Sustainability in Construction Projects: Setting and measuring impacts

Ramprasad, Priyanka1; Dave, Bhargav2; Zilliacus, Martin2; Patel, Viranj2
[1]CEPT University, India
[2]Visilean, India
priyankabola@gmail.com, bhargav@visilean.com, martin@visilean.com, viranj.patel@visilean.com

Abstract –

The construction industry has proposed many frameworks to tackle its significant impact on sustainability. But there is a dearth of tools that help stakeholders quantify and understand the impact of their activities, particularly in the construction phase of a building. This study started with a literature review followed by interviews with field experts to find more about the problems in existing frameworks and the best way to bridge the gap between the concept of sustainability and the actual practice.

The outcome was a framework with quantifiable parameters that could help identify, track and measure sustainability targets incorporated in existing software. The Framework was used to create a tool that professionals in the field could easily use to assess the impact of the construction activities using dynamic inputs from the site. It helps the stakeholders comprehend the implications of variations in the construction processes and provides data to strategize and achieve their sustainability targets.

Keywords –

Dynamic, Sustainability impact assessment, Life cycle assessment framework, Construction phase

1 Introduction

Sustainability is broadly defined as the ability to meet our current needs without compromising the lack of future generations. Conventionally, sustainability is divided into three categories or pillars: environmental, social, and economic. The three pillars are interdependent, which means improvement of one can sometimes be at the cost of another. Recognizing this, United Nations, 2016, came up with 17 sustainable development goals, which act as a blueprint for all the nations to work on to achieve a more sustainable future.

1.1 Sustainable development goals and the construction industry

To tackle the growing environmental problems holistically, the United Nations developed sustainable development goals (SDG) in 2015. After studying 60 recent publications on the role of the construction and real estate sectors in achieving sustainable development goals, it was concluded that 44% of agendas and ten critical goals under the 17 SDGs were dependent on construction activities, and ten critical goals were impacted by it. According to a report by the world economic forum, buildings consume 30% raw material and 12% potable water. It contributes to 25-40% of solid waste generation and about 20% of water effluents [14]. Because of this, the sector is increasingly being focused upon by governments, field experts, and practitioners, with the SDG providing them with a new way to approach the issues like waste generation and efficient resource usage [7].

As of 2021, the construction industry contributes nearly 5% of GDP in developed nations and up to 8% in developing countries. It accounts for about 39% of process-related emissions of carbon, making the field accountable for the future of sustainability. With an average global growth of 3.9 % per annum, its contribution will only increase.

1.2 Construction industry and sustainability

The existence of these issues in the construction industry is backed by studies that point toward high waste generation, inefficient usage of resources, and low productivity. Other typical problems include misuse of land, emissions of dust and gas, and pollution [12][13]. It also mentions that sustainable project management means the effective execution of a project to minimize the waste produced, which includes waste of materials and idle time. The entire life cycle of buildings needs to be considered to make the sector truly sustainable [12]. Thus, not only does sustainability help improve the working environment, but it also makes the process more efficient and beneficial for stakeholders.

Due to the adverse effects of its activity on the environment and the inherent benefits of inculcating sustainability in the process, the industry has tried to come up with various guidelines and frameworks for tracking it, with green building rating systems and Life cycle assessment (LCA) being the most notable ones.

While green building rating systems have been criticized for being qualitative, life cycle assessment has been recognized to be too complex for a regular stakeholder to understand.

1.3 Stakeholders and their role in sustainability

The use of stakeholders in the entire supply chain, from the vendors to the clients, architects, and contractors, can lead to the successful implementation of sustainability from the early stages of the design itself [11]. Definition of sustainability is not aligned among the project managers, making it difficult to aim for sustainability in buildings and assess it uniformly [13]. While PMBOK recognizes the inclusion of economic, social, and environmental factors as beneficial, it doesn't provide any guidelines to do so [13]. There is a need to create a verifiable quantitative framework that can be incorporated into the project management system that can be implemented on construction sites [3].

The study aims to identify and track the sustainable factors or indicators at the project and site level in the construction phase and develop a framework for the stakeholders. This can help them set sustainable goals and identify the impact of the decisions and processes on the goals by providing them with a tool to periodically track it and change the process or propose alternative if required.

