state, the process goes further to the development of mitigation strategies for each operation, development of the future state map, implementation of strategies to achieve the future state, and periodic status review (i.e., periodic monitoring of progress to ensure adequate correction if there is a negative diversion from the plan). Having set dates for review and action plans for corrective actions to ensure that work operations are on course to achieving the targets will help ensure that we can have more reliable information on the expected outcome. In contrast to Figure 2, Figure 7 includes the addition of present and future state maps to the framework.

In line with the project hypothesis. Research question and goal, this study presents a framework on how to ensure that actionable goals are identified and developed for the project. In addition, a description of how value stream mapping can be applied as an improvement tool for the environmental impacts of building construction operations is presented. Figure 8 below and Figure 9 of the appendix shows a model to encourage continuous improvement from one project to the other. A plan for the improvement of the environmental impact of building construction with the implementation of lessons learned from a project to improve the performance of future projects (continuous improvement efforts) will help in the goal towards vision zero for the environmental impacts of construction operations. Future lines of studies should include the evaluation of alternative materials for building construction (especially materials that are made from recycled products). The site visits for this project were for some sections of the construction operation. Further study is recommended for a complete evaluation of the environmental impact of building construction. Tables 2 to 4 in the appendix may be used as a guide to starting data collection. This will have to be further expanded on the site. This project recommends that all construction companies have employees that are designated to monitor, report and develop improvement strategies for the environmental impacts of their construction operations.

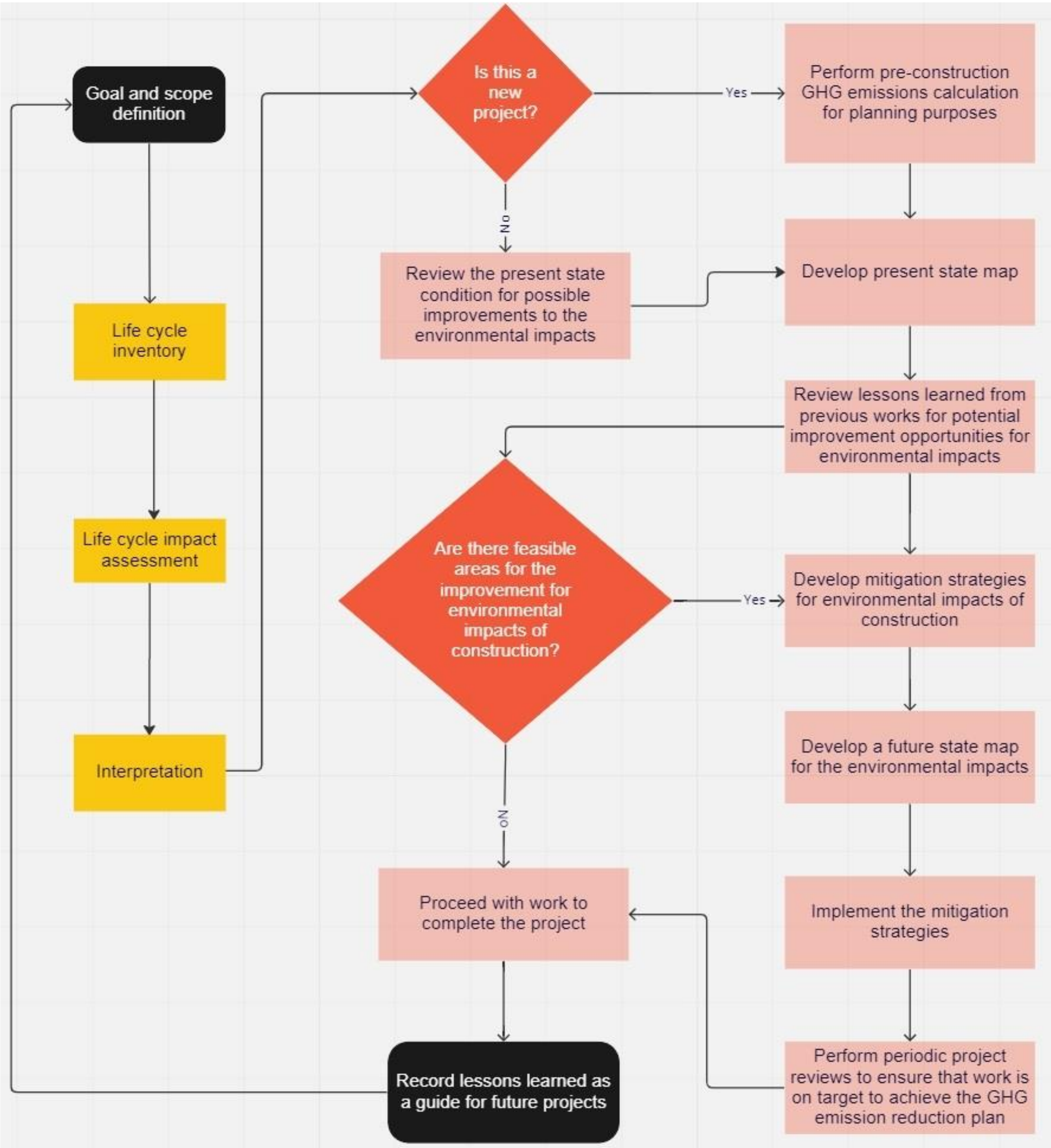

Figure 8. A framework for evaluation of improvement opportunities for environmental impacts on construction works using life cycle assessment and value stream mapping concepts [Adapted from 27, 52, 54, 71].