2 Literature study

2.1.1 Existing Frameworks for assessing sustainability in construction projects

Different assessment systems of sustainability can be classified into the following, listing their drawbacks [4]:

1. **Performance-based design systems:** The emphasis is more on the outcomes of design, and the approach helps adopt any means to get that outcome. It helps accomplish the client's requirements and can be modified to be building-specific.

2. **Sustainable building rating and certification system**: The weightage for each of the common factors across all the sustainability evaluation tools might differ based on the local context. Having a universal weightage that can be adapted in all the countries and identifying the factors for each of the building typologies is a time-consuming process. Assessment of established green building rating systems like LEED and BREEAM stated that one of the problems with creating assessment methods is that there is no universally established objective assessment system of excellence in building sustainability performance 0.

3. **Life cycle assessment systems:** This process requires a lot of background information on each of the building components involved. The data required for such an assessment is huge and might not always be available. The bigger the supply change, the more data-intensive it is.

There are more than 600 rating tools for the assessment of sustainability, with the number of indicators ranging from 6 to 70 [10][1]. Sustainability indicators Any of these approaches can be adapted, sometimes in conjunction with each other, and customized based on the requirement of the stakeholder to provide them with the best way to analyze the sustainability of the buildings.

2.1.2 Problems with Existing Frameworks for assessing sustainability in construction projects

Most of the sustainability evaluation tools used in construction projects are comprehensive though they do little to help practitioners apply them practically and strategize to improve sustainability at a project level. The drawbacks of most of the existing frameworks were the subjective nature of weights, the predominantly qualitative approach resulting in a subjective analysis of impact, and subjective methods of assigning weights0 [3]. Analysis of the existing sustainable review tools (SRT) by a study to identify drawbacks suggested that the comparability problems of the tools might be due to the different standards in different regions. Problems in using LCA as a basis of the Framework include problems with standardization leading to difficulty in comparison, as the building has a much longer life than general products. It also needs an extensive database, and the process needs expertise and time due to the complexity[2][6][9][11].

3 Methodology

In order to propose an effective system of sustainability tracking for stakeholders, the study started with a literature review to know the existing sustainability assessment frameworks in the field and the sustainability parameters or indicators that are used in frameworks. As seen in 2.1.2, Analysis was done to find out the gaps in the assessment system to derive the desirable characteristics or features for the proposed Framework to be effective. This was followed by an interview with field experts to better understand the desired characteristics of the new Framework and problems in the existing ones.

Finally, an existing framework from 2.1.1 was identified as a reference framework from which a new one could be modelled based on identified desirable characteristics, keeping in mind the provisions of the existing software. The last stage is an application of the newly modelled Framework on a sample project to see if the outcomes accomplish the objective.

3.1 Semi-structured Interview

Further to the literature review, a semi-structured interview was conducted with three experts in the field to discuss the requirements that emerged from the literature study. The various tools available in the industry to measure sustainability were discussed, with emphasis on finding out if and how they were falling short of being the required tool for stakeholders to control and strategize sustainable processes. The current requirements of the stakeholders were identified. The First interviewee was an industry expert and environment technologist. Second, a LEED Fellow and Energy efficiency expert, and the third was an academician with expertise in Building Energy and Performance. The key takeaway points were that the current processes weren't dynamic enough to track and bring changes to processes on-site during the construction phase or to measure the impact of the many variations at the site. They also pointed out the lack of information on site and proposed a system that could help stakeholders control the amount of information to provide and a tool that could accommodate this feature and give the impact with available information. Essentially a tool that would have provision for different levels of detail.

3.2 Characteristics of Proposed LCA-based Framework

The frameworks' characteristics were proposed based on the literature study and outcomes of the semi-structured interviews with experts.

It was decided that the Framework should have universal parameters applicable to all projects across the globe and shouldn't be limited by geographical boundaries. The system should be quantifiable so that projects can be compared against each other with the least number of possible inputs. The proposed guideline should focus on the construction phase of the building due to the available support from existing software. Also, since very few frameworks address this phase in-depth in a dynamic way, this would be a point of focus and lead to proactive decisions rather than reactive ones. The level of detail needs to be introduced so that stakeholders can control the amount of information that is required to be put into the system and help them set sustainability targets as per their requirements. The Framework is being built for the stakeholders who need to nderstand the direct impact of their actions on sustainability. The proposed system should be user-friendly.

Having recognized the gaps in the existing frameworks, followed by the inputs from experts, Life Cycle Assessment (LCA) Framework was chosen as a basis for the new system as it addressed the desired characteristics.

3.3 Life cycle assessment and its applicability to the proposed Framework

Following the resolutions of the Kyoto Protocol, the construction industry introduced ways to include sustainability through tools such as building rating systems and, eventually, the concept of LCA in the construction industry around the 1980s [6]. The ISO International Organization for Standardization) created a guideline in 1997 to help people evaluate the buildings based on LCA and make them comparable. The ISO, along with EPD (Environmental product declaration), made it possible to standardize the parameters to assess the impact and quantify the same. LCA has four defined steps:

Step 1: Goal and Scope
Step 2: Life Cycle Inventory
Step 3: Impact assessment
Step 4: Interpretation

The features of LCA overcame the problems in existing frameworks identified through literature reviews and semi-structured interviews in the following ways:

1. **Sustainability and reduction in costs**: The use of LCA leads to a reduction in economic and environmental costs as it encourages the reduction use of energy-intensive resources, equipment, and processes[9].
2. **Universal Parameters:** The parameters to measure the impact of the construction industry are the same throughout the world. The impact factors are the same across all the typologies of buildings and geographies, providing a much more consistent basis for measuring compared to the other types of frameworks.
3. **Quantifiable:** The proposed Framework is based on the LCA or the life cycle assessment, which has several guidelines on the details of the procedure and has almost no qualitative factors. It is a science-based approach that is quantifiable.
4. **Use in the construction industry**: Though several tools exist to analyse the construction industry, though a few are modelled on LCA, none dynamically evaluate or emphasize the construction phase making it an area of interest.
5. **Level of details:** The various stages in LCA Framework help provide a basis for introducing the concept of different levels of detail, which was suggested by experts and was part of the desired characteristics. It will help stakeholders set the level of information they need to give, enabling control over the level of assessment of sustainability. It helps in effectively considering the alternative approaches to construction at multiple stages and setting targets as per the level of information that

can be provided.

3.4 Proposed Framework.

3.4.1 Modifications to the existing LCA framework

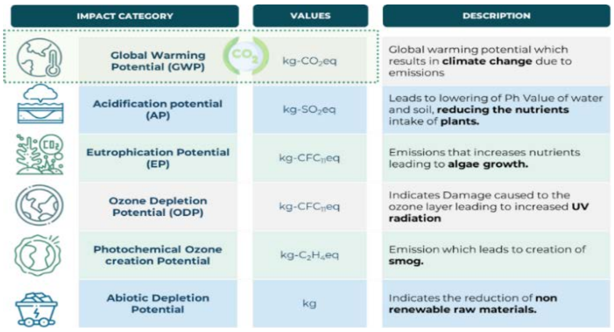
Step: 1 Goal and Scope

As per LCA, the following are the stages of the construction lifecycle:

A1- Raw material extraction
A2- Transport to the manufacturing site
A3- Manufacturing
A4- Transport to the construction site
A5- Installation/ Assembly at the site.

Out of this, A1-A3 are the Product stage, and A4- A5 are the construction stage. Rest is B1- B7 – Use stage, C1-C4 end of life stage. The goal and scope stage is to decide what stages will be assessed for our/Users' Project. The experts recommended keeping the research limited to product and construction stage (A1-A5) so that it is more focused on actual execution.

Step: 2 Life Cycle Inventory



IMPACT CATEGORY	VALUES	DESCRIPTION
Global Warming Potential (GWP)	kg-CO_2eq	Global warming potential which results in **climate change** due to emissions
Acidification potential (AP)	kg-SO_2eq	Leads to lowering of Ph Value of water and soil, **reducing the nutrients** intake of **plants.**
Eutrophication Potential (EP)	kg-CFC_{11}eq	Emissions that increases nutrients leading to **algae growth.**
Ozone Depletion Potential (ODP)	kg-CFC_{11}eq	Indicates Damage caused to the ozone layer leading to increased **UV radiation**
Photochemical Ozone creation Potential	kg-C_2H_4eq	Emission which leads to creation of **smog.**
Abiotic Depletion Potential	kg	Indicates the reduction of **non renewable raw materials.**

Figure 1 Sustainability indicators and parameters

This stage is data collection, and the section explains the sources of information for each of our chosen stages. As per LCA, there are 6 parameters that are used to measure environmental impact, as shown in Figure 1. To reduce confusion, make it user friendly and understandable for layman, the suggestion of experts was considered, and the impact was mainly calculated and presented in terms of the GWP parameter or the carbon footprint since it is a well-known parameter.