6. Conclusions

This study presents a framework for the evaluation of improvement opportunities for the environmental impact of building construction works and also establishes an improvement plan to achieve a reduced environmental impact for future construction operations. The methodology for life cycle assessment was described. In addition to the four stages of LCA (goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation), this study suggested the addition of five additional steps for a continuous improvement culture for construction works. This includes the development of the present state map, and the development of mitigation strategies after the identification of the present impacts through life cycle impact assessment, development of future state map, implementation of mitigation strategies, and periodic status review before the end of the project. The lessons that are learned on each project should be recorded and adequately considered for the improvement of the environmental impacts of future projects. The study described how we can use the Value stream mapping (VSM) technique to establish targets for environmental impacts in building construction operations (development of present state and future state maps for environmental impacts on construction works). Implementation of the strategies that are developed to reach the targeted future state condition for environmental impacts of construction works is recommended. Potential research areas to reach a desirable future state for the environmental impacts of construction were mentioned in this study. A periodic review of the targets is meant to ensure that the entire operation is on course to achieve the goal of reducing the environmental impacts of construction operations. Continuous improvement of the environmental impacts of building construction works is not a one-time event. It is meant to be a continuous endeavor with new targets aimed at the reduction of the environmental impacts of construction each year. This study recommends that every construction organization have at least one employee (such as an 'environmental monitoring engineer') for monitoring the environmental impacts of construction operations from the start of the project to its end. This designate can be responsible for records of all the factors that contribute to the environmental impact of the work. In collaboration with senior executives in the company, the environmental monitoring engineer may also be responsible for the recording of lessons learned from previous projects, target setting, and analysis of the status of the project to ensure that they are on the right trend to achieving the targets for the expected future state conditions for the environmental impact of the company's construction operations. Given the prospects in value stream mapping for target setting for environmental impacts of construction operations as described, this study recommends the use of value stream mapping on a larger scale for target setting for the improvement of environmental impacts of construction operations.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