The values of the six parameters are considered for the calculation of A1-A3 stages and are available on registered products EPD which are available both for free and at payable basis. These values from open-source database will be connected to the software for the backend emission calculation. The values for A4 and A5 will be calculated based on information provided in the software.

Step 3: Impact Assessment of the proposed Framework

Impact assessment is done using coefficients of emission for every parameter of material/ vehicle/ equipment, which is collected from EPDs along with the information provided by users from the site.

To calculate the impact of the process on the environment as per LCA, the steps followed are:

1. The quantity of material used in construction is multiplied by the emission factor of that material specification (extracted from EPD) to get the impact of the A1-A3 phase.
2. For A4 phase, the quantity of material being transported is multiplied by the coefficient of emission of transport being used (extracted from EPD), the number of vehicles, along with the transportation distance.
3. Finally, for A5 Phase, which uses on-site input for activity, is considered for the coefficient of emission. It is usually equipment. The coefficient of emission of that equipment (extracted from EPD) is then multiplied by the amount of time the equipment was used. The time depends on the quantity of the material.
4. The emissions so obtained in every phase of the activity are then added to get the final emission of the activity.

Accordingly, an example has been shown of the calculation of the impact of the construction of a 10 m^3 slab in Table 1

Table 1 Impact calculation

Stage	Quantity	x	Coefficient of emission of material/ vehicle/ equipment (from EPD)	=	Total environmental impact of that phase
A1-A3 (Manufacturing)	(Manufacturing of M30 Concrete) 10 m3	x	(Coefficient of emission of 1m3 M30 concrete) 266.69 kgCO_2e/ m^3	=	2666.9 kgCO2e
A4 (Transportation)	(Transportation of M30 Concrete for 11Km) 10x 1.133-ton x 11km	x	(Coefficient of emission of 1m3 M30 concrete in transit mixer) 0.13 kgCO2e/ tonkm	=	16.2 kgCO2e
A5 (Assembly/ Construction)	(Tiime taken for Pumping 10 m3 of M30 Concrete @ 40 m3 per hr) 0.25 h	x	(Coeffecient of emission of diesel concrete pump) 16.28 kgCO2e/ h	=	4.07 kgCO2e
Total emission from concreting of 10 m3 of slab (From Phase A1-A5)				=	2687.17 kgCO2e

Step 4: Interpretation of results

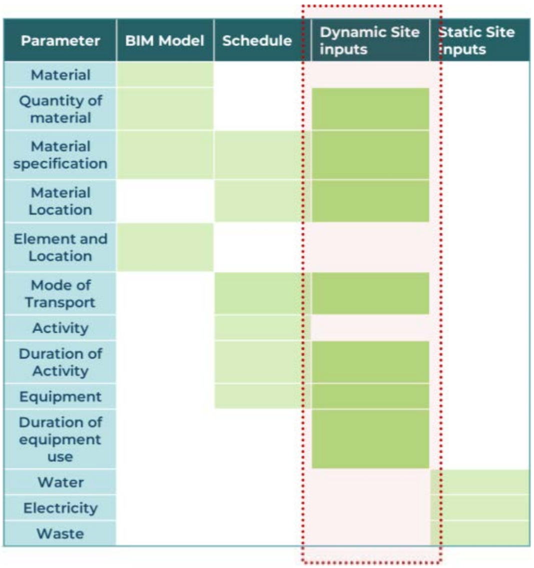
Interpretation of results comes in the end. This helps analyze the problematic areas of the construction activities and get insights as per the requirement of the user. An example of the result is shown in .

The interpretation of the results shown has been made in such a way that the user can identify the item they want to assess the sustainability of (activity, trade, element, location). They can set targets or phases to analyze (A1-A3, A4, A5) and calculate the impact using universal and quantifiable sustainable indicators (GWP, ADP, etc.) to eventually know the impact of variations in the process (change in material specification, change in

transportation distance, change in the transport vehicle, change in equipment used and change in the duration of work or quantity of material due to rework).
The aim was to provide an easily understandable quantifiable tool that can help the users know the impact and reduce the same. This tool has dynamic inputs provision in A1-A5 and based on the background of the user, the takeaway changes. A sample dashboard can be seen in Figure 2

Figure 2 Interpretation of results

3.4.2 Information required in the proposed Framework



Parameter	BIM Model	Schedule	Dynamic Site inputs	Static Site inputs
Material	🟩			
Quantity of material	🟩		🟩	
Material specification	🟩	🟩	🟩	
Material Location		🟩	🟩	
Element and Location	🟩			
Mode of Transport		🟩	🟩	
Activity		🟩		
Duration of Activity		🟩	🟩	
Equipment		🟩	🟩	
Duration of equipment use			🟩	
Water				🟩
Electricity				🟩
Waste				🟩

Figure 3 Inputs for the process

To enable dynamic tracking, Figure 3 shows the inputs required for the process, the sources of these inputs, and the exact parameters that need to be calculated from the site. The parameters required from the site are:
A1-A3: Material name, specification, and quantity
A4: Material quantity, the distance of transportation, mode of transport
A5: Equipment used, duration of use, water, electricity, and amount of waste collected
Information regarding water, hazardous, radioactive, and non-hazardous waste disposed off, which can be static inputs from site at frequent intervals from the project.

3.4.3 Difference between the existing LCA-based frameworks in the market and the proposed Framework

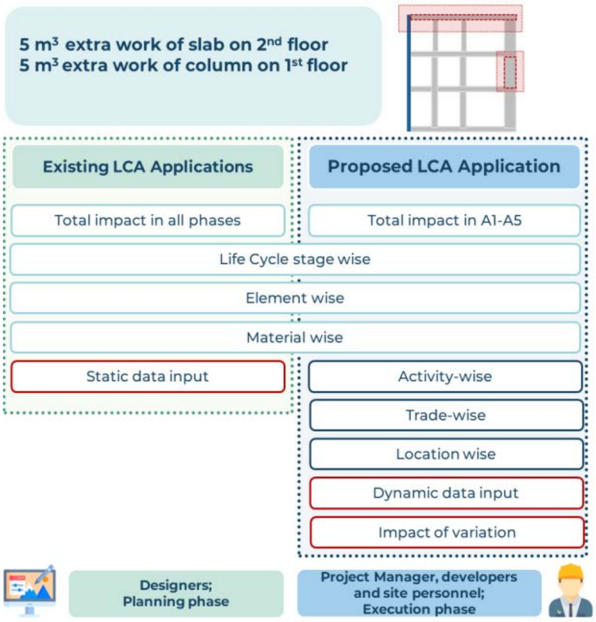


Figure 4 Difference between the results of existing LCA-based frameworks in the market and the proposed framework

If the example from Figure 4 is taken and there are changes in the highlighted elements in the form of 5 m3 of extra work on slab and column of different floors, the outputs in existing and proposed applications have been listed:

1. While the existing application shows the impact on all phases since it caters to the designers and planners, the proposed Framework gives importance to A1-A5 phases that are from the manufacturing of construction materials to the handover of the building/ This makes it easier to cater to the project managers and on-site personnel to help them make decisions at that stage.
2. The data input for existing LCA applications is static. They can either be done at the beginning or the end for them to be useful. The minute changes and impact of variations during construction activities will not be noticeable or highlighted. It also becomes tedious to collect and input the required data for the calculation. Lack of data input during construction activity makes it difficult for dynamic use and makes tracking variations or recording the advantage of using more sustainable alternatives virtually impossible. This will not be the case for the proposed Framework.

A problem user faces in existing applications is the difficulty in identifying the exact activity that affected the expected impact and the root cause of problem. This is tackled in the proposed Framework by giving the impact results activity-wise, trade-wise, and location-wise. This can help the site personnel realize the root cause and exact impact of the variation in planned activities, making it easier for them to learn from their mistakes. This is not specific to the given example and is applicable in the case of finding the impact of any element and any kind of variance in the entire building and is scalable in nature as it is applicable to all kinds of buildings.