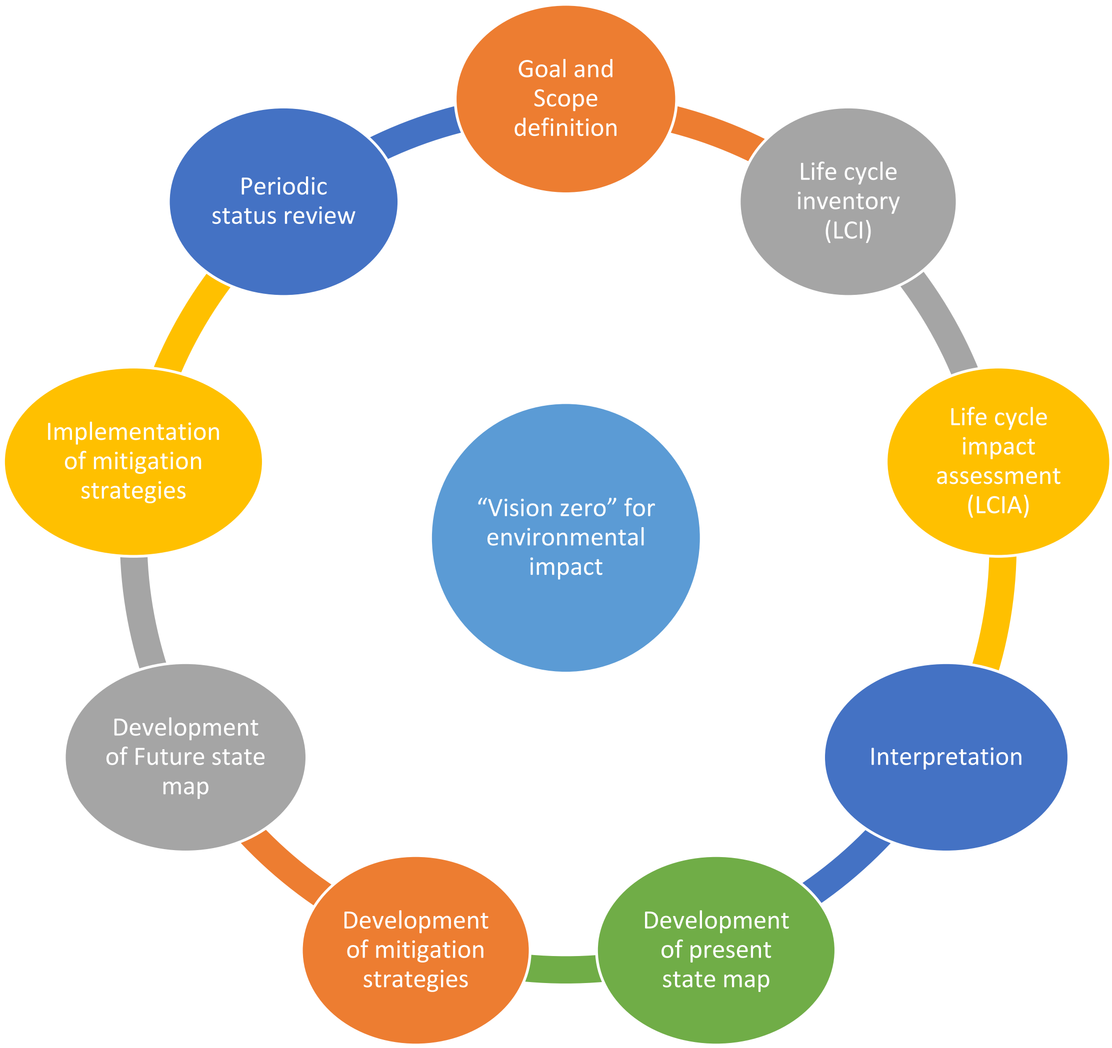

Figure 9. A framework (model) for continuous improvement of the environmental impacts of construction operations.

Illustration for a continuous improvement framework on environmental impacts of construction works (towards vision zero environmental impacts).

Appendix B

Some of the work items in building construction works (tables 2 to 4) that can be used as a kick off note for collection of data that contributes to the environmental impact of construction operations. Note that a section for quantity of materials used, quantity wasted, and reason for the waste will also be helpful in identifying potential areas of improvement for construction waste. Material information can also help in the evaluation of alternative materials for the construction works.

Table 2. Material delivery information – onsite construction * Adapted from [72]

Description	Material delivery Information						
	Type of delivery vehicle	Round trip distance for material delivery (Km)	Number of trips for material delivery	Name of vehicle for material delivery	Type of energy source for material transport	Energy use rate per kilometer for material delivery (liters/km)	What other material for the project is included in this delivery
Get Permits and Kick off project							
Plot Plan & Stake-Out (Main building and garage)	XYZ Vehicle 1 XYZ Vehicle 2			Brand name for Veh. 1 Brand name for Veh. 2			
Connect Temporary Power							
Excavation							
Shoring operation							
Footings							
Inspection: Footings / Steel							
Foundation							
Inspection: Foundation / Steel							
Waterproof Foundation							
Flatwork: Basement & Garage							
Flatwork: Outside							
Backfill & Rough Grade							
Framing (Floors, walls, stairs, decks and entire skeletal structure of the building							
Roofing							
Rough Plumbing							
HVAC Rough							
Electric Rough							
Insulation							
Drywall Hang							
Interior and exterior handrails							

Table 3. Equipment information – Onsite construction*Adapted from [72]

Description	**Equipment information**						
	Name of equipment	Round trip distance for mobilization and demobilization of equipment to and from the site	Type of vehicle used to bring equipment to the site	Energy source for the equipment	Power rating for equipment (W)	If fossil fuel, how many liters per hour of fuel does the equipment use	Total hours to complete this section of project
Get Permits and Kick off project							
Plot Plan & Stake-Out (Main building and garage)	XYZ Equip 1 XYZ Equip 2 XYZ Equip 3						
Connect Temporary Power							
Excavation							
Shoring operation							
Footings							
Inspection: Footings / Steel							
Foundation							
Inspection: Foundation / Steel							
Waterproof Foundation							
Flatwork: Basement & Garage							
Flatwork: Outside							
Backfill & Rough Grade							
Framing (Floors, walls, stairs, decks and entire skeletal structure of the building							
Roofing							
Rough Plumbing							
HVAC Rough							
Electric Rough							
Insulation							
Drywall Hang							
Interior and exterior handrails							

Table 4. Work breakdown structure (sectional) for offsite construction. Adapted from [57]

Work description	Manpower information						
	Number of workers on this work item	Round trip distances for all workers to the job site for this work item	Number of workers traveling to work with electric vehicles (Include additional note if commute to site is other than by fossil fuel or electric powered vehicle)	Number of days the workers are on this work item	Number of hours the workers are on this work item	Number of hours the employees work in a day	Other work items that the worker is working on the same day that the worker is on this work item
Floor fabrication: Floor framing							
Floor Sheathing							
Floor finishing							
Wall framing							
Roof framing							
Roof interior							
Roof finishing							
Panel Assembly: Wall erection							
Roof erection							
Panel Connection							
Construction finishing							
Transportation of completed modules to site and completion of onsite portion of works							

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