3.4.4 Flowchart of information for the proposed Framework

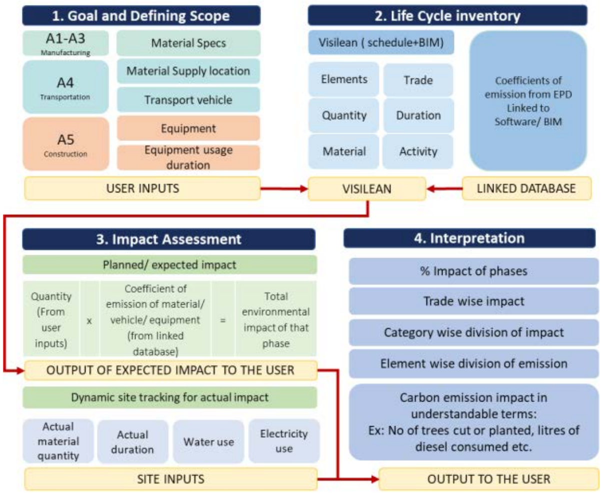


Figure 5 Flow of input

The flowchart in Figure 5 brings together the four steps of the LCA with the inputs and the outputs. Process flow can be explained as follows:

1. User input: The process starts with extra inputs from the user. This is where the level of detail or setting of sustainability targets can be selected depending on the amount of information user has. It helps stakeholders control the sustainability assessment. The information to be provided in various forms has been given in Figure 3.

2. Visilean: The input in the first step goes to Visilean, which already has a system of existing interlinked inputs from the user's schedule and BIM model. The user inputs will then be added as attributes to existing inputs like material/ duration. This step accomplishes part of the life cycle inventory (Step 1), where the information based on planned quantities is entered into the Framework.

3. Database: The emissions' information regarding given user inputs will be collected from the various EPD database that will be linked to the software will be linked to each activity.

4. Output of expected impact to the User: The information obtained in LCI from user inputs and emissions will be used to calculate the expected impact as per Table 1 to give the expected impact on sustainability. Obtained depends on the level of the information fed by the user.

5. Site inputs: Dynamic site inputs as detailed out in Figure 3, help factor in the delays and rework. This is the key to realizing the dynamic part of the proposed sustainability assessment. The total electricity used, water used, and waste output, in the end, will finally give the total impact on the site of the construction activities listed in the schedule.

6. Output to the user: The final interpretation part of LCA can be accomplished by giving useful outputs regarding existing impacts and the impacts due to modification in a way that they can understand so that they can better control the impact and know the impact of inefficiencies in the processes dynamically, as shown in Figure 6

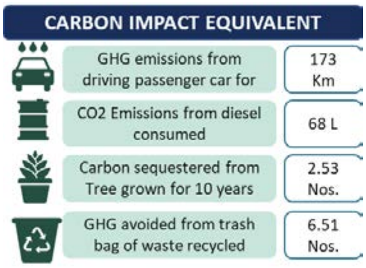


Figure 6 Carbon equivalents for better understanding of positive and negative impact on sustainability

3.4.5 Sample testing of the Framework

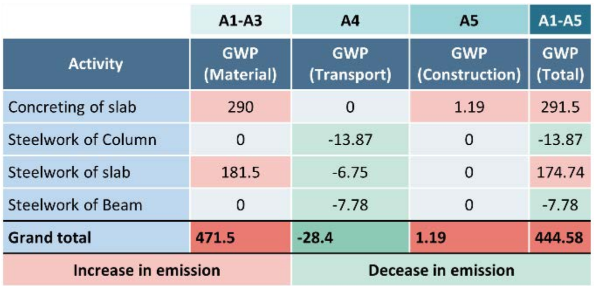
This proposed Framework has been tested by manually calculating the information extracted from a sample BIM model of a building and its schedule.

Scope: The activities considered were Concreting and steelwork of Slab, Beam, and columns of floor 7 of a sample residential project. The quantity and material specification can be extracted from the BIM model, the latter of which can also be taken as user input on software. The emission details and quantities from all the phases were brought together to calculate the expected impacts as explained in point 4 of 3.4.4

Changes in process were introduced to check if the Framework was successful in measuring the impact of variation. For this exercise, it was assumed that there was a rework of the slab, which increased the material quantity by five cum, and there was a reduction in the distance of steel transport by 5 km. Due to a change in the vendor. The factors that changed were:

1. The material quantity increased, due to which the impact in A1-A3 (manufacturing stage) and A5 (use of equipment duration in construction stage) increased as can be seen highlighted in red in Figure 7

2. Material transport distance was reduced due to which carbon impact was reduced in A4 (Transport stage) as can be seen highlighted in green in Figure 7



	A1-A3	A4	A5	A1-A5
Activity	**GWP (Material)**	**GWP (Transport)**	**GWP (Construction)**	**GWP (Total)**
Concreting of slab	290	0	1.19	291.5
Steelwork of Column	0	-13.87	0	-13.87
Steelwork of slab	181.5	-6.75	0	174.74
Steelwork of Beam	0	-7.78	0	-7.78
Grand total	**471.5**	**-28.4**	**1.19**	**444.58**
Increase in emission		**Decease in emission**		

Figure 7 Variation impact calculation and display

Only the carbon footprint has been calculated and presented in terms in which a layman can understand, as seen in Figure 6. The results show that while reducing transport distance (A4 phase) reduced expected impact (green), rework added to the impact (red) in both Manufacturing (A1-A3) and Construction phase (A5). It can also be seen that the most impact percentage is of manufacturing phase, which can be mitigated by stakeholder by opting for a material/ brand with lesser impact. The stakeholder also comprehends the impact of a minor rework, thus incentivizing the priority of quality, to help avoid it in future.

4 Integrating with existing software

The steps in the Framework were included at various points in the existing Visilean application. This has been explained in 3.4.4. and incorporated in the following ways:

a) Material specification: The material specification can be extracted from the BIM Model or from a list linked to EPD for the A1-A3 phase of the construction.

b) Location of the material: The material section will provide the list of materials being used. The material warehouse/ vendor location for the material chosen, with provision adding multiple pick up points, thus obtaining distance travelled till building. This is for the A4 phase of the construction.

c) Equipment used: The List of equipment to be used in construction activities with a large amount of power consumption or energy consumption can be listed. For example, a Crane for hoisting the rebars and a Concrete pump for concreting slabs can be listed. The type of fuel Ex: Diesel, based, Petrol based, or electricity-based, should be kept in mind and selected from options in linked EPD. This is important for the A5 phase of the construction.

After putting the information, the data can be linked to activities using the Gantt chart view or scheduler. The emission for a particular activity will consider phases. Along with the total impact on all the elements calculated as described in Table 1. The impact can be seen in the following categories: Phase wise; Trade wise; Activity, wise and the same can be seen in sample dashboard of software in Figure 8. Carbon impact is used to measure and represent as in Figure 6 easier comprehension.

Furthermore, the user can track the impact of variation using a sustainability tracker, as seen in Figure 7. Here, the input can be taken for specific weeks with every activity having variation listed. The ones with positive changes will be highlighted in green along with the difference, and the activity with the negative changes will be highlighted in red.

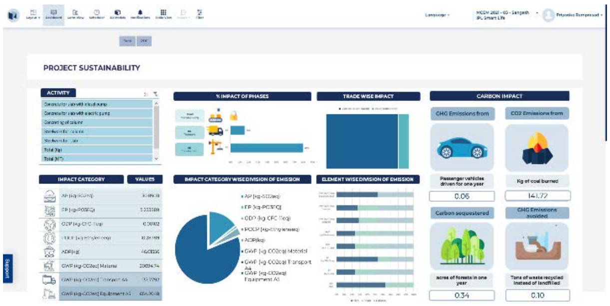


Figure 8 Screenshot of the sample dashboard of sustainability tracking in Visilean software

4.1.1 Data Enhancement for the proposed Framework

Despite reducing the amount of data required, the proposed system will still be a time-consuming process. To make it more efficient, growing technologies like Artificial Intelligence and Machine Learning can be leveraged to develop an engine that would facilitate the automatic linking of the plan and the BIM model in software to enable seamless data integration, making dynamic input of required sustainable parameters possible. The planned duration and quantities for scheduled activities can be directly extracted from the AI Linked BIM model, thus reducing the amount of user input required to just the actual duration and material variation during execution, thereby making dynamic monitoring and sustainability tracking much more efficient.

5 Conclusion

The research found that construction industry impacted about sustainability due to inefficiencies in the industry that resulted in increased material consumption and waste. There was a dearth of tools for field personnel that would help them easily understand the impact and come up with measures to reduce the same. Through a combination of literature reviews and interviews with field experts, the Framework of the characteristics required was summarized. It was to be quantifiable and universal in nature; they had to include the construction phase, be user-friendly, and needed to provide the option to set the level of assessment based on the amount of accessible information. A dynamic system was also desirable for active tracking of the variations that might come up in the processes. LCA was chosen as the ideal Framework that includes all of these, but it came with its own set of challenges which include the complexity of the system and the data-intensive nature of the Framework, which made it difficult to comprehend the process and the impact.

The proposed Framework has overcome these by creating a system that involves using existing software which has the required data and by adding limited, easily accessible quantifiable user inputs to calculate LCA. In the dashboard, the impact is calculated according to the elements of a building, different phases, or across the materials used in a building. This information can be used by user to relook at the inefficient parts of process and replan, to make sure that sustainability is the aim at every phase regardless of its part in the life cycle, even during construction. In the future, the tool can be developed to cover the entire lifecycle for better assessment.

6 References

[1] Berardi, U. (2012). Sustainability Assessment in the Construction Sector: Rating Systems and Rated Buildings. *Sustainable Development*, *20*(6), 411–424. https://doi.org/10.1002/sd.532

[2] Bilec, M. M., Ries, R. J., & Matthews, H. S. (2010). Lifecycle Assessment Modeling of Construction Processes for Buildings. *Journal of Infrastructure Systems*, *16*(3), 199–205. https://doi.org/10.1061/(asce)is.1943-555x.0000022

[3] Borja, L. C. A., César, S. F., Cunha, R. D. A., & Kiperstok, A. (2018). A quantitative method for prediction of environmental aspects in construction sites of residential buildings. *Sustainability (Switzerland)*, *10*(6), 1–38. https://doi.org/10.3390/su10061870

[4] Bragança, L., Mateus, R., & Koukkari, H. (2010). Building sustainability assessment. *Sustainability*, *2*(7), 2010–2023. https://doi.org/10.3390/su2072010

[5] BRE Global Limited. (2019). *CEEQUAL Version 6 Technical Manual*. 187. https://www.ceequal.com/version-6/

[6] Buyle, M., Braet, J., & Audenaert, A. (2013). Life cycle assessment in the construction sector: A review. *Renewable and Sustainable Energy Reviews*, *26*, 379–388. https://doi.org/10.1016/j.rser.2013.05.001

[7] Fei, W., Opoku, A., Agyekum, K., Oppon, J. A., Ahmed, V., Chen, C., & Lok, K. L. (2021). The critical role of the construction industry in achieving the sustainable development goals (Sdgs): Delivering projects for the common good. Sustainability (Switzerland), 13(16). https://doi.org/10.3390/su13169112

[8] Hope, A., Ebbesen, J. B., & Hope, A. (2016). Re-imagining the Iron Triangle : Embedding Sustainability into Project Constraints . Re-imagining the Iron Triangle : Embedding Sustainability. *PM World Journal*, *II*(MARCH 2013), 1–13.

[9] Joaquin Diaz, L. A. A. (2014). *Sustainable Construction Approach through Integration of LCA and BIM Tools*. 283–290.

[10] Matar, M. M., Georgy, M. E., & Ibrahim, M. E. (2008). Sustainable construction management: Introduction of the operational context space (OCS). *Construction Management and Economics*, *26*(3), 261–275. https://doi.org/10.1080/01446190701842972

[11] Palumbo, E., Soust-Verdaguer, B., Llatas, C., & Traverso, M. (2020). How to obtain accurate environmental impacts at early design stages in BIM when using environmental product declaration. A method to support decision-making. *Sustainability (Switzerland)*, *12*(17), 1–24. https://doi.org/10.3390/SU12176927

[12] Shen, L. Y., Li Hao, J., Tam, V. W. Y., & Yao, H. (2007). A checklist for assessing sustainability performance of construction projects. *Journal of Civil Engineering and Management*, *13*(4), 273–281. https://doi.org/10.1080/13923730.2007.9636447

[13] Silvius, A. J. G., & Schipper, R. P. J. (2014). Sustainability in project management: A literature review and impact analysis. *Social Business*, *4*(1), 63–96. https://doi.org/10.1362/204440814x13948909253866

[14] World Economic Forum. (2016). Environmental Sustainability Principles for the Real Estate Industry. January, 1–23. https://www.weforum.org/ Yu, W. Der, Cheng, S. T., Ho, W. C., & Chang, Y. H. (2018). Measuring the sustainability of construction projects throughout their lifecycle: A Taiwan Lesson. *Sustainability (Switzerland)*, *10*(5). https://doi.org/10.3390/su10051